ISLS Annual Meeting 2022

Hiroshima, Japan, June 6 – 10
Workshops: May 30 – June 5
International Conference Center Hiroshima (Online Event)

International Collaboration toward Educational Innovation for All: Overarching Research, Development, and Practices

- ICLS Proceedings –

16th International Conference of the Learning Sciences (ICLS) 2022

Clark Chinn, Edna Tan, Carol Chan, & Yael Kali

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2nd Annual Meeting of
the International Society of the Learning Sciences
(ISLS)

Editors:
Clark Chinn, Edna Tan, Carol Chan, & Yael Kali

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International Society of the Learning Sciences

Preface

With its 16th edition, the International Conference of the Learning Sciences (ICLS) continues its now-annual convening in tandem with the International Conference of Computer-Supported Collaborative Learning (CSCL). ICLS is pleased to join with CSCL as a part the 2022 Annual Meeting of the International Society of the Learning Sciences.

ICLS 2022 was set to be the second ICLS meeting held in Asia, following the 2016 meeting in Singapore. Unfortunately, ongoing pandemic travel restrictions in Japan required that conference organizers move the conference online, like those of the past two years. Nonetheless, there will be local events held in Hiroshima to celebrate the conference and its setting, the city of Hiroshima along the beautiful Seto Inland Sea of Japan. Hiroshima is of course a worldwide symbol of peace as the first city ever to suffer an attack with an atomic bomb. The Hiroshima Peace Memorial Park stands to remind us of the urgent need to advance world peace in its many forms--a need only more urgent in the current worldwide climate of inequities and the eruption of war. Hiroshima University's School of Education is also the site of the second oldest teacher education professional school in Japan, established in 1902. The virtual setting of this year's conference is an inspiration to advance our work linking education with advancing peace and justice.

ICLS 2022 invited contributions and embraced multiple and diverse perspectives focusing on theoretical, conceptual, design-based and empirical work for advancing our understanding of learning and how it can be promoted. The conference called for papers on (a) promoting diversity, equity, and justice in educational settings, (b) investigating innovative pedagogies, technologies, and learning environments, (c) elucidating theories and processes of learning and teaching, and (d) connecting research, practice, and policy. ICLS received overwhelming interest from the Learning Sciences community and related fields, with a total of 735 submissions, which we believe to be record high in ICLS history. All submissions were blind reviewed by at least 2 reviewers (for papers and posters) or 3 reviewers (for symposia); a senior reviewer wrote a meta-review for each submission synthesizing the reviews and feedback. In total, 33% of long paper submissions (110 of 329) and 38% of short paper submissions (82 of 215) were accepted in the same category in which they were submitted. Other papers were accepted in a different category as space allowed. Most of the 27 symposium proposals were rated very highly by reviewers and senior reviewers; space permitted acceptance of 17. The final submissions are published in the ICLS Proceedings featuring 17 symposia, 110 long papers, 200 short papers, and 198 posters coming from six continents and 35 countries. We believe that the number of papers to be presented also represents a record number at ICLS.

The content of the LS track covers a number of exciting contemporaneous topics, including computational thinking, teacher practices, STEM education, design-based implementation research, game-based learning, data visualization, epistemic practices, learning in virtual environments, equity and justice, knowledge building, emotions, and much more. We are proud of the way that scholarship within the learning sciences community reflects and explores the realities of our everyday world with an eye on making it a better place to live.

Organizing a high-quality conference is contingent on the entire Learning Sciences community. With the largest number of proposals ever submitted and accepted in ICLS's history, we are indebted to the painstaking work and generosity of 747 reviewers and 115 senior reviewers for making this conference program possible.

It has been our honor to edit this year's conference proceedings for the Learning Sciences community in ISLS. We hope you enjoy the conference and are enriched by your participation.

Clark Chinn, Carol Chan, Yael Kali & Edna Tan, ICLS 2022 Conference Program Co-chairs

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International Society of the Learning Sciences

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"Everything that's hard got harder": Preservice teachers' attempts at rigorous and responsive instruction during online pedagogical rehearsals in the Covid pandemic

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Abstract: At the onset of the COVID-19 pandemic, our teacher preparation program shifted to an online setting, disrupting a key feature of practice-based teacher preparation: Preservice science teachers' (PSTs) approximation of rigorous and responsive instruction during extended pedagogical rehearsals called macroteaching. Given this unplanned shock to their preparation, we examined how PSTs viewed macroteaching and their evolving participation in the teaching rehearsal. Using a situative perspective, we collected multiple forms of data. We found that while PSTs wanted to enact rigorous and responsive instruction, their participation was deeply impacted by the sudden shift to an online setting. Our analysis of video-recorded lessons confirmed PSTs' observations that their instruction became less rigorous and responsive over time. We conclude with questions about teacher preparation during the pandemic.

The title of the paper is a quote from a preservice teacher (PST) describing her experience as an instructor for an extended pedagogical rehearsal during a practice-based secondary science methods course. Noting the difficulty of teacher preparation during a typical year, this PST succinctly summaries the herculean challenge of learning to teach during the COVID-19 pandemic when the teacher preparation program necessarily and abruptly ended in-person methods courses and shifted to online instruction in March 2020. In our secondary science method course, the shift from in-person to online participation immediately disrupted a key feature of practice-based teacher preparation: PSTs' approximation of rigorous and responsive instruction during pedagogical rehearsals (Grossman et al., 2009). In these rehearsals, dubbed "macroteaching" by a former student (Stroupe & Gotwals, 2018), PSTs learn to provide students with opportunities to examine puzzling phenomena and construct evidence-based explanations (rigor) while noticing and attending to student thinking as they build a classroom community with students (responsiveness) (Thompson et al., 2016, see Literature Review for further descriptions). At the start of the 2020 semester, macroteaching resembled previous instantiations. PSTs were divided into four content groups (biology, earth science, physics, chemistry). The first two groups – biology and earth science – each completed a round of in-person macroteaching, which included the use of 10-12 course instructional hours for the rehearsal of one unit of content instruction taught to peers in the methods course. The physics group completed one in-person lesson in March 2020. Then, as COVID-19 forced the shuttering of the university, the PSTs requested to continue macroteaching online.

As teacher educators, we wanted to support PST participation, and as a class, we decided to continue macroteaching with the remining physics unit and the entire chemistry unit using the Zoom™ video teleconferencing platform . However, given this unplanned and unwanted shift in the context of the practice-based teacher education methods course, we became curious about how the PSTs viewed maroteaching and their participation when COVID-19 forced them online. In addition, we wanted to understand how PSTs' participation around rigor and responsiveness during marcoteaching, both as instructors and students, might be shaped by the online setting. We asked:

- How did PSTs frame the purpose of macroteaching when COVID disrupted the practice-based methods course?
- How were PSTs' participation in macroteaching, and their attempts at rigorous and responsive instruction, shaped by the sudden disruption of practice-based methods course?

Background and framing

As Kang (in press) argues, the field of teacher education struggles to design professional learning opportunities for teachers to take up rigorous and responsive instruction. We extend this concern to teacher preparation, and claim that more research to examine the opportunities for PSTs to learn about, rehearse, and receive feedback about their attempts to enact rigorous and responsive instruction. While we hoped that macroteaching might provide such a learning opportunity for PSTs, moving the methods course online fundamentally changed the dynamic of the class and the instructional episodes that PSTs enacted during macroteaching (See table 1).

Rigor

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While some people may have an image of rigor as extensive content coverage and difficult tasks to complete, we claim rigor is an emergent property of discursive classroom interactions (Thompson et al., 2016). We frame rigor as a collaborative effort to construct and revise scientific explanations, which is a central practice across scientific disciplines (See Table 1).

Responsiveness

Like rigor, defining and understanding responsiveness in teaching is difficult. Broadly, from the perspectives of teachers, responsiveness involves noticing, attending to, interpreting, and using students' ideas and needs to shape pedagogical actions (Kang, in press; van Es et al., 2017). For this study, we focused on two dimensions of responsiveness: building on students' scientific ideas, and encouraging participation and building classroom community (See Tables 2 and 3).

Practice-based science teacher preparation

Given the need for a better understanding of preparing teachers for rigorous and responsive instruction, some researchers have focused on supporting PSTs through practice-based teacher preparation. By practice-based teacher preparation, we mean a framing of teacher education that focuses on disrupting preservice teachers' images of disciplinary work and teaching, reimagining teaching through a lens of equitable instruction, and learning core teaching practices through multiple opportunities to rehearse teaching, and building relationships with students and their communities (Stroupe, Hammerness, & McDonald, 2020). Through scaffolded work on interactive practices that encourage principled improvisation, preservice teachers can learn the more interactive relational judgments required by the teaching profession.

Macroteaching

While a practice-based approach to teacher preparation provide a framework for supporting PSTs, teacher educators must design learning opportunities for PSTs to approximate instructional practices. In our methods class, we use "macroteaching" as a learning opportunity for PSTs to approximate rigorous and responsive instruction. Macroteaching takes place at a large Midwestern university, where PSTs participate in a five-year teacher preparation program in which they major (and minor) in a science discipline while fulfilling requirements for a teaching certificate. During the PSTs' final year of coursework, they participate in two sequential four-hour per week secondary science methods courses. Macroteaching involves groups of PSTs planning, teaching, and reflecting on eleven to twelve consecutive hours of instruction to their peers (approximating a complete unit of instruction) during methods class. During macroteaching, PSTs engage in five learning opportunities:

- *In-the-moment consultations.* The teaching team gathers (often in a "huddle") to discuss their immediate and upcoming instructional decision.
- *"Time-out/time-in."* A pause during instruction—called a "time-out"—in order to engage in immediate reflection about a recent event.
- *"Rewind."* At times, following the time-out/time-in or instructional coaching, a teaching team member requests an immediate opportunity to retry an interactive episode.
- *Question-and-answer session at end of each lesson*. During the final five to ten minutes of each lesson taught by the teaching team, the PSTs serving as students and instructors ask the teaching team to decompose pedagogical decisions they made during class, and inquire about upcoming lessons.
- *Teaching team debrief at the end of the unit.* The preservice teacher "students" and instructors ask the teaching team to decompose pedagogical decisions made during the unit, and to reflect on instructional opportunities they might shift in the future.

Learning to teach in virtual settings

While macroteaching usually occurs in person during our methods class, the COVID-19 pandemic forced the PSTs to enter a virtual setting (Zoom™) to continue their preparation work. When investigating how to engage in teacher preparation online, we encountered a dearth of research about learning rigorous and responsive teaching practices in virtual settings (though studies do exist – see Cohen et al., 2019, and Watkins et al., 2020 for examples). This study, then, adds to literature by examining how PSTs' participation shifted when attempting to teach in a virtual environment.

Theoretical framing

We used situative theory to address the complexity of examining how and why PSTs' participation might be shaped moving into an online setting. Situative theory is a hybrid analytical lens framing individuals' learning through their participation in activities that occur through interactions with actors, tools, and discourses of a context (Greeno, 2006). A situative perspective on PSTs' participation helps focus researchers' analytical lens to make sense of why PSTs' participation might be shaped by an online setting given the new norms and expectations for participation (see Fairbanks et al., 2010; Peressini et al., 2004; Putnam & Borko, 2000).

Methods

Design Experiment

Given the conceptual framework and dual roles as instructors and researchers, we viewed this study as a forced design experiment. By forced design experiment, we mean that outside circumstances (i.e., the COVID-19 pandemic) required fundamental changes to the original design of the methods course. In turn, we rapidly and simultaneously engineered particular forms of participation for our PSTs while engaged in a systematic study of that participation within the new virtual methods class context (e.g., Penuel et al., 2011).

Participants and Methods Class Context

The 15 participants, all undergraduate students majoring in a science field, were peers in a secondary science methods course we co-taught and framed around rigorous and responsive instruction. The participants self-identified as: 9 women (1 East Asian, 1 Iraqi-American, 7 White Americans) and 6 men (White Americans). The methods course in this study was the second in a two-course sequence. We met for four hours per week, two hours per class.

Macroteaching

Importantly, the PSTs wanted to continue macroteaching online when the university shut down in-person instruction. As a classroom community, we co-designed an action plan given the impending closure, and the two macroteaching groups that did not teach in-person (physics and chemistry – see below) requested to continue macroteaching in order to have the opportunity for the extended pedagogical rehearsal. We constructed the teaching teams based on disciplinary major and teaching interests. In addition, we assigned each team a typical disciplinary topic that they would likely teach during their teaching career. Below, we list each team with participant pseudonyms, their science topic, and the time frame that participants enacted each unit:

- Biology (Human impact on ecosystems): Mallory, Kurt, Tom, Pam. Taught in person from January 21 – February 4, 2020).
- Earth Science (Tides): Victoria, Matt, Michael., Andi. Taught in person from February 11 – February 25.
- Physics (Sound and waves): Xuexue, Jay, Edna. Taught one lesson in person, and the remainder online from March 10 – March 26.
- Chemistry (Acids and bases): Phil, Zoe, Shirin, Raven. Taught online from April 2– April 16.

Data Collection

We collected and analyzed multiple forms of data from four different types of interactive episodes: (1) requested or informal planning communication, (2) observations/video recordings of macroteaching, (3) participant-generated artifacts, and (4) two types of interviews. We selected these data sources for three reasons. First, we wanted to collect an array of data to better understand how and why we and the PSTs learned over time. Second, we needed multiple forms of data to examine how the PSTs' pedagogical reasoning evolved during important episodes of professional work – planning, instructing, and reflecting. Third, given our situated theoretical framework, we thought that the data sources could better capture episodes of participation as the PSTs engaged in instructional practices.

Data Analysis

In this section, we describe four interacting phases of data analysis: (1) developing and applying codes to the initial round of interview coding, (2), using a priori codes about rigorous and responsive instruction to analyze macroteaching instruction in the online setting, and (3) pattern finding and triangulating data. The first phase of the data analyses focused on developing a coding scheme. The coding scheme was initially informed by the literature on rigorous and responsive teaching, approximations of practice, and later by emergent themes from the data. For interviews, the coding scheme was debated and iteratively revised in weekly research meetings until we reached a consensus. We each coded a sample of data using the final coding scheme, identified areas of disagreement and refined the coding process over time. For coding instructional episodes (see below), we used observation instruments validated in a prior study (see Stroupe & Gotwals, 2018)). We examined teaching episodes, or "small, socially shared scripted pieces of behavior" recognizable across most classrooms (Leinhardt & Steele, 2005). In total we coded 77 episodes within the 18 lessons.

Findings

In this section, we organize the findings around three assertions. First, while PSTs wanted to participate in rigorous and responsive instruction during online macroteaching, how they framed the purpose of macroteaching reflected the sudden shift in the medium of interaction and the timing of the rehearsals. Second, all participants observed that their participation was shaped by the rapid shift to a new classroom setting. The PSTs serving as instructors noticed that they altered their enactment of instruction, and the PSTs serving as students engaged with their instructors and peers differently than they hoped during macroteaching. Third, our analysis of video-recorded macroteaching observations aligned with the PSTs' stated observations during interviews: The PSTs' words and actions became less rigorous and responsive as macroteaching progressed. All

quotes are taken from whole class debriefing conversations, planning communication, class activities, or interviews. Note that our analysis and claims focus on macroteaching that occurred in the online setting after COVID forced a drastic shift in the practice-based teacher preparation program. We do not compare in-person macroteaching to online macroteaching. However, the PSTs used their experiences during in-person macroteahing to make sense of the dramatic shift in context, and this study aims to both share their stories based on their words and actions, and to examine their attempts at rigorous and responsive instruction as they navigated a terrible situation.

In terms of rigor, the physics and chemistry instruction decreased from focusing on how and why a phenomenon occurred, to asking students to describe what happened during a phenomenon. By the end of both units, the instructors' became focused on students citing facts and definitions about a phenomenon, the lowest rating on our coding scheme for rigor. For example, the physics group initially pressed students to determine *why* radio telescopes on Earth received fast radio bursts at regular intervals from space. During the first lessons, the physics group provided students with opportunities to consider how observable features of the phenomenon related to unobservable features, and to justify their thinking with initial evidence and life experiences. However, as the unit progressed, the physics group became more concerned with covering content and ensuring that students stated correct information. By the end of the unit, the physics group shifted from a focus on 'why" to a "what" focus in terms of rigor. The chemistry group followed the same pattern: Beginning the unit with high rigor by asking students to explain why chemicals might make people sick, but over time, decreasing the rigor and hoping that students might be able to recall information about chemical reactions.

Similarly, responsiveness (in terms of "Responding to and building on students' scientific ideas", BSI, and **"**Participation structures and the building of a community", PART) decreased after initial attempts to create online classroom communities in which students felt safe and valued to share and build on each other's science ideas. In both units, students' initial science ideas that could have become valuable resources for the classroom community were elicited and publicized, but never again used by the teaching team. For example, in the chemistry unit, the instructors asked students about a phenomenon of people becoming poisoned by mixing household cleaning products. One student, Edna, eagerly shared her story of a similar experience in the university chemistry laboratory in which she mixed chemicals, caused a potentially toxic gas to be created, and was decontaminated by the university fire patrol. This story triggered memories from other students who were in the chemistry building that day, recalled the evacuation, and wondered how a chemical reaction could clear out an entire campus building. Edna's story had the potential to shape the instructional team's unit, and during the first lessons, the PSTs engaged in features of responsiveness that rated highly on the coding scheme. By the end of the unit, however, the chemistry team "forgot about Edna story" (Phil), and instead focused on content coverage. Thus, our analysis of classroom videos aligned with PSTs' observations that their attempts at online macroteaching decreased in rigor and responsiveness over time.

Given the decline in rigor and responsiveness during macroteaching, PSTs also noticed that student talk decreased during macroteaching. Our analysis shows that instructional teams may have contributed to the decline by enacting instructional episodes that provided fewer opportunities for student talk. Specifically, we found that episodes that might promote talk, such as whole class conversations, became less frequent over time. In addition, episodes types that might limit possibilities for talk, such as content injection and seat work, increased in frequency during macroteaching Some episodes that might promote talk, such as small group conversations, were enacted across macroteaching lessons. While such episodes remained consistent in terms of frequency of enactment, the decrease in rigor and responsiveness of the episodes limited opportunities for talk, thus shaping student participation. Importantly, the PSTs' observations and instruction aligned: A decrease in rigor and responsiveness (especially in terms of BSI and PART) indicates that students had fewer opportunities to talk about science ideas, which is the phenomenon reported by the PSTs in interviews.

Discussion

This study occurred in the midst of a global pandemic that forced PSTs into an online setting, requiring them to make pedagogical decisions that they never anticipated, nor as they noted, ever wanted to make. As the course instructors, we wondered how the PSTs' participation in an extended pedagogical rehearsal – macroteaching – might be shaped by the new online setting. In this section, we make sense of the findings by noting that while the online setting constrained PSTs' participation, in another way, the online setting helped strengthen their desire to enact rigorous and responsive instruction because they experienced teaching episodes that limited their opportunities to learn with and from each other's ideas.

Rigor and responsiveness decreased

As noted in the findings, the rigor and responsiveness of instructional episodes decreased over the two macroteaching units taught online. Student talk became less frequent, teacher talk increasingly resembled Initiate-Response-Evaluate (IRE) discourse aimed at moving a conversation in the teacher's direction, and the

overall science talk became more focused on facts than on explanatory conversations about phenomena in the units. Thus, the cognitive demand of the class decreased (Michaels and O'Conner, 2012), even though the online setting was in place for half of the macroteaching units. While PSTs attempted to support conversations in which students might engage in rigorous and responsive activity, the reduction in participation constrained opportunities to hear and use students' ideas as resources to shape instruction. Subsequently, instruction resembled "delivery pedagogy" (Stroupe, 2016), in which the teachers are the sole knowledge authority their focus remains on controlling the classroom and covering curriculum (Duschl, 2008).

Using a situative perspective, we offer a two-pronged explanation that emerged from the data for the reduction in rigorous and responsive instruction over the course of macroteaching online. First, PSTs' engaged in pedagogical reasoning while simultaneously making sense of a new and rapidly changing setting. While the PSTs expressed disappointment that their participation dwindled and that their instruction drifted away from rigorous and responsive instruction, they understandably made participatory decisions that focused on surviving and accepting the online teaching rehearsal. The online setting required PSTs to question their initial instructional goals, and they subsequently made decisions based on their interpretation of possibilities. PSTs could simultaneously envision how they wanted to participate based on their experiences in-person, but still chose to think and act in ways that decreased rigor and responsiveness over time citing the online medium as the cause of their dual thinking.

Second, PSTs explicitly described how the online setting limited opportunities for using students' ideas and experiences as resources to shape instruction, which is a hallmark of rigorous and responsive instruction. PSTs lamented that the online setting limited how much time they could provide students to talk, engage in activities, and make sense of puzzling phenomena, and thus, they heard less from students over time. Without students' ideas available PSTs resorted to information delivery in the hopes of covering content deemed important during planning sessions. Even when students shared experiences that were immediately relevant to the unit (such as Edna's story about the chemistry lab evacuation), such ideas were rarely elevated to the public plane of talk at the whole-class level, or were lost in the chaos of online instruction. While online settings provide spaces for students' ideas to exist, PSTs often used such spaces as storage sites rather than inscriptions to be leveraged for later lessons. Again, PSTs frequently noted they wanted to use student thinking as they encountered during macroteaching in-person, but their reasoning about survival and enduring led them to make instructional decisions that limited the elicitation and use of students' ideas.

PSTs' participatory opportunities changed

Given PSTs' decisions to survive and accept the limitations of the context, their participatory opportunities changed for two reasons from a situative perspective. First, PSTs felt unable to use the learning opportunities embedded in macroteaching, such as time-outs and group consultations. Prior to moving online, PSTs serving as instructors witnessed the five learning opportunities embedded in macroteaching, and observed how their peers' participation was aided by the opportunities. In the online setting, however, PSTs expressed frustration because they felt limited in their learning opportunities in the online setting, especially after watching the biology and earth science groups engage in the reflective teaching during in-person macroteaching. PSTs, then, made decisions to survive and endure online macroteaching at the expense of more time-consuming but beneficial learning opportunities they observed in-person.

Second, as Philip et al. (2019) note, teaching practices are inherently relational. As the PSTs noted, the relational work of online instruction seems different than the possibilities for building and growing relationships in-person. In the online setting, PSTs serving as instructors could not engage in hallmarks of rigorous and responsive instructional practices that emphasize relational work such as providing daily opportunities for students to reason through productive talk and making student thinking public and subject to consideration by the classroom community (Engle & Conant, 2002; Lehrer & Schauble, 2006). Unlike in-person macroteaching, PSTs attempting online instruction did not prioritize relational work, which ultimately limited opportunities for students participation.

Tension between desired and enacted instruction

Given the decrease in rigorous and responsive instruction, and the reduction in PSTs' participatory opportunities, we worried that PSTs might begin to express an interest delivery pedagogies, or would become disenchanted with teaching. However, all PSTs reported that participating in an online setting helped strengthen their desire to enact rigorous and responsive instruction because they experienced teaching episodes that limited their opportunities to learn. Further, PSTs realized there was striking difference in their participation as instructors and students in-person or in online settings, and they vehemently expressed frustration that they could not enact instruction that aligned with their developing vision of from rigorous and responsive instruction.

The tension expressed by the PSTs between the instruction they wanted to enact and the instruction that occurred during online pedagogical episodes is not unique to this study. Teachers, regardless of setting, make

pedagogical decisions during planning and in-the-moment with students that reflect a constant conversation between a personal vision of instruction and learning and a context's implicit and explicit messages about what counts as success. The PSTs in this study made the decisions they felt necessary to "survive" and "cope" given the rapidly changing participatory circumstances. They balanced immediate needs of engaging in a pedagogical rehearsal in a drastically different setting with long term goals of learning to teach. Importantly, their vision of teaching that they wanted to enact remained unchanged, even as rigor and responsiveness of the instruction declined. The PSTs recognized that they could enact better instruction, and given a different setting that allowed for in-person interactions, they felt confident that they would make different pedagogical decisions that resulted in rigorous and responsive learning opportunities.

Conclusion

We are left with two lingering questions for the field to consider about practice-based teacher preparation and supporting PSTs as they learn about rigorous and responsive instruction. First, can online settings support practice-based teacher preparation? Second, will PSTs be more likely to push themselves to enact rigorous and responsive instruction during their first years of teaching? Will they be more attentive to student participation since they noticed how instruction and participatory structures are linked and can decline rigor and responsiveness in tandem?

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Table 1. Forms of Explanatory Rigorous Talk.

1 **Definitions without epistemic features**	2	3	4 **Fully theorized science explanations**
Explicating definitions. Talk is about facts, procedures, equipment. Emphasis is on static entities (i.e. defining forces, evolution, etc.).	Offering descriptions or observations of a phenomenon – "what" you can see happening. OR talking about recording data about a phenomenon – what could be measured or recorded. When describing a correlation between variables – the emphasis is on "what" happens to X when Y is changed. Talk about unobservable ideas is in the form of vocabulary and is not specifically linked to the phenomenon under investigation.	Explaining "how" a phenomenon "works"—in one of 3 ways: 1) Talking about "how" a phenomenon is part of a larger process, 2) Talking about simple cause-effect relationships between two observable features of a phenomenon – simple correlation/ causation, or 3) Talking about what is happening on an unobservable (i.e. molecular) level but this is only tangentially linked to observable events.	Explaining theoretical underpinnings for "why" a phenomenon happens in the form of talking about scientific theories, models, laws [either standard ones or student-generated ones] that go beyond simple cause-and-effect relationships. Observable features of the phenomenon are broken down and underlying unobservable processes or entities are used as evidence for the theory or model.

Table 2. Dimension of Responsiveness: Responding to and building on students' scientific ideas

Features of Scientific Thinking/Talking in Classroom Discourse			
	Responding to individual's utterances (1.x)	*Responding to multiple students' answers (2.x)*	*Responding to multiple ideas in the community (3.x)*
Re-voicing ideas (x.1)	1.1. Teacher responds or re-voices students' science ideas, recognizing the students' contributions and providing feedback on students' ideas (1 student or multiple students) VERSION B: T. asks students to clarify their idea before doing the above moves (1.1b)	2.1. Teacher adopts a student word/idea as a part of the ongoing classroom discourse to build towards a scientific word/idea. Teacher might also show student work to the rest of the class.	3.1. Teacher and students re-voice ideas or use other students' ways of talking about science ideas.
Responding to content (x.2)	1.2. Teacher collects multiple students' ideas and stitches students' ideas together	2.2. Teacher encourages students to respond to one another's science ideas (i.e. juxtaposing or weaving students' ideas by clarifying which ideas need to be added to). T. adds "filler" (such as, "and", "because") words to support students in building on one another's ideas. Students do not just state ideas independently. Students use additive language in which they make arguments for claims that become more sophisticated over time, raise new questions, recognize a confusion, or made a new connection among ideas.	3.2. Teacher and students respond to partial understandings of others and both build on and critique the ideas.

Highlighting concepts (x.3)	1.3. Teacher highlights important contributions students make OR T. tacks on new pertinent content to s. idea toward the construction of an ideal/ normative scientific explanation	2.3. Teacher tracks and recounts to students their ideas that can be used to co-construct a scientific explanation (in small groups teacher tells students which of their ideas they need to stitch together, in whole class teacher tracks piece by piece students' contributions or draws attention to a part of an explanation students are struggling with).	3.3. Teacher tracks how students are formulating scientific ideas. Teacher encourages students to explore and build their own scientific ideas (explanatory flexibility). Non-normative forms of science talk are worked with on a public plane to elaborate and challenge known science ideas.
Reflecting on scientific practices (x.4)	1.4. Teacher tells students about conventional ways scientists represent ideas.	2.4 Teacher helps students distinguish characteristics of good scientific explanations and arguments from forms of talk in every-day language.	3.4. Students discuss what counts as good explanations and argumentation and distinguish from everyday talk. Students create hybrids between naturalistic ways of talking and following discursive norms in science.

3. Dimension of Responsiveness: Participation structures and the building of a community

Features of Scientific Thinking/Talking in Classroom Discourse			
	Responding to individual's utterances (1.x)	*Responding to multiple students' answers (2.x)*	*Responding to multiple ideas in the community (3.x)*
Soliciting student participation (x.1)	1.5. Teacher encourages student participation (teacher asks to hear multiple students' ideas, and asks students to listen to one another)	2.1 Teacher encourages students to respond to other students' ideas (generally, not science specific). Teacher (verbally or non-verbally) asks *each* student to contribute a thought or response to another student. Students make bids for other students to participate.	3.1 Students invite participation from classmates and refer to one another without intervention from the teacher (reversing authority).
Animating and reinforcing norms for participation (x.2)	1.2 Noticing the need for classroom participation norms	2.2 Teacher reflects with students on how classroom norms are being enacted in classroom conversations OR T. consistently reminds students of his/her high expectations for student participation ("I am expecting great things from this table").	3.2 Teacher and students reflect on how norms are supporting conversations.
Using status treatments for equitable participation (x.3)	1.3 Teacher attempting a status treatment (for example assigning participation roles, or using popsicle sticks to call on individual students for answers).	2.3 Teacher uses status treatments to invite more students to share/ hear ideas with one another (i.e. jig-saw activities that position students as knowledgeable when sharing information with classmates).	3.3 Teacher employs status treatments that change how dominating/not dominating students interact with one another by increasing the number of participants and the range of ideas up for discussion (i.e. structured turn-and-talks that elaborate students' causal hypotheses).
Labeling the purpose of participation as building a classroom and/or scientific community (x.4)	1.4 Teacher makes statements about being a good participant, listener.	2.4 Teacher draws parallels between classroom & places where scientists work; students are "like" scientists.	3.4 Students are recognized for legitimate participation in authentic science conversations or debates, critiquing one another's ideas and legitimized science ideas. Students' ideas and forms of participation are marked as contributions to science.

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From participants to creators: Considerations for community-led citizen science

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Abstract: There is a plurality of opinions as to what citizen science looks like. We adopt a community-led approach and argue that enabling communities with no or limited science expertise to engage with designing their own scientific investigations is a means to democratising research. To understand the requirements for this form of community participation, we surveyed 150 participants of nQuire - a web-based solution that scaffolds the research design process - and identified factors that enabled and inhibited non-researchers from participating in research. Participants acknowledged the importance of taking part in scientific studies and reported learning benefits in terms of increased awareness and behavioural change. The majority of participants expressed interest in joining studies in the future, yet reported that they are rather unlikely to create their own investigations due to a lack of time, skills and support needed. Implications for the design of community-led citizen science are discussed.

Introduction

Researchers have been engaging the general public or non-researchers, with research activities for years. Many used to refer to, and treat research participants, as passive agents or "subjects" of research. In 1998, an advisory board from the National Health Service (NHS) in England moved away from the term "subjects" and replaced it with "participants", encouraging researchers to abide to a *"firm commitment to involving consumers in research—not as "subjects" of research, but as active participants in the process of deciding what research should take place, commissioning research, interpreting the results, and disseminating the findings"* (Boynton, 1998). Since then, the direct involvement of people with scientific or research activities is found to vary. Under the banner of Citizen Science (CS), we have seen the public collecting or processing data to support research activities led by scientists such as making or transcribing biodiversity observations. In other cases, it is involved in other aspects of the research processes like negotiating and deciding on what to study, how to collect and analyse data, or contribute to reports and publications (Shirk et al., 2012; Haklay, 2013).

Recently a further shift in terminology has been observed. Participation in CS is referred to as Community Citizen Science (CCS). There is a growing emphasis on bringing together communities to examine personally relevant and authentic topics and identify solutions that best match local needs (Audubon Center, 2018; Herodotou et al., 2021). The participation of the public in research has been viewed as a means to promote inquiry learning and critical thinking (Herodotou et al., 2017) and develop agency to solve global societal issues such as sustainability challenges (Sauermann et al., 2020). In this paper, we build on this definition to argue that CCS or community-led CS is a methodology that can *democratise research* by opening up all the stages of the scientific process to communities and individuals and allow the public to understand, get motivated and take part actively in these processes. This is not a straightforward endeavour; it requires capacity building in research institutions and organisations in order to change established perceptions and practices of how participants engage and support research, while at the same time, empower communities through, for example, appropriate training and technological tools, as to how to contribute or pursue their own research agendas in ways that are scientifically and ethically robust and thus acceptable by the research community.

Amongst the challenges reported when initiating or conducting a CCS project are the financial viability of the project, concerns about the quality of data, a lack of integration with learning, time demands to plan for such a project, and little appreciation in academia and policy (Hecker et al., 2018). There is often a lack of time and resources to design a project well, promote it and establish communication channels with participants, while technological skills are often needed for running it. On the other end of the spectrum, there are concerns about the accuracy of data collected and whether sampling is representative and sufficient. Technological development and innovation can be a means to overcome some of these challenges including having volunteers designing their own projects, communicating project findings during and after the project ends and sustaining engagement with participants, using web-based tools. In particular, at The Open University UK, we have developed a web-based platform - the nQuire platform (nquire.org.uk) - for managing the research process from start to end. Our intention is to enable non-researchers to become active creators of research and take control in defining and pursuing their own personally-relevant research agendas, with support from technology and research experts.

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In this study, we surveyed 150 nQuire participants who had taken part in at least one nQuire study in the past. None of them was involved in designing or managing their own study. Our motivation behind this work was twofold: the anecdotal observation that individuals with limited or no scientific background were less likely to show interest in setting up a study on nQuire, and the very low response-rates accompanying completion of online research (e.g., surveys). Therefore, in this study, we aimed to identify the factors that facilitate or inhibit (a) participation in scientific research as led by scientists and (b) intention of participants to create and lead their own research. In particular, we identified motivations of taking part in nQuire studies including any learning benefits, and sought participants' future intentions to participate and create their own studies. In the next section, we describe a learning-oriented theoretical framework this line of work is drawing from.

Theoretical background

Community Citizen science (CCS) shares similarities with Community-Based Participatory Research (Tremblay et al., 2018) in the sense that participants and researchers are perceived as equitable partners who are engaged in all the stages of scientific work with the aim to benefit communities and bring desirable change and development. What is unique in our approach to CCS are: (a) an emphasis on large-scale research, stemming from traditional conceptions of citizen science as a crowdsourcing activity, and (b) an explicit focus on facilitating participants' life-long learning and development. The former points to the engagement of the public with research at large-scale; this can be enabled by web-based technologies and tools that facilitate participation in research. Large scale research has the potential to engage more and diverse voices with research (especially when appropriate sampling processes are adopted), while it can be particularly suitable for pursuing research with communities that are not geographically bounded but defined by common problems or common interests. The latter refers to a learning-oriented approach to understanding and structuring engagement with research, which we coined as Community Inquiry (Herodotou et al., 2021). Community inquiry refers to participation in research through engagement with inquiry learning processes. Drawing from Bloom's taxonomy (Anderson et al., 2001), community inquiry can be structured upon the following learning objectives, through which participants can be guided to design their own investigations: (1) identify or recall an issue of interest or concern, (2) understand this issue through explanations and interpretations that result in defining specific and measurable research questions, (3) apply specific methods to answer these questions, (4) collect and analyse data emerging from these methods, (5) evaluate findings and the degree to which they answer given research questions and (6) create reports, publications, social media content for sharing findings. Scientists and technology are seen as an integral part of the process of design; scientists should scaffold communities to meet the above learning objectives, for example, by sharing expertise about the pros and cons of specific methods of data collection or discussing limitations of a given method of data analysis. Technology could help communities author their studies, collect and access data, and disseminate findings. In the next section, a technological solution designed to scaffold community-led research is described.

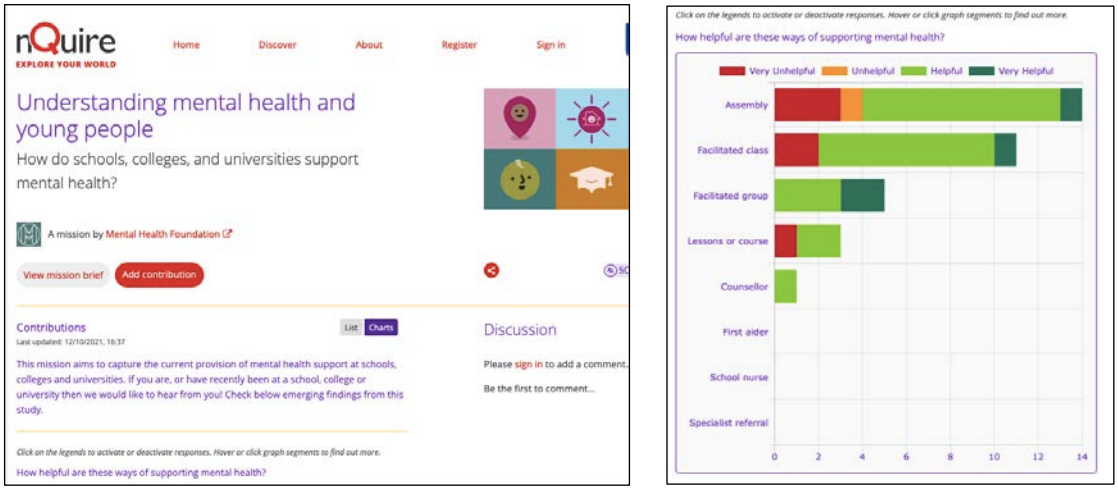
A technological solution for community-led citizen science

The nQuire platform (nquire.org.uk) has been designed with support from the Open University/BBC partnership in an effort to engage the general public with scientific work in ways that support their interests, learning and development. It has been iteratively designed by educational experts and in close consultation with end-users following principles of design-based, participatory research (Herodotou et al., 2018). nQuire enables communities or individuals to, either take part in scientific investigations designed by others, or be guided to design their own, personally relevant studies.

In terms of the former and as a means to support learning processes, participants receive *immediate* feedback: (a) after submitting their responses to an investigation (called a *mission*) in the form of narrative (text) informing them about issues related to the investigation they took part in and suggesting further relevant readings and studies. Also, they can receive *personalised* feedback based on their responses to specific questions, for example, the degree to which they can identify misinformation in news or get recommendations about how creative activities can improve their wellbeing, and (b) when visiting a mission in the form of data visualisations (interactive graphs of collected data) (See Figure 1) and reading, commenting and liking other people's actual responses to the mission questions. We perceive this as a means to open up the process of data analysis to the public and re-engage people with missions more than once, as they can revisit the mission at any time and observe how emerging findings are changing the more people take part in a study. In addition to this and following existing guidelines (Tweddle et al., 2012), the benefits from taking part in a mission are clearly communicated to participants and stated in the mission brief. Similarly, experiential learning or physical practice - shown to be effective in supporting learning processes (Alhajri et al., 2018) - is promoted by asking participants to complete

hands-on activities for data collection such as taking photos of nature, and measuring temperature and growth of trees.

Figure 1 A nQuire mission providing immediate access to data findings



Two mechanisms support participants in designing their own scientific investigations and taking control of the research process: (a) technology and (b) collaboration with scientists. The first mechanism is an authoring tool that guides the process of designing, testing and iterating a study through a series of steps including instructions about how to set up a "Big question", selecting different types of questions that enable the collection of text, image, map location and sensor data, enabling personalised feedback in the form of text or visualizations, piloting functionality (any data collected during piloting are deleted when the mission goes live), and downloading data collected after a mission goes live on nQuire (more details about the functionality of the authoring tool can be found in Herodotou et al., 2021). Participants can choose to create or take part in (i) confidential missions in the sense that all responses are private; anonymised data files can be accessed and downloaded by a mission author only, or (ii) social missions where all responses are open to the public to read, comment and like.

The second mechanism that scaffolds participants when creating their own investigations is a thorough process of review and approval led by Open University scientists that ensures the scientific and ethical quality of proposed studies (Herodotou et al., 2021). OU researchers communicate with mission authors to review, provide constructive feedback and suggest improvements to proposed investigations in ways that are scientifically valid and ethically correct. The process of approvals includes reviewing aspects of the mission such as the language and structure of the mission, ethical considerations, originality, copyrights, piloting and ensuring authors share interim and final reports with findings with their participants via nQuire (Herodotou et al., 2021).

The majority of missions on nQuire have been designed by academics or researchers affiliated with universities in the UK. Other missions have been designed by organisations such as the Mental Health Foundation, the Young Foundation, BBC Springwatch and BBC Weather, and the Royal Meteorological Society. One mission has been designed by an individual with research expertise and interest in engaging communities with research. These insights suggest that organisations with research expertise and/or interest in doing research and engaging with the public are those likely to use the nQuire authoring tool and initiate their own studies. The question raised is how we can engage individuals and communities with limited or no research expertise and interest in scientific investigations with the process of designing and implementing a scientific investigation.

Community-led research is timely; communities are better aware of where problems in their communities lie and have a vested interest in finding solutions (Whittle et al., 2012). Societal challenges such as sustainability transitions towards for example renewable energy use could be better addressed if communities were engaged in the problem definition and the framing and generation of potential solutions (Sauermann et al., 2020). Proposed solutions would be owned by communities and thus more likely to be adopted and applied in sustainable manners, as opposed to being imposed by research and policy experts. The online implementation of nQuire and the catering for large-scale research mean that concerns about sampling and reliance on small, atypical samples (Weigelhofer, & Pölz, 2016; Whittle et al., 2012) can be addressed as, with appropriate advertisement strategies, different populations can be reached. Also, nQuire visualisation tools enable awareness of the locations data are collected from that can inform promotion interventions to increase geographical sample representation. We acknowledge

that access to technology and the internet relate to persistent socioeconomic inequalities (Fiske et al., 2019) that may exclude certain populations from accessing the benefits of community-led research and these should be examined further and addressed. In this study, we consulted participants of nQuire missions in an effort to understand the factors that enable or inhibit this cohort of individuals from taking part, creating and pursuing their own scientific investigations.

Methodology

Survey questions were hosted in the JISC online survey platform. We asked participants to state the number and type of nQuire missions they took part in, their motivations for taking part in these missions including any learning benefits (to understand the reasons why people engage with scientific work) and their intention to take part and design their own study in the future. We emailed participants who took part in a scientific investigation or mission during the last year, and who had indicated at that time that they consented to be contacted about future studies. Closed questions were analysed using descriptive statistics (summary graphs and tables), while open-ended questions followed principles of thematic analysis (Kvale, 2007), capturing and reporting diverse voices and perceptions. We received responses from 150 participants. Participants were over 16 years old, as per the age limit for using nQuire. This research project has been reviewed by and received a favourable opinion from the Open University's Human Research Ethics Committee.

Results

The vast majority of respondents took part in one mission only (85%). Ten people (6.67%) indicated they had participated in two missions, six (4%) in three missions, a further six (4%) in 4-5 missions, and one person stated they had been involved in 11 or more missions. The topic of the missions participants took part in varied. As shown in Table 1 below, a majority took part in missions related to the environment including birds, pollinators and gardens. 20% of participants took part in literature-related missions and 12% in climate-related missions. Participation in missions was influenced by a number of factors including the range of mission topics available at a given time on nQuire as well as the degree of promotion of each mission. For example, the Gardenwatch missions were promoted by the BBC during the Springwatch 2019 TV series and reached more than 230K contributions.

Table 1
Number of participants and content of missions

Topic of mission participants took part in	Number and % mentioning (where 100% = 138)
Birds, pollinators (e.g., bees), mammals, worms	50
Therapeutic value of sounds of nature	7
	Total: 57 (41%)
Novels, literature, characters	27 (20%)
Climate related (heatwaves, climate anxiety)	17 (12%)
Covid-19 related	12 (9%)
Cognition/memory/sound	6 (4%)
Astrobiology	1
Chronotypes	1
Online teaching and learning	1
Others (participants could not recall or were unsure about the name of the mission)	14 (10%)

The main motivation for taking part in a scientific study on nQuire was to contribute to research and science (59%). A number of other participants participated because they believed that helping with science is

important (13%) or had an a priori personal interest in the topic of the investigation (11%). 10% wanted to learn more about the topic of the investigation, 5% wanted to experience what is like to participate in a CCS project and 3% stated other reasons.

In terms of learning in particular, a substantial number (43%) said that there was no change in their knowledge and explained that by (a) not remembering a lot about the mission they took part in and this inhibited them from being able to reflect on their learning, (b) previous knowledge about the topic: "*I'd already learned to recognise different species of bumblebee, but the project just wanted "bee" or "butterfly"*, and (c) not being informed about the findings of the study: *"Haven't heard any results"*. The latter stresses the important role of sharing findings with participants during and by the end of a project that can support their learning.

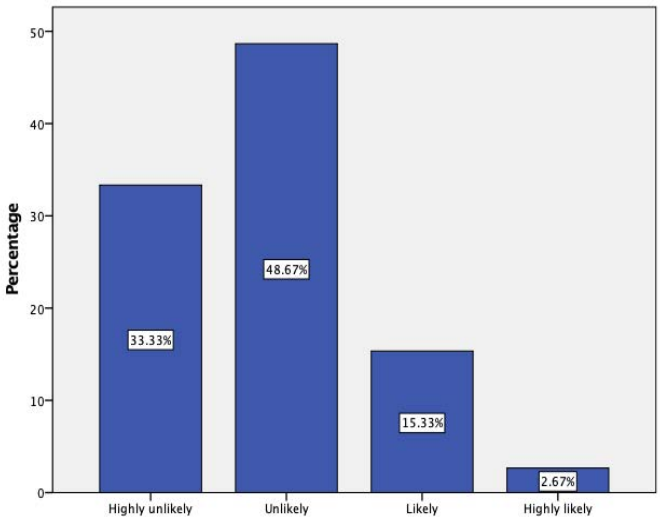
A majority of 48% said they know a little more about the topic of the mission, and 8% a lot more about it. Those participants reporting changes in their knowledge in terms of (a) increased awareness about the topic: *"I have become more aware of the diversity in my garden"* (Participant 1); *" questioning as to how a particular book has influenced/affected me on various levels, e.g., perception challenged, emotional response, escapement from the everyday, stimulated interests/new ideas, etc."* (Participant 2), *"Aware of what plants are likely to benefit insects and keen to make my garden more insect and pollinator friendly*" (Participant 71*).* (b) desire to learn more about the topic: *"The knowledge I gained has given me a desire to find out more through books. I would like to be involved with gaining practical knowledge especially with identification"* (Participant 13). (c) a change in everyday habits: *"To listen to more ambient sounds while out walking and not just plugging my headphones in. This has led to my walks making me feel more productive and calm." (Participant 32), "It was good to actively look at the environment of my garden and observe the insect life closely, I enjoyed the opportunity to slow down and take the time needed to identify then photograph the individual species...this is something I will do again. I actively garden for the benefit of wildlife anyway but this survey helped me understand the benefit of that on a more visceral level" (Participant, 20),* (d) taking action to support biodiversity: *"It led me to read up on helping pollinators and providing habitat in my garden"(Participants, 44), "I set up an Instagram account and posted photos on the [mission name] it encouraged me to take part in other surveys." (Participant, 83).*

A great majority of 89% expressed an intention to take part in future missions, stating that this is likely or highly likely to happen. 11% stated that this is unlikely. Their follow-up explanations showed that, such an action would depend on (a) a personally relevant research topic: *"If something was of interest to me I would participate" (Participant, 102)*, (b) time and effort required to take part: *"If I get invited and have time while the Mission is open then I probably would take part, especially if it's short and can be done at any time." (Participant, 54), "depending how many questions i need to answer" (Participant, 67),* (c) a general motive to help with science: *"If it helps with furthering scientific research"* (Participant, 134), (d) prior expertise in research: *"Volunteer entomologist, survey invertebrates. Volunteer in a research group at London NHM for many years. Record garden birds for BTO. Have MSc in Biological Recording." (Participant, 139),* (e) the possibility for unexpected discoveries: *"Finding something unusual would prompt me to take part unsolicited." (Participant, 87),* (f) having their voices heard: *"It is a way of having my understanding heard by someone relevant, rather than the rubbish from the media" (Participant*,103) (g) general interest in taking part in research: *"always happy to take part in surveys" (Participant, 122), "I love taking part in questionnaires and surveys. I am passionate about literature and reading" (Participant, 79).*

As shown in Fig. 2, only a small percentage of participants expressed an intention to design their own missions in the future and this was explained by (a) having the skills or competence to do so: *'I do this stuff off my own interest already' (Participant. 13), 'I'm a postgraduate social scientist, and I have a lot of interest in doing my own research. Some of it is unlikely to be properly funded through but it would still be interesting to do some surveys and have a go with it.' (Participant, 51),* and (b) having significant prior knowledge about the topic that can help them in designing a mission: *'Having expanded my knowledge on the importance of such a wide variety of pollinators I am wanting to survey a 1.75acre traditional hay meadow to establish how it is used by pollinators and other wildlife so decisions on future management and how it can be improved for wildlife can be made.' (Participant, 77).*

A large percentage of participants (83%) considered it unlikely or highly unlikely they would create their own study. Amongst the reasons given for this were (a) a lack of time: *"Lack of time to design, analyse and make useful use of the data" (Participant, 45),* (b) a lack of knowledge and skills: *"I would not have the knowledge of how to do this" (Participant, 61), "Not qualified" (Participant, 24), "I don't really have a suitable topic for inquiry" (Participant, 73), "I'm not that inventive to establish a project" (Participant, 81),* (c) a lack of support: *"I just don't have the type of work environment that would warrant me embarking on such a project" (Participant, 133)*, and (d) a lack of awareness that this is possible: *"I wasn't aware it was possible" (Participant, 101),* and (e) creating a project is not for the general public: *"why should I?"(Participant, 22), "There is no reason why I should (this is an odd question)" (Participant, 109).*

Figure 2 Likelihood of creating your own study in the future



Discussion

In this study, we surveyed 150 participants who took part in research studies or "missions" hosted on nQuire - a community citizen science (CCS) inquiry platform. The majority of participants participated in one mission, yet they reported an interest in taking part in more missions in the future. Half of them reported learning benefits after taking part in a mission expressed, as in other studies (Herodotou et al., 2020) in knowledge improvement, in particular increased topic awareness and a desire to learn more about the topic under study. Some responses revealed evidence of identity change or agency (Ballard et al., 2017) including changes in everyday habits and taking action to support biodiversity initiatives after taking part in a mission. Participants who did not report any learning benefits were either already knowledgeable about the mission topic or they had not been informed about the project findings, stressing the importance of sharing findings with participants and validating them as genuine contributors in research, as this could promote learning, and the value of accessing collected data and project findings (de Vries et al., 2019). Showing the personal and societal benefits of a study "constitute an effective informational nudge" that was shown to motivate further participation and increased awareness about environmentally-related topics (Cappa et al., 2020). Some nQuire missions related to literature, Covid-19 and pollinators have shared findings with participants, yet others have not done so yet and this may explain why some participants raised the need to access findings. These insights have informed the nQuire process of approvals which now requires authors to upload interim and final reports with findings to the platform as a means of providing feedback to participants and facilitating engagement. Participants receive email alerts when findings are available.

Aligning with existing studies (Jennett et al., 2016), the main motivations for taking part in a mission were to contribute to scientific research, the importance of helping with research, an *a priori* personal interest, and curiosity expressed in a desire to learn more about the topic. Participants' intention to participate in future missions was explained by multiple factors including (a) some of the aforementioned motives such as a desire to help with science and a personally relevant topic, (b) practical reasons including time and effort needed to take part in a mission, favouring short investigations, (c) prior research expertise that could help a mission, (d) the possibility for unexpected discoveries, and (e) to share personal opinions and have their voices heard.

As reported by participants, the transition from participating to creating scientific investigations is not a straightforward one; we observed a great majority of participants reporting that it is unlikely or highly unlikely that they would create their own mission. Amongst the factors explaining these perceptions were a lack of knowledge and skills for designing a study, a lack of support, and a lack of time. Of special interest is the fact that some participants were not aware that it is possible for them to design a study or could not see the value or benefit of having themselves doing so. These findings suggest that the shift from *participants* to *creators* necessitates concerted efforts in order to, first, raise awareness about the role communities and individuals can play in decision making and how their participation can contribute to solving societal problems in ways that best meet their needs. Second, training resources and tools are needed to support skills' development, scaffold the process of design, and lead to designing robust and ethical scientific investigations. Online platforms such as nQuire can support the process of designing personally meaningful projects by making explicit the design process through a series of steps and collaboration with scientists, whereas the provision of immediate feedback to participants after taking

part in a study and data visualisations allow for ongoing feedback that can support learning and motivate further participation.

Conclusions

One of the limitations of this study was the timing of the survey circulation as some participants had difficulties to recall the specific study they took part in and accurately report on its impact. Future studies should time such assessment close to when a study has been completed or embed questions assessing e.g., learning, motivation in the design of a study. Also, a single CCS platform, nQuire with specific design affordances has been studied. CCS platforms with different functionality are likely to promote other forms of community-led research, focusing on specific stages of the scientific work. For example, Zooniverse can scaffold the process of data analysis by enabling access to data collected by scientists, whereas iNaturalist supports the process of data collection and identification by enabling communities to record and upload species of biodiversity. As such, they are likely to support different forms of learning and engagement. In addition, the process of enabling non-researchers to design and implement their own studies necessitates further and more in-depth examinations. This study provided initial insights as to people's perceptions about community-led research and associated barriers. Further studies should engage with specific communities using e.g., interviews, focus groups, observations to understand specific requirements and trial interventions that can empower people to initiate their own studies and start thinking of themselves as scientists.

Careful consideration should be given to the time and effort needed for the general public to take part in CCS activities. In this study, survey participants valued the importance of helping science and expressed interest in taking part or initiating CCS activities, should time requirements be considered. Reflecting on these insights, bite-sized learning might be an appropriate approach to engaging the general public with CCS in ways that are not time consuming. Bite-sized learning (Manning et al., 2021) refers to activities that are short, focused on achieving one learning objective at a time, and less cognitively demanding. Taking as example the nQuire missions, a study could be divided into a series of separate, short missions, with few questions in each one and shared with participants at different points of time. For creating a community-led mission, this may mean that the different stages of scientific work become separated; for example, brainstorming ideas about a mission's big question could form a mission on its own. Similarly, identifying the most appropriate methods of data collection could be a separate voting mission.

In terms of pursuing community-led research, there is a need for researchers to communicate clearly the benefits of such activity for how decisions are made and how the voices of different people can be considered in the production of knowledge. Also, they should showcase ways such activities can be scaffolded through support from technology and scientists. Community-led research should be seen as an interdisciplinary activity where researchers and communities work closely together to share expertise and understanding and design studies that are inclusive and considerate of the specificities of a community.

Finally, the Open University/BBC partnership showcased the significant role large and well-known organisations can play in engaging the general public with CCS. The BBC has partnered with the Open University for over 50 years to provide access to learning at scale, at first via late night TV lectures, and recently through the co-production of content for TV, radio, podcasts, social and digital media. Encouraging the public to join or initiate CCS activities could be actively promoted as part of Open University/BBC social good agenda, bringing the public closer to science and supporting the development of scientific work. The development of CCS capacity in such organisations could be actively pursued through collaboration with institutions with expertise in CCS such as museums, charities and universities.

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Interactive Transcription Techniques for Interaction Analysis

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Abstract: Interaction analysis is a valuable method and approach to study knowledge in use in the learning sciences and CSCL communities. Central to interaction analysis is the creation of transcripts to selectively encode and represent audio and video data. However, current transcription techniques used in interaction analysis, including multimodal transcription techniques, have yet to explore the strengths and weaknesses of interactive visualization to selectively encode and represent people's interaction in context. Drawing from recent efforts to amplify, not automate, transcription in qualitative research, this paper interactively visualizes one video dataset in five different ways using contemporary interactive visualization techniques. Findings and discussion characterize these visualizations as interactive transcripts that demonstrate techniques valuable to interaction analysis, but also highlight the need to expand how people, things, and context are represented through visualization mediums such as visualization programming languages to align with work more meaningfully in the learning sciences and CSCL communities.

Introduction

Interaction analysis is a valuable method and approach to study knowledge in use in the Learning Sciences and CSCL communities (Jordan & Henderson, 1995; also see Hall & Stevens, 2015). Interaction analysis relies on detailed analyses of audiovisual data to characterize interaction in ways that support analyses of learning or teaching, often from sociocultural or social practice perspectives. Central to interaction analysis is the creation of transcripts, which selectively encode and represent audio and video data to understand events from the perspective of participants and everyday people. However, current transcription techniques used in interaction analysis, including multimodal transcription techniques, derive primarily from the use of tools such as Microsoft Word or PowerPoint and have yet to explore the strengths and weaknesses of interactive visualization to selectively encode and represent people's interaction in context.

Drawing from recent efforts to amplify, not automate, transcription in qualitative research, this paper interactively visualizes one qualitative, video dataset in five different ways using contemporary interactive visualization techniques. Findings and discussion characterize these visualizations as interactive transcripts that demonstrate techniques valuable to interaction analysis, but also highlight the need to expand how people, things, and context are represented through visualization mediums such as visualization programming languages to align with learning sciences and CSCL research, including recent efforts to expand the methodological commitments of interaction analysis (see Krishnamoorthy et al., 2021; Marin et al., 2020; Silvis et al., 2022).

We begin by reviewing relevant work concerning transcription and interaction analysis as well as relevant visualization theories. Subsequently, we describe the video dataset we analyze in this paper. We then describe five different interactive visualizations of this dataset by unpacking the techniques, encoding decisions, and insights made visible in each visualization. These visualizations are web-based, open source, and made available in this paper. Findings and discussion summarize the contributions of these visualizations as interactive transcription techniques for interaction analysis but also highlight the need to expand how people, things, and context are represented through visualization mediums in future research.

Theoretical framework

Transcription and interaction analysis

Transcription is used to encode and translate various forms of unstructured data such as audio or video into a representation that aids in interpreting unstructured data (see Atkinson & Heritage, 1999; Erickson, 2004; Duranti, 2007; Jefferson, 1984; Gee, 1999; Goodwin, 1994; Hall & Stevens, 2015; Mondada, 2007). For learning sciences and CSCL researchers who use interaction analysis, transcription is central to selectively representing sequences of interaction in order to study learning or teaching (for recent examples see DeLiema, Enyedy & Danish, 2017; Keifert & Stevens, 2019; Kelton, 2021; Hennessy Elliott et al., 2020; Ma & Munter, 2014; Marin, 2020; Jung et al., 2020; Steier, 2014; Taylor, 2017; Vossoughi et al., 2020). Notably, transcription is viewed as a theory laden and selective practice of encoding data (Ochs, 1979; also see Hall, 2000; Derry et al., 2010). This means that any transcription method encodes and represents data in ways that are reflective of the assumptions, biases, and goals

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of the researcher (or computer) doing the transcribing. Likewise, qualitative researchers highlight the value of manual transcription (Lapadat & Lindsay, 1999; Erickson, 2004). While manual transcription is slow and tedious, the process provides ways to understand qualitative data that are fundamentally different than automated techniques emerging in fields such as computer vision and machine learning.

While transcription has evolved in many ways over the years, the mediums and tools used to produce transcripts have not changed considerably. Apart from a few examples (see Angus et al., 2012; Shapiro, Hall & Owens, 2017), transcripts are typically produced with language-based tools such as Microsoft word and PowerPoint that support static and typically text-focused transcripts. This is the case even as transcription has rapidly expanded in innovative ways from a focus only on language to multimodality (Bezemer & Mavers, 2011; Kress & van Leeuwen, 2006), with multimodal transcripts often using the same tools to characterize phenomena such as gesture. Put simply, while researchers continue to highlight how these tools are inadequate to characterize the complexity and layeredness inherent to studying interaction in settings such as classrooms, the potential strengths and weaknesses of interactive visualization to address some of these limitations remains unexplored.

Alternative visualization theories and integrative visualization

In response to broader arguments about how visualization can more meaningfully and intimately represent and communicate with people and communities, new theories of visualization have emerged that focus on alternative ways of knowing, non-binary approaches to data, and the contextual dimensions of data (e.g., D'Ignazio & Klein, 2016; Lupi, 2017). This paper draws from our developing efforts to connect these theories with qualitative research through the notion integrative visualization (Shapiro, 2019).

As we describe in prior work, integrative visualization is a human-centered process to interpret unstructured data such as audio or video typical of qualitative research in ways that support the development of grounded theory (Glaser & Strauss, 1967) and contextual computational tools. A key part of integrative visualization is the use of visualization mediums such as graphics editors or programming languages to support manual and iterative transcription of data collected in context. Such transcription amplified by visualization aims to further the grounded theory process (e.g., generation of categories, codes, units of analysis and questions) and lead to insights that can inform the development of contextual computational tools. Notably, integrative visualization extends the practice of "integrative diagramming" (Strauss, 1987) as used by qualitative researchers and is summarized as follows:

data context → transcription amplified by visualization → grounded theory & computational tools

This paper contributes to a deeper understanding about the strengths and weaknesses of visualization mediums such as graphics editors and programming languages to amplify manual transcription, specifically for interaction analysis as used in the learning sciences and CSCL communities.

Data sources

Our subsequent analysis draws from a video from a bilingual elementary classroom. This 2-minute video of classroom interaction shows the teaching of a key idea in the physics of matter—that matter occupies space—in a kindergarten-first grade classroom and is available at the following link: https://youtu.be/d8_pRUR-hmg. In the video, a teacher is seated with her students around her on the floor of a classroom and conducts a brief experiment involving a jar and marbles to illustrate how matter occupies space. The teacher also facilitates a discussion about the experiment with the class. This dataset was chosen because it was collected by and is well known to researchers who use interaction analysis in the learning sciences and CSCL communities. Notably, this video was central to a recent conference supported by the Spencer Foundation at Arizona State University where an interdisciplinary group of older and younger scholars gathered to document the basic patterns of visual and auditory attention employed by researchers who use video to study social interaction (Erickson et al., 2017: see: https://www.learninghowtolookandlisten.com).

Analysis

Our analysis uses an established visualization programming language called D3.js to interactively visualize this dataset in five ways. Figure 1 shows a static image of each of these five visualizations along with a screenshot from the video dataset introduced previously. Interactive visualizations of each of these images are open source and can be explored at the following link, and we encourage readers to explore each interactive visualization while reading our subsequent analysis: https://mrmathur.github.io/mos-visualizations/

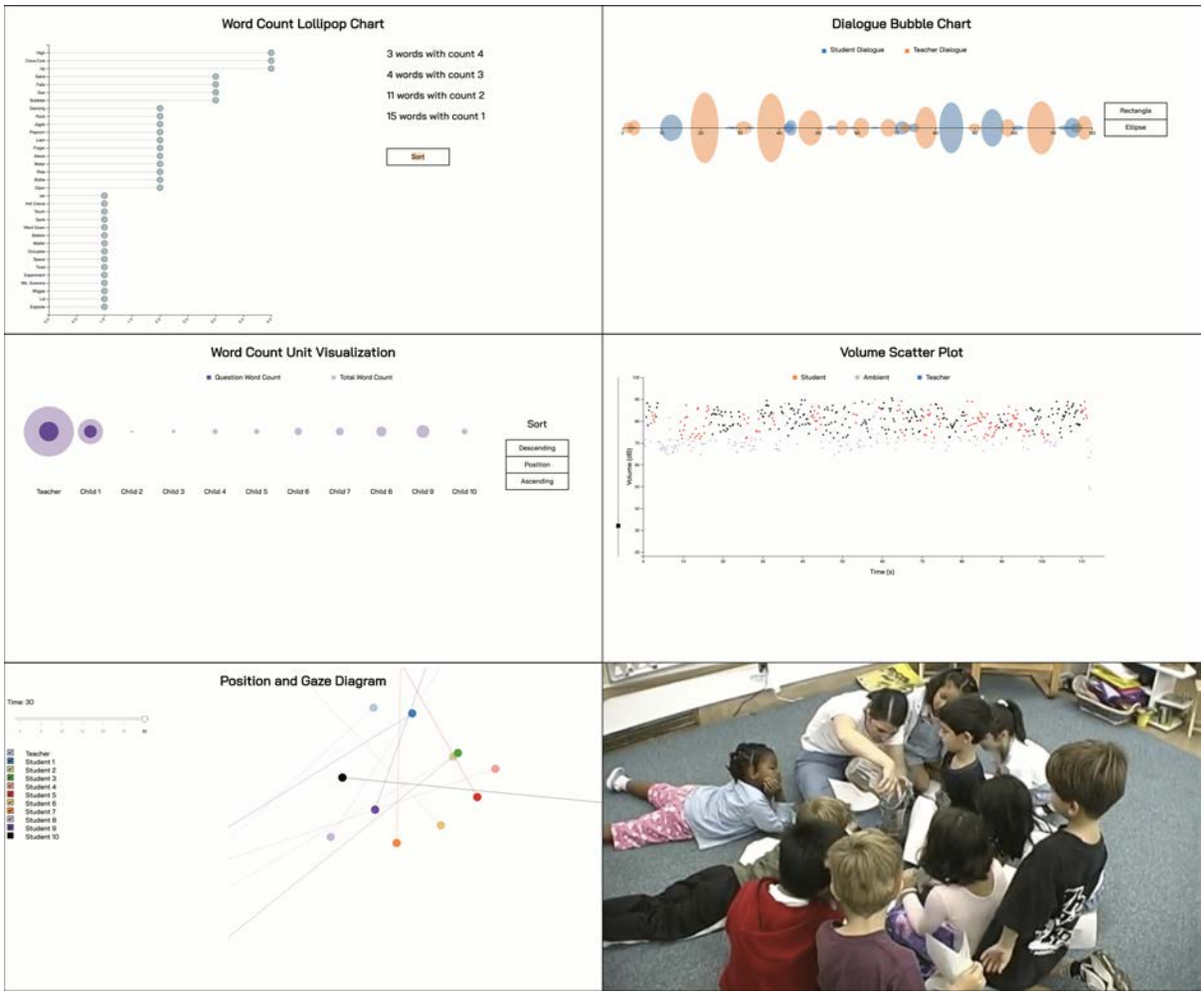

Figure 1. Screenshots from five different interactive visualizations of a two-minute video of classroom interaction. Interactive visualizations available at: https://mrmathur.github.io/mos-visualizations/

In the following we unpack each image and corresponding interactive visualization in this figure (from top left to bottom) by describing the a) specific representation and interaction techniques, b) encoding decisions and c) insights generated in each visualization. Our analysis aims to bridge language used by interaction analysts and visualization researchers in ways that help us discuss strengths and weaknesses of contemporary visualization techniques, including methodological commitments that are inherent to languages such as D3.js.

Visualization 1: Word count lollipop chart

Techniques

The first visualization is what is known as a lollipop chart, which is an extension of the more widely known bar chart. In this case, the length of each horizontal line across the X-axis encodes the number of times a word has been spoken during the 2-minute video of classroom interaction. Moreover, the chart supports standard forms of user interaction in two ways: Sorting and hovering (see Yi et al., 2007). Namely, the words can be sorted in ascending or descending order by using a button. Hovering over each circle also reveals the sentences in which the word was spoken and allows users to view and read these sentences.

Encoding Decisions

A database (i.e., a .csv file) was generated with each word, its frequency, and the sentences during which these words were spoken. Conversation spoken by teachers and students was occasionally in Spanish. The authors decided to only use the English translation of words in the video. Notably, articles and pronouns were also not included. With the database in place, a lollipop chart was made, by encoding the x position of the circle as the word length, and the y-axis as the rank (either ascending or descending, based on the user's selection). A lollipop

chart was used as opposed to a more standard bar chart because a lollipop chart affords more ways for users to interact with the data, in this case by reading sentences from which each word was derived.

Insights

Many basic insights are visible through this simple, standard representation. For example, while the central topic of this sequence of classroom interaction is the notion that "matter occupies space", those particular words are rarely spoken by the teacher or students. In contrast, metaphors such as CocaCola, Sand, Bubbles, and Dancing are repeatedly uttered. A few student names are also recurrent, however not all student names are spoken. Furthermore, the possibilities to interact with this visualization allow users to consider the context in which each utterance is spoken at a sentence level offering very different ways to read turns of talk in comparison to traditional, non-interactive transcription methods. However, many insights are also lost through this type of representation in comparison to a more traditional transcript. For example, coherence of participants' sense-making is difficult to recover even through interaction.

Visualization 2: Dialogue bubble chart

Techniques

The second visualization is a bubble chart, where each ellipse represents a conversation turn (i.e., in this case, uninterrupted speech that could span multiple sentences) spoken by either the teacher or a student. Ellipses are organized across a conventional timeline or time series display and the beginning and end (or left and right) of each ellipse marks the beginning and end of each conversation turn. Moreover, the visualization supports user interaction by allowing users to toggle between rectangles and ellipses to represent conversation turns, which allow users to explore subtly different aspects of conversation structure from this sequence of interaction. The users can also hover on a conversation turn (ellipse or rectangle), to display and read the dialogue spoken.

Encoding Decisions

A database was generated with each conversation turn, its content, and who spoke each conversation turn. Notably, each conversation turn was defined as a sequence of uninterrupted speech, which could span over multiple sentences. With the database in place, a bubble chart was made. The height of the ellipse indicates the number of words in each conversation turn. Thus, taller ellipses or rectangles (depending on the view selected by the user) indicate more words spoken during a conversation turn or a faster conversation turn. The left and right of each ellipse or rectangle indicate the beginning and end of each conversation turn. Thus, where ellipses or rectangles overlap indicates overlapping speech. The color of the bubbles represents who made each conversation turn. Hovering on a bubble reveals the content of the dialogue.

Insights

The bubble chart reveals several relevant insights. First, one can observe the general pacing of each conversation turn (i.e., length of conversation turns with respect to both the number of words and amount of time). This makes visible how the teacher speaks for much longer stretches of time and the parts of this interaction where students speak for long periods of time, often while asking a question. Likewise, the moments during this interaction when no one is speaking can be quickly identified. Moreover, overlapping ellipses (or rectangles depending on the view selected) are an interesting phenomenon. For example, these overlaps show that while students speak over one another they do not speak over or interrupt the teacher's speech. Furthermore, the teacher utters many more words per conversation turn in comparison to students, who generally speak fewer words and for shorter periods of time. Finally, the ability to quickly hover over each ellipse or rectangle and read conversation provides a fundamentally different way to compare conversation turns in comparison to existing transcription methods.

Visualization 3: Word count unit visualization

Techniques

The third visualization is what is known as a unit visualization. It is named so because every individual from the video is represented by a spherical unit. Different attributes of this unit encode different characteristics. Here, the area covered by the outer and inner circles represent the number of total words and also questions uttered by each student and the teacher during this sequence of interaction.

Encoding Decisions

A database was generated with each individual, the word count for each individual, and the question word count for each individual. Notably, expressions and exclamations were not included in word counts for each individual.

A distinction between a statement and question was made by judging the intonation of the dialogue, with the intent being to explore the role and significance of questioning in the classroom. With the database in place, a unit visualization was created. The area of the lighter circle indicates the total word count for each individual whereas the area of each darker circle indicates the question word count for each individual (as represented by the legend). Importantly, area (as opposed to the use of radius) was selected to encode total and question word counts because the consensus in the visualization community is to use area, as it is a more intuitive indicator of quantity. The x position of each individual is determined by one of three modes or orders selected by the user.

Insights

The visualization supports comparative analysis across individual speakers with respect to the number of words uttered and the number of questions posed. For example, the teacher speaks many more words and also a far larger number of questions whereas students have much lower word counts and fewer questions. The visualization makes evident differences in contributions between students. For example, the visualization highlights child 1 as a significant speaker in the classroom; Notably, she also asks the teacher the largest number of questions. Altogether, the visualization is quite useful to analyze conversational parity or whether there are equitable opportunities to talk. However, the coherence and meaning of conversation are backgrounded.

Visualization 4: Volume scatter plot

Techniques

The chart is a scatter plot, where each dot represents a 0.2s instant in the video. The x position of the dot encodes the timestamp of the instant, the y position encodes the volume of the video at that instant, and the color represents the volume contributor, which is indicative of the source of the volume at that instant of the video. The user can interact with the visualization by rescaling the y-axis through a vertical slider, which allows them to zoom into relevant parts of the graph.

Encoding Decisions

Using a free, mobile application, a database was generated that encoded the volume organized by contributors from the sequence of interaction at time intervals of 0.2s. Volume contributors (i.e., Student, Teacher and Ambient Noise) at every time stamp were manually encoded by the authors. Key decisions were made about how to allocate volume to individuals. For example, at times multiple individuals spoke, and in this encoding scheme, the individual with the longest conversation turn was chosen. Moreover, ambient noise reflects a general category that groups other types of noises during this sequence of interaction not related to speakers. From this data, a scatterplot was generated which encoded time on the x-axis, volume on the y-axis, and the contributor as color.

Insights

The scatterplot makes particular phenomena visible that are quite different than other visualizations reviewed thus far. For instance, stretches of ambient sound (when no one is speaking) correlate to when the teacher is conducting the demonstration that grounds the sequence of interaction. Moreover, the variety of intonations of different speakers are visible in ways quite different from how intonation is typically represented by textual conventions of current transcription methods. Furthermore, average volumes can be viewed and compared, for example, to understand how loudness or strength of projection by a speaker influences classroom interaction that in turn encourages or dissuades others to speak.

Visualization 5: Position and gaze diagram

Techniques

The chart is a position and gaze diagram, where each dot is positioned according to a person's pixel values in the video, and the line represents the gaze of the person, at any instant of time. Users can use the provided time slider to observe the positions and gaze at specific intervals of time while filtering capabilities via checkboxes allow users to selectively view everyone's position and gaze, simplifying the visualization.

Encoding Decisions

To deal with the complexity and size of data, 5 second intervals were chosen. Moreover, pixel values from the video were used to indicate the position of the person, as opposed to a bird's eye view of the room. Likewise, the gaze in the video is in 3D space. However, the gaze was mapped in 2D space, because of the two-dimensional nature of a video. The gaze was defined as the line between every student (and teacher), and the point at which the field of view intersected with the screen's boundary. A database was generated with 5 second intervals, the

pixel values for each person's head position, and the pixel values for the point at which their gaze intersects with the boundary of the screen. Circles were plotted at the pixel locations of each person's head positions, and a line was generated from the head to the gaze point. Each circle was color coded to identify the corresponding person.

Insights

The visualization indicates aspects of how the teacher, individual students, and the class collectively focus and manage their attention or, in other words, how gaze is recruited and allocated. Notably, it highlights the ebbs and flows of how gaze is collected and released during this sequence of interaction in ways that are different than traditional representations and conceptions of how gaze is recruited and allocated. In this case, ebbs and flows refer to moments when participants focus on a particular object or person simultaneously for a period of time or look at many different objects simultaneously. For example, around the 5s mark, it becomes clear that all the students begin looking at the center of the classroom or experiment, as opposed to many different directions observed earlier. Most students look at the teacher, whereas the teacher's gaze fluctuates between students. Those sitting away from the teacher seem to focus their gaze on the teacher, whereas those sitting next to her seem to look at other students. These interesting aspects of spatial noticing also expand traditional conceptions of gaze: Namely, it is typically assumed that all participants have equal affordances in a shared space, but this representation allows one to see how certain participants may have more or less affordances depending on where they are positioned within a shared space. This pattern repeats across the two-minute sequence of interaction in response to how the teacher gathers and releases attention through her gesture and talk.

Discussion

We characterize the previous visualizations as interactive transcripts and focus our discussion on how these transcripts, on one hand, highlight particular techniques valuable for interaction analysis but, on the other hand, demonstrate the need to expand how people and context are represented by visualization mediums such as visualization grammars and programming languages like D3.js. We unpack these statements in order.

The preceding interactive transcripts make use of standard visualization techniques to encourage analysis of new phenomena and questions about this dataset and classroom interaction. For example, as we demonstrated, conversation turns can be compared in ways that are very different than traditional transcription techniques. Such comparisons support new ways to study the pace of conversation, turn-taking patterns, instances of overlapping talk, and volume of conversation in ways quite relevant to situative studies of classroom interaction that view such phenomena as central to people's opportunities to learn. Likewise, as we highlighted, techniques such as the interactive unit visualization are quite useful to analyze conversational parity or whether there are equitable opportunities to talk—something that is challenging to show and study with traditional transcription techniques. Still further, techniques demonstrated through the positioning and gaze diagram challenge typical assumptions about how all participants have equal affordances in a shared space, showing how certain participants may have more or less affordances depending on where they are positioned within a shared space.

While we suggest such interactive transcription techniques are valuable to interaction analysis beyond the example discussed in this paper, like all transcripts, these techniques are theory laden. Notably, in comparison to traditional transcripts, the transcripts in this paper embody theories and methodological commitments inherent to contemporary interactive visualization techniques. Particularly, they highlight how such techniques were not designed to represent people and notions of context important to traditions of interaction analysis as used in the learning sciences and CSCL communities (see Matuk, DesPortes, & Hoadley, 2021). Indeed, as described by Bostock et al. (2011), the goals of D3.js are to make it easy to implement popular and conventional visualizations (such as bar charts, line charts, scatter plots) as well as custom visualizations on the web. Like many existing visualization programming languages or libraries, D3.js embodies visualization grammars or formal models of describing visualizations including data, transformations, scales, and visual marks. Such grammars were designed for data that is already structured (e.g., as a CSV file), typically characterized as raw or objective, and not focused on depicting people's interaction or complex learning ecologies such as classrooms or the natural world.

Extending ideas reviewed at the beginning of this paper, we suggest there is a need and opportunity to expand the notion of a "visualization grammar" to more deeply consider how people and context are represented in ways that align more meaningfully with work in the learning sciences and CSCL communities, including recent efforts to expand the methodological commitments of interaction analysis (Krishnamoorthy et al., 2021; Marin et al., 2020; Silvis et al., 2022). For example, such work might develop interactive glyphs for interaction analysis specific to different settings, new types of interaction techniques to take on the perspective of participants as they engage in interaction, or extend sketching metaphors and commitments to equity and accessibility foregrounded by programming languages such as p5.js that more meaningfully align with the iterative nature of qualitative traditions of interaction analysis (e.g., repeatedly watching video and iteratively developing transcripts).

Conclusion

We began this paper by reviewing how transcription is currently used in interaction analysis as well as our recent efforts to expand alternative visualization theories for qualitative research through integrative visualization. Subsequently, we illustrated and unpacked five different interactive transcripts that demonstrated visualization techniques to characterize types of classroom interaction in ways fundamentally different that traditional transcription approaches. We highlighted the value of such transcripts but also their weaknesses, emphasizing interactive transcripts provide another means to augment, not replace or automate, existing transcription practice for interaction analysis. Notably, we outlined the need and opportunity for researchers to explore how interactive transcription techniques can more deeply represent people and notions of context central to traditions of interaction analysis as used in the learning sciences and CSCL communities. Such work focuses on how visualization can expand qualitative traditions of interaction analysis in ways that are not focused solely on scaling research across contexts, but rather on studying the details of interaction within particular contexts from the perspective of everyday people, noting as others have that both lines of work can and should inform one another (Sherin, Kersting, & Berland, 2018; also see D'Angelo et al., 2020).

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Why Feedback Literacy Matters for Learning Analytics

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Abstract: Learning analytics (LA) provides data-driven feedback that aims to improve learning and inform action. For learners, LA-based feedback may scaffold self-regulated learning skills, which are crucial to learning success. For teachers, LA-based feedback may help the evaluation of teaching effects and the need for interventions. However, the current development of LA has presented problems related to the cognitive, social-affective, and structural dimensions of feedback. In light of this, this position paper argues that attention needs to shift from the design of LA as a feedback product to one that facilitates a process in which both teachers and students play active roles in meaning-making. To this end, implications for feedback literacy in the context of LA are discussed.

Introduction

Learning analytics (LA) emerged as an interdisciplinary field a decade ago with a key mission to advance the understanding of learning and enhance this by using large datasets generated by learning processes. Early LA examples were largely motivated by the need to improve student retention in higher education, with a particularly common approach the application of predictive modelling to identify risks of failing (e.g., Arnold & Pistilli, 2012). Over the years, there has been growing awareness of the importance to ground LA in educational theories to identify meaningful metrics for the measurement of a learning phenomenon (Gašević et al., 2017). However, approaches to LA have been largely driven by behaviourism, in part due to constraints related to sources of data available; namely, commonly collectable data tend to focus on learner behaviour, such as log-ins and clicks. Despite this constraint, recent work in LA has made substantial break-throughs in inferring cognitive and meta-cognitive development among learners using LA (e.g., Jovanović et al., 2017; Uzir et al., 2020). However, the adoption of LA in real-world settings remains small in scale, thus limiting its expected impact on learning (Tsai et al., 2020; Viberg et al., 2018). Although there is abundant literature exploring social-technical issues that impede LA adoption (e.g., Macfadyen et al., 2014; Prinsloo & Slade, 2017; Tsai et al., 2021), there has been relatively little attention to key skills required for teachers and students to benefit from LA as a feedback process. A recent study by Gray and others (2021) proposed a framework for continuous professional development in LA for students, professional services, and teaching staff, focusing on three phases of skill development, including using and practicing feedback. However, the study has not explored skills that may be required for teachers and students to make sense of and use feedback generated by LA. This position paper is intended to bridge the gap by conceptualising feedback literacy in the context of LA for the purpose of enhancing the effectiveness and sustainability of LA and, more importantly, improving the overall feedback processes in higher education. To this end, I first conceptualise feedback and feedback literacy before outlining issues with LA-based feedback. Following that, I argue the importance of installing LA-specific feedback literacy among teachers and learners by highlighting three key dimensions required to make LA feedback effective.

Conceptualising feedback and feedback literacy

Feedback plays an important role in learning, and the main purpose is to bridge the gap between a desired learning goal and the current performance (Evans, 2013). According to Hattie and Timperley (2007), feedback serves to answer three broad questions: Where am I going (*feeding up* to learning goals or expected standards that a learner works towards)? How am I going (*feeding back* on a learner's actual level performance in relation to goals and standards)? Where to next (*feeding forward to* greater possibilities for learning)? Traditionally, feedback is perceived as *information* generated and delivered from teachers to students. This transmission model is based on a cognitive perspective, and teachers are considered the ones mainly responsible for the effectiveness of feedback (Boud & Molloy, 2013; Evans, 2013). This conceptualisation is still very much present in ways teaching quality and student experience are measured in higher education (Winstone & Carless, 2021), which to some extent have also influenced how teachers and students see feedback (Winstone et al., 2021). While not mutually exclusive, compared to the cognitive perspective, the social-constructivist paradigm highlights the importance of feedback as a *process* that requires teachers and students to work in tandem, i.e., to have shared responsibilities (Boud & Molloy, 2013; Evans, 2013). For example, Yang and Carless (2013) discussed three inter-related dimensions of feedback: *cognitive, social-affective, and structural*. At the *cognitive* level, feedback needs to help students narrow the gap between their current and desired performance in addition to increase their self-regulated learning (SRL) skills. However, activities that happen in the cognitive dimension can be subject to the *social-affective* dimension;

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that is, the power relationships between agents of feedback (e.g., teachers, students, and peers) and emotional reactions to feedback. As argued by Price et al. (2010, p. 280), "if the feedback is viewed as a product rather than part of a relational process, it is less likely to generate a response". In other words, a trust relationship between teachers and students is considered crucial to productive engagement with feedback, and treating feedback as a dialogic process may help offset power imbalance and cultivate trust (Yang & Carless, 2013).

The *structural* dimension is related to how feedback is organised and managed by the teacher and institution, e.g., timing, frequency, sequence, and modes of feedback. This dimension situates feedback in a wider learning context in which resources and policies can be determining factors of feedback effectiveness. When evaluations of feedback quality overemphasise this dimension, sustainability can become an issue because institutional resources are finite. In light of this, Boud and Molloy (2013) argue that for feedback to be sustainable, students need to be seen as active agents of change rather than passive recipients. Similarly, Winstone et al. (2021) suggest that a culture of responsibility sharing in feedback processes needs to be developed in order to move from feedback as telling to feedback as dialogue. On the other hand, Carless and Winstone (2020) suggest that in addition to *design* and *relational* dimensions, teacher feedback literacy has a *pragmatic* dimension; that is, a teacher's ability to be able to navigate tensions resulting from practical issues, such as resource and time constraints, by making inevitable compromises between the ideal, the defensible, and desirable feedback or leveraging technology for efficiency and timeliness.

Although both teacher-centred feedback and student-centred feedback highlight the importance of action in closing a feedback loop, the former assumes that learners depend on others to drive their learning and that learners would know what action to take when being provided with diagnostic information about their learning. In contrast, the latter emphasises the agency of learners who facilitate their own learning through active information seeking and sense-making (Boud & Molloy, 2013). Drawing on this student-centred view of feedback, Carless (2019) describes that feedback can take forms of *single, double*, and *spiral* loops. While feedback as a *single* loop focuses on short-term improvement of performance (predominantly task-driven), the *double*-loop process focuses on long-term impacts of feedback on the meta-cognition process, e.g., SRL, and the *spiral* process depicts learning as a complex, ongoing process in which learners continue to tackle some unresolved learning puzzles through continuous sense-making and the use of past feedback. In the core of this argument is the active role of learners who need to be able to *appreciate feedback*, *make judgement* based on feedback, *manage affect* resulted from feedback, and *take action* based on feedback – these are defined as key aspects of feedback literacy by Carless and Boud (2018). Building on this work, Molloy et al. (2020) further identified seven features of feedback literacy that emphasises feedback as an active, reciprocal process in which learners elicit information and enact outcomes of information processing, whereas Ryan et al (2021) proposed a model of eight feedback components that serve three functions: supporting future impact, enabling sensemaking, and supporting agency. In short, student-centred feedback processes requires feedback literacy to be present in both teachers and students, as have argued by Boud and Molloy (2013) that sustainable feedback depends on what learners bring and what the curriculum promotes in addition to what the environment affords. In this paper, feedback literacy for teachers is seen as *the ability to design and implement feedback not only as a piece of information that can help students achieve desired learning goals and personal development, but also as a process that serves pedagogical, social, and political purposes*; whereas feedback literacy for students is perceived as *the ability to seek feedback, decode and encode meanings of feedback relevant to their learning (thus resulting in beliefs and knowledge updates or action), and engage in feedback as a socio-cultural process*.

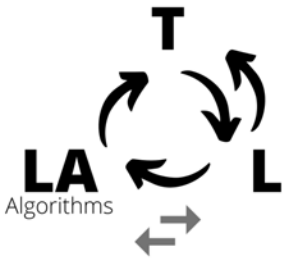
Learning analytics-based feedback

Learning analytics (LA) is commonly defined as "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Long et al., 2011, p. 3). A LA cycle is described with four key elements: learners, data, metrics, and interventions (Clow, 2012). As learners interact with learning activities and environments, a range of data such as clickstream, login, forum discussion, academic performance, and sensory data, can be processed into metrics or analytics, often visualised in forms of dashboards as feedback for teachers or learners. The intention is to provide information useful to inform interventions (e.g., curriculum updates) or conversation with students (Bennett & Folley, 2019; De Laet et al., 2020; Wise, 2014). In line with Winne and Butler (1994) who argue that feedback is an inherent catalyst of SRL, LA-based feedback serves to trigger an iterative cycle of self-monitoring (internal feedback), performance, evaluation, and external feedback. For learners, LA as external feedback may prompt them to assess their knowledge and beliefs, including domain knowledge, strategy knowledge, and learning motivations, based on which learners may devise learning plans. Similarly, for teachers, LA-based feedback may prompt them to assess their knowledge and beliefs about their domain knowledge, pedagogical

knowledge and strategy, and their current understanding of the learners, thereby reflecting on the effectiveness of teaching approaches and materials and the need to make change or provide interventions.

Unlike traditional feedback that typically involves teachers and learners, LA-based feedback includes the *algorithm* as a key agent that takes part in the process of measuring and evaluating learning outputs and communicating the results and feedback (Pardo, 2018). If feedback is directed to learners (student-facing LA), learners are expected to be able to make sense of the feedback and devise actions based on the presented data. In other words, there is an implied assumption that users have a functional level of feedback literacy and data literacy. If LA-based feedback is directed to teachers (teacher-facing LA), teachers act as a mediator between LA and students. In other words, teachers will be responsible for making sense of LA-based feedback and deciding whether and how to provide further feedback to learners as well as ways to incorporate LA into teaching practice. In this process, the direct interaction learners have is with the teacher. Thus, LA can facilitate two different loops of feedback, each highlighting the roles of learners and teachers differently in the sense-making process of LA-based feedback (Figure 1). In both loops, the outputs from learners (e.g., behaviour, performance, and emotional states after feedback is received) continue to feed back to LA, thus forming continuous feedback processes.

Figure 1
Two loops of learning analytics (LA) feedback directed at teachers (T) and learners (L) respectively



Problems with learning analytics-based feedback

Although students generally welcome timely feedback enabled by LA to keep them on track of their learning (Galaige et al., 2018; Tsai, Mello, et al., 2021), current practice has presented some issues threatening the effectiveness of feedback. In the following, I frame these issues within the feedback triangle proposed by Yang & Carless (2013): *cognitive, social-affective*, and *structural* dimensions.

Considering the *cognitive* dimension, LA appears to focus more on *feeding back* (learning progress) and *feeding up* (learning goals), but less on *feeding forwards* (where to next). For example, a systematic review by Matcha et al. (2019) on 29 LA dashboards found that 18 focus on presenting learning progress and the most common indicators are numbers of logins, posts, and tweets, followed by indicators of domain knowledge, e.g., exam marks. Similarly, a review on 95 articles about student-facing analytics system (Bodily & Verbert, 2017) found that when text feedback was provided, it tended to be descriptive about what happened in the past and how students were doing up to the point of the feedback. As the most referenced theoretical concepts of learning analytics dashboards (LADs) design are SRL, reference frames are common techniques adopted to raise awareness and prompt reflections on one's learning progress, such as through social comparison with peers, comparison between current achievement and goals (the *feeding up* element), and comparison with the earlier self (Jivet et al., 2017). Compared to *feeding back* and *feeding up*, the *feeding forward* element has been an area of weakness in LA as empirical studies continue to report issues about lacking actionable insights (Bennett & Folley, 2019; Jivet et al., 2020; Lim et al., 2019). For example, Corrin and de Barba (2015) found that students struggled to translate LA into learning strategies; Jivet et al. (2017) identified little support of LADs in scaffolding goal setting and planning; Cha and Park (2019) reported that students desire prescriptive tips and suggestions to help them achieve desired goals; and Li et al. (2021) found that teachers struggled to infer student learning or identify learning problems from analytics results. As such, aligning LA with pedagogical practices and learning sciences continues to be a focused area of development in the field (Knight et al., 2014, 2020; Wise, 2014).

The *social-affective* dimension of feedback emphasises the dialogic (Sutton, 2009) and relational (Price et al., 2010) nature of a feedback process, which requires trust and balanced power relationship between the provider and the recipient of feedback (Winstone et al., 2021). Although scholars have argued the value of LA in facilitating dialogue between teachers and students (De Laet et al., 2020; Wise, 2014), LA as a feedback process involves not only teachers and students, but also algorithms as a key feedback agent (Figure 1). As such, distrust in LA algorithms and data or facilitators of LA can hamper the dialogic and relational aspects of feedback. For example, Jones et al. (2020) argue that issues around data privacy can violate a trust relationship between students

and institutions; whereas Tsai et al. (2021) outline three areas of trust issues related to LA from perspectives of teachers and students: 1) numbers are subjective, 2) fear of power diminution, and 3) design and implementation. The first area includes issues about data accuracy, bias, and incomplete representation of learning. The second area includes negative impacts on professional and learner agency, unfair judgement on learning or teaching practice, the inability to remain in control of one's data. The third area is related to practical issues, including workload, the interpretability and usefulness of LA, equity of treatment, and demotivation to learn. Similarly, other studies that look into the social-affective dimension of feedback based on LA have identified students' fear of being treated as numbers (Roberts et al., 2016; Tsai, Mello, et al., 2021), and Lewis et al (2021) pointed out further that students who felt being noticed as individuals were more willing to seek support and engage with learning when LA is used.

The *structural* dimension of feedback focuses on how feedback is integrated into the instructional design and institutional processes. The rise of LA is in part a response to the growing pressure on higher education institutions to demonstrate quality (Ferguson, 2012; Tsai et al., 2020) and LA has demonstrated promising results in providing feedback at scale in a timely manner (Pardo et al., 2019). However, adoption and impacts of LA have been limited (Ferguson & Clow, 2017; Viberg et al., 2018) partly due to structural issues such as the complexity of educational systems (Macfadyen et al., 2014; Tsai et al., 2019) and the emphasis on analytics over learning (Guzmán-Valenzuela et al., 2021; Williamson et al., 2020), in addition to some of the trust issues mentioned above. A related issue to higher education's mounting pressure on boosting student satisfaction with timely feedback is that LA has been predominantly perceived as a technological tool to support this agenda rather than a process that requires proper integration into pedagogical practice (Wise, 2014). As a result, not only does LA-based feedback tend to be perceived as a product in line with the traditional feedback model – feedback as telling, but evaluations of LA also often focus on assessing its usability (e.g., acceptance, usefulness and ease-of-use) and impact on behavioural change to the extent that it is observable and the data is capturable (Jivet et al., 2018). This dominant conceptualisation of LA as feedback overlooks the cognitive and social-affective dimensions of feedback. It may also be argued that LA continues to promote a transmission model of feedback (Boud & Molloy, 2013), which considers a feedback loop closed in so far as action is taken by learners regardless of whether it is a passive response without learning actually taking place.

Learning analytics feedback literacy

Returning to the definition of LA as a process that aims to not only *understand*, but also *optimise* learning (Long et al., 2011), we need to move beyond evaluation to enhancement of learning. For example, before seeking better approaches to predict or measure learning results, ask first what learning gain can be expected by applying LA in teaching (Kitto et al., 2018). Before making algorithmic choices, ask first how the decisions align with human values (Chen & Zhu, 2019) and educational values (Wise et al., 2021). Before choosing what data to collect, ask first what metrics are meaningful to a teaching context (Brown, 2020). Before asking what students prefer for an LAD, ask what they need (Jivet et al., 2020). Important to all these questions is a thoughtful consideration of what teachers and learners offer. It is thus necessary to ask what feedback literacy means in a LA-based feedback process. In the following, I build on Carless and Boud (2018) and highlight three broad dimensions of feedback literacy that is important to effective feedback and the exertion of agency by both teachers and learners in the context of LA.

First, *appreciating LA-based feedback with critical awareness of its value and limitations*. To elicit a response from learners to feedback, it is crucial that learners recognise the value of feedback in learning so as to be receptive and proactive (Carless & Boud, 2018; Winstone et al., 2017). Similarly, the uptake of LA as data-driven feedback requires appreciation of data as computational representation of learners and learning, which can navigate attention to areas that may need intervention from the teacher or learners themselves (Gibson & Martinez-Maldonado, 2017; van Leeuwen et al., 2017). However, it is important to recognise that LA is valuable in so far as providing a snapshot of learning, the meaning of which is not complete until learners who generate the data and the teacher who facilitates learning activities bring in their interpretations drawing on their understanding of and experience in the learning or teaching situation. The knowledge of learners and teachers is particularly valuable in filling gaps of information that is not capturable by LA.

Second, *translating the computational representation of learning to psychological self or others and enacting the derived meanings*. As described earlier, LA-based feedback provides computational representations that describe what learners do or how they perform. Gibson and Martinez-Maldonado (2017) describe the sense-making process as an act of translation between the *computational epistemic domain* (computer) and the *psychosocial epistemic domain* (human). The former involves encoding what is observed from learners and processing it into a form (the computational representation) suitable for human interpretation. The latter involves a cognitive cycle of interpreting the computational representation in relation to the psychological *self* or *others*,

thereby constructing meanings and turning this into further products, such as action or the creation of an artefact or digital traces. Thus, a key dimension of feedback literacy in an LA-feedback process is the ability to move between the two domains. This requires both teachers and learners to actively interpret analytics in relation to their situations (e.g., learning and teaching approaches) and decide what action to take or not to take.

Third, *managing affect and negotiating power in the feedback loop*. Same as other forms of feedback, LA-based feedback can induce stress, anxiety, frustration, and other negative emotions especially when feedback continues to flag underperformance or when comparisons are made between individuals and peers (e.g., see Jivet et al. (2020) and Lim et al. (2019)). In addition, as data processing is not simply computational, but also inherently social and political, various decisions are made by a range of stakeholders (e.g., researchers, developers, managers, and service providers) involved in the overall LA cycle – from choosing data and algorithms to delivering downstream intervention. As such, both learners and teachers need to be proactive in questioning whose interests are being served when interacting with LA-based feedback. Moreover, depending on how data is collected, processed, shared, and presented, the process can cause discomfort when a sense of surveillance is experienced (Kwet & Prinsloo, 2020; Selwyn, 2020). It is thus necessary to engage in dialogue with decision makers to offset imbalanced power relationships and increase transparency, validity, and accountability. In other words, being LA literate is not only about being able to make sense of LA-based feedback productively, but also about having the ability to engage with LA in the wider social-political context, such as interrogating the ownership of one's own data or decisions made about or for an individual.

Conclusion

There is no doubt that LA has opened a door to a multitude of opportunities to understanding learning patterns and how learners interact with learning environments and others therein. It also has great potential to deal with one of the biggest feedback challenges – traceability (Malecka et al., 2020) – by iterating feedback loops through continuous data collection as shown in Figure 1. However, the effectiveness and sustainability of LA-based feedback are questionable if it does not support learners and teachers to exercise their agency or scaffold the development of LA-specific feedback literacy, which is conceptualised with three broad dimensions in this article:

- Appreciating LA-based feedback with critical awareness of its value and limitations
- Translating the computational representation of learning to psychological self or others and enacting the derived meanings
- Managing affect and negotiating power in the feedback loop

An important implication for practice is the need to scale training for both teachers and students. For the former, the training should focus not only on strengthening skills in the three aspects, but also related pedagogical skills including ways to enhance a feedback process with LA as part of the learning design and ways to support students to develop LA-feedback literacy. For students, such training may be the most effective if incorporated into their first-year curriculum so as to maximise their opportunities to benefit from LA-based feedback, as also suggested by Molloy et al. (2020) regarding feedback literacy development in higher education. There are also implications for LA design. Firstly, the design should prompt *dialogue*, such as showing reflective or even provocative questions to encourage thinking around important issues related to educational and human values, or embed communication channels for users to raise questions and express opinions to relevant stakeholders in an institution. Secondly, the design should *foreground sense-making*, such as providing mechanisms to guide interpretations in relation to where data comes from, what it means, and how it relates to oneself. Thirdly, the design should *support possibilities for further learning* (feeding forward)(Hattie & Timperley, 2007), such as providing recommendations based on inputs from teachers. In this way, LA may move away from a transmission feedback model to one that is student-centred, relational and process driven, with shared responsibilities between teachers and learners in making feedback effective.

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International Society of the Learning Sciences

Advancing the goals of problem-posing education in a Knowledge Building Community: An exploratory case study

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Abstract: Scholars of critical pedagogy have long argued for the transformation of schools from oppressive to emancipatory. Although Knowledge Building Communities (KBCs) were initially designed to achieve epistemic goals there exists a significant overlap between the theory underlying the KBC approach and Freire's notion of problem-posing education. Therefore, we asked how KBCs could mediate some key features of problem-posing. In this paper, we present qualitative findings from an exploratory case study of a KBC that was designed for the purpose of problem-posing. Our findings indicate that repurposing KBCs to achieve ethical aims holds promise, and we conclude with some specific question that we believe would be worthwhile to investigate in future studies.

Introduction

Paulo Freire is best known for his book *Pedagogy of the Oppressed* (Freire, 2005), in which he articulated a compelling critical social theory of education. Freire argued that education systems can be either oppressive or emancipatory, depending on how learners interact with teachers and content. Freire's impact has grown in recent years, especially in light of the "political turn" in the learning sciences (Philip et al., 2018). In addition, contemporary scholarship has identified similarities between Freire's work and some of the sociocultural learning theories that have become increasingly influential in the learning sciences (Vossoughi & Gutiérrez, 2017).

Knowledge Building Communities (KBCs) have long been recognized as a promising alternative to traditional learning environments (Scardamalia & Bereiter, 2014). The KBC approach fuses theory, pedagogy, and technology, and has been successfully applied in many educational contexts (Chen & Hong, 2016). Although individual KBCs differ from one another they share the goal of knowledge creation rather than internalization. Consequently, while KBCs typically aim to achieve epistemic aims, repositioning students as agentive subjects also realigns classroom power dynamics.

Notwithstanding clear differences between the KBC literature and Freire's vision, there is a substantial degree of overlap between them. Both approaches seek to reposition students as more agentive and to inspire open-ended knowledge-building trajectories that connect between students' real-world experiences and the content they engage with. This article begins by reviewing the theoretical overlap between Freire's vision and the KBC approach, and then presents findings from an exploratory case study intended to flesh out the connections between them. Ultimately, our aim is to open the door to a new avenue of KBC research that defines its aims in ethical terms in addition to epistemic ones.

Problem-posing education

Some goals of critical pedagogy

Widely recognized as the father of *critical pedagogy*, Freire (2005) maintained that many traditional learning environments are fundamentally oppressive, because they quell curiosity and creativity, thus denying learners the ability to think critically about the world around them and their place within it. In addition, they treat knowledge about the world as value-neutral, abstract, and static. Coupled together, these two features "create people who see no other serious possibility to the economic and cultural assemblage now extant" (Apple, 2004, p. 6).

Indeed, scholars of critical pedagogy have argued for the transformation of schools from oppressive to emancipatory, into institutions "where students can be educated to take their places in society from a position of empowerment rather than from a position of ideological and economic subordination" (Giroux, 1997, p. 120). In Freire's (2005) seminal work, emancipation is achieved through *praxis*, as learners combine reflection and action to assume the role of agentive subjects. Hence, one primary goal of critical pedagogy is to employ pedagogic means to empower students to rethink what they know about the world and their place within it, in a process that can promote equity and social justice.

From students-of-the-teacher to students-teachers

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At the heart of Freire's (2005) pedagogic vision is a contrast between *banking education* and *problem-posing education.* The former conceptualizes learning in terms of teachers depositing knowledge into students' minds, while the latter opens the door to more dynamic forms of learning (2005, p. 79). Shifting from banking to problem-posing repositions teachers, students, and knowledge vis-à-vis one another. When practicing *banking education*, teachers are active, learners are passive, and knowledge is value-neutral, objective, and static. Yet, in a *problem-posing* context, teacher, student, and knowledge dynamically co-constitute one another: "Through dialogue, the teacher-of-the-students and the students-of-the-teacher cease to exist and a new term emerges: teacher-student with students-teachers… People teach each other, mediated by the world". (Freire, 2005, p. 80).

How is problem-posing enacted? Freire outlines three unique features of the *students-teachers* who can be found in emancipatory learning environment. First, problem-posing aims to elevate students-teachers' awareness of reality and of themselves. This is achieved by transcending investigations that are mechanical and limited in scope, and by seeking out "the links between themes, a concern to pose these themes as problems, and a concern for their historical-cultural context" (p. 107). Second, students-teachers de-mythicize and problematize elements of their own world. Knowledge of real-world experiences (for instance, learners' own poverty) is no longer perceived as inevitable; rather, it is subject to change. Finally, teachers do not rely on claims of authority to motivate students. Instead, responsibility is distributed between the teacher-student and students-teachers.

Knowledge Building Communities

Theoretical underpinnings

The Knowledge Building Community (KBC) approach first emerged in the early 1990s (Scardamalia & Bereiter, 1991), and has been a central thrust of design-based research in the learning sciences ever since. KBCs are distinguishable by (1) their expectations from learners, (2) their ontological view of knowledge, and (3) the role played by discourse, dialog, and community (Chen & Hong, 2016).

Theoretically, these three points are all grounded in a distinction between *learning* and *knowledge building*, where learning is defined as "a change in [private and internal] mental state", and knowledge building as the "production of [out-in-the-world] designs, theories […] and the like" (Scardamalia & Bereiter, 2014, p. 397). In a KBC, learners' primary aim is *not* to internalize something that is already known to the teacher or to other students, but to produce and advance novel, out-in-the-world, ideas (cf. Popper, 1978) by engaging in productive knowledge building discourse (Bereiter & Scardamalia, 2016).

The Copernican shift that positions ideas – rather than learners – as the objects of change (cf. Sfard, 2015) means that KBCs afford learners higher levels of agency, so that they can collaborate to simultaneously advance many different ideas of their choice in myriad ways (e.g., Zhang et al., 2007). In addition, *humanistic* KBCs have also been shown to afford the co-construction of self and of ideas in humanistic learning environments that were inspired by the legacy of Carl Rogers (Hod & Ben-Zvi, 2018; Hod & Katz, 2020; Rogers, 1970).

Thus, notwithstanding the different theoretical underpinnings underlying problem-posing and KBCs, there exists a significant degree of overlap between them, most notably in how they view learners, knowledge, and the connection between the two. Both approaches value efforts to "rise above" (Scardamalia, 2002) specific real-world knowledge to inductively articulate broad and inclusive categories; both view knowledge and identity as dynamically and reflexively co-constituted; and both seek to transfer responsibility from teachers to learners.

KBC design principles: Socio-cognitive and technological dynamics

Scripted, procedure-based, pedagogical approaches provide detailed instructions for teachers and students to follow. In contrast, principle-based pedagogies define "core values and principles" (Zhang et al., 2011, p. 263), which teachers adapt to local contexts. The KBC approach is principle-based, offering teachers and researchers a set of twelve design principles that "serve an important regulative function for both teachers and students, helping to keep higher-level goals in mind" (Scardamalia & Bereiter, 2014, p. 403) (cf. author, 2021).

Each design principle comprises socio-cognitive and technological dynamics. Socio-cognitive dynamics are actualized through different types of participant structures; i.e., the "different norms and rights for speaking that different group arrangements[…] afford" (Michaels et al., 2004, p. 2355). Technological dynamics are embodied in the design of The Knowledge Forum (KF), an proprietary online tool designed to support KBCs (Scardamalia, 2017). Because it is principle-based, enacting the KBC approach in a given context is challenging. However, the existing set of principles and technology means that the KBC approach is more readily applicable than Freire's notion of problem-posing education, which is theoretical and abstract. The KBC design principles and much of the research surrounding them can be viewed as *Principled Practical Knowledge*, "which […] unlike formal theoretical knowledge, its main purpose is not explanation or prediction but practical guidance" (Bereiter, 2014, p. 6). Freire's work, in contrast, is theoretical and focused on explanation rather than on implementation.

Specifically, there are three KBC design principles that directly correspond with the features of students-teachers: *rise above*; *real ideas and authentic problems*; and *collective responsibility for community knowledge* (Table 1). While successfully enacting them is no small feat, embedding them into the learning environment does not require teachers to reinvent the wheel. Rather, teachers and researchers build on the design principles and existing literature to design learning environments that integrates the necessary participant structures and makes good use of KF, to mediate the desirable socio-cognitive and technological dynamics.

Table 1
Correspondence between the features of students-teachers and the KBC design principles

Feature of students-teachers (Freire, 2005)	**KB Socio-cognitive dynamics (Scardamalia, 2002)**	**KB Technological dynamics (Scardamalia, 2002)**
(1) *Elevated awareness*: "Thematic investigation thus becomes a common striving towards awareness of reality and towards self-awareness".	*Rise-Above*: "Creative knowledge building… means learning to work with diversity, complexity and messiness, and out of that achieve new syntheses".	Rise-above notes and views support unlimited embedding of ideas in increasingly advanced structures, and support emergent rather than fixed goals.
(2) *Knowledge and identity are co-constituted*: "students-teachers reflect simultaneously on themselves and the world without dichotomizing this reflection from action, and thus establish an authentic form of thought and action".	*Real ideas; authentic problems*: "Knowledge problems arise from efforts to understand the world… Problems are ones that learners really care about—usually very different from textbook problems and puzzles".	Knowledge Forum creates a culture for creative work with ideas. Notes and views serve as direct reflections of the core work of the organization and of the ideas of its creators.
(3) *Shared responsibility*: teachers and students "become jointly responsible for a process in which all grow. In this process, arguments based on 'authority' are no longer valid".	*Collective responsibility*: "Contributions to shared, top-level goals of the organization are prized and rewarded as much as individual achievements. Team members produce ideas of value to others and share responsibility for the overall advancement of knowledge in the community".	Knowledge Forum's open, collaborative workspace holds conceptual artifacts that are contributed by community members. Community membership is defined in terms of reading and building-on the notes of others, ensuring that views are informative and helpful for the community, linking views in ways that demonstrate view interrelationships.

Research focus

The purpose of KBCs has seldom been defined in terms of critical pedagogy. According to Scardamalia and Bereiter, the value of KBCs is primarily epistemic, in that they promote the type of design thinking required for "an 'innovation-driven' society" (Scardamalia & Bereiter, 2016, p. 3), or in their ability to mediate authentic scientific discourse (Bereiter et al., 1997). However, we conjectured that the KBC design could also be harnessed to achieve some of the goals of problem-posing education. Specifically, this article asks how the socio-cognitive and technological dynamics detailed in the KB design principles *rise above*, *real ideas and authentic problems*, and *collective responsibility for community knowledge*, can mediate the features of students-learners?

Method

General approach

The empirical data presented herein comes from an *exploratory case study* (Yin, 2009) intended to flesh out some of the ways in which the goals of critical pedagogy might be advanced by means of the KBC design. Given the lack of any existing theoretical or empirical work, the primary aim of our investigation was to pave the path for future research on how KBCs might be harnessed in support of the goals of critical pedagogy.

Context

Participants
We collaborated with a tenth-grade class in Central Israel comprising 25 students and their teacher, Amos (all names are pseudonyms). All the students identified as Jewish, and none were outwardly religious. Students came from diverse cultural, racial, and socioeconomic backgrounds. The school was publicly funded and belonged to the Jewish state-secular stream. Most of the students were unacquainted with each other or with the teacher.

Curricular content
Emancipation and oppression through learning are both tied to "everyday, informal, and popular culture and how the historical patterns of power that inform such cultures are imbricated in the formation of individual subjectivity and identity" (McLaren, 1994, p. 21). In Israel, the discourse surrounding race, nationality, religion, socioeconomic status, and other social categories is often dominated by the larger question of what it means to belong to the Jewish majority, or to a non-dominant minority, most notably Palestinian or Arab-Israeli. Israel is a Jewish state, but being Jewish means different things to different people, and can serve as a catch-all phrase that is unconsciously associated with the elements of one's identity that are most valued. Given the fluid definition of Jewish identity, its position at the crux of Israel's identity discourse, and its immediate ties to everyday life, we conjectured that exploring what it means in a KBC environment could offer students an emancipatory experience. The curriculum highlighted several points. First, that definitions of identity can overlap, complement, or contradict one another. Second, Jewish identity is not abstract; it shapes everyday life in Israel. Third, questions of identity are inescapable, but answers are always provisional. Finally, that identity discourse inevitably leads to marginalization. Students read op-eds and news articles, philosophical and legal texts, and additional resources.

Participant structures
Roughly a third of the time was dedicated to group meetings and the remaining two-thirds were spent in small groups. For *Group meetings* the students and teacher sat in a circle. Sometimes, participants discussed a new assignment or recent progress; and other times, group meetings were dedicated to personal conversations in which students reflected on their experiences and established trust and openness in the learning community. *Small groups*, usually numbering 2-4 students, typically gathered around one laptop as they read assignments, discussed various themes, and co-authored new notes that were added to KF.

Knowledge Forum
Our analysis requires explicating some basic functions of KF: *Notes* are the most basic type of contribution to KF. Notes include a title, co-authors and timestamp, scaffolds, and the note's content. *Scaffolds* are tags students select from a sidebar to bracket a segment of text in their note, which help ensure discourse is productive. *Build on* allows students to add a new note in response to an existing one. *Rise above notes* have all the functionality of standard notes, while also allowing users to drag-and-drop multiple existing notes into one space. *Views* are individual webpages, which begin as an empty canvas to which students can add notes, images, links, or files.

Data

Collection
Data included all notes from KF; students' end-of-year essays; video recordings of 25 lessons; and unstructured interviews with the teacher and students. The author attended all the lessons and took field notes throughout.

Selection and analysis
We drew on Sandoval (2014), who distinguished between the *embodiment* and *mediation* phases in DBR. To answer our research question, we sifted through the data, seeking out *rich points* (Agar, 1994, p. 232). For each rich point we selected, we conducted a detailed micro-analysis of what transpired in the *mediation* phase, asking what students did, wrote, or said; what motivated them; and what other alternatives were available. We then reflected on the mediating role of the curricular content, participant structures, and KF, which together constituted the essence of the *embodiment* phase, and asked how the design impacted the learning experience.

Findings

Elevated awareness
For the first assignment, the class was provided links to ten online news articles that illustrated how Jewish identity shapes everyday life in Israel. Articles touched on race, ethnicity, religion, and more. After splitting into groups and contributing ten notes to KF that summarized the articles, students were given the following instructions:

> [note title] Assignment #2: rising above
> [author] Amos [the teacher]
> [date] 11/12/2018
> [note body] One of the most crucial steps in knowledge building is called "rising above". Now that we have made some progress it's time to stop and think, so we can take the knowledge we've built to the next level… If you haven't done so already, read all the notes summarizing news articles. Each note discusses a different case, but some of them are connected. Join with another group or two whose notes' content is connected to yours. From 10 groups, you now must create no more than 4 groups in total. After creating a new group add a "rise above" note that takes our knowledge to the next level…

One group of students summarized an article about a controversy surrounding Ethiopian immigration to Israel. The Jewish community in Ethiopia is divided between Beta Israel, whose customs and rituals are outwardly Jewish, and the Falasha Mura, whose ancestry converted to Christianity. Because Israeli law grants automatic citizenship to all Jews except those who converted to a different religion, Beta Israel Ethiopians are typically allowed to immigrate to Israel and Falasha Mura are not. Another group read an article about Yoram Kaniuk, an Israeli author who won a heated court battle after demanding that he be identified as a "Jew of no religion". The four members of the two groups joined together and co-authored a new rise-above note (scaffolds *italicized*):

> [note title] Rise-above
> [authors] Ron, Eli, Zack, Shani
> [note body] *merging ideas* We decided to merge the articles "Falasha Mura" and "A religious-less man" because both talk about "who is a Jew" – under what circumstances someone is considered Jewish. In the first article, the Falasha Mura… are seeking recognition as Jews from the State. In the second article Yoram Kaniuk… is asking the court to be recognized as non-Jewish. Therefore, the articles are about the same principle of [recognizing] who is a Jew, yet each of them has an opposite view about the Jewish religion.

In this case, the move towards *elevated awareness* was significant. By seeking out the common denominator between the articles, the students were able to articulate a central theme in identity discourse – namely, *mutual recognition* (Ricoeur, 2005). This theme was new to them, but it became central to the class discourse especially as some students went on to explicitly demand recognition for themselves or for marginalized groups in Israeli society. This development was mediated by the tools and participant structures embodied in the KBC. KF allowed students to drag-and-drop their separate ideas into a shared space, while scaffolds indicated that this was a desirable knowledge building move [authors, 2020]. The participant structures (small groups that merged into larger ones) likewise mediated the process. Merging the groups, merging the notes, and merging the content, were three processes that were all embodied into the design of the KBC, and together they mediated an important facet of students-teachers.

Co-constructing knowledge and identity

The rise-above assignment generated a series of abstract questions that arose inductively from discussions of everyday life in Israel and marked a shift from news articles and op-eds to philosophical and legal texts. Amos uploaded eight texts to a new view on KF, and for each of the texts, provided some background information. Students were asked to form groups, select and read one text, and add a note to KF summarizing key takeaways. Each group then created a PowerPoint and presented their findings in a round of reciprocal teaching. One group chose segments from an article that juxtaposed *extreme* and *moderate* forms of Judaism. According to the author, moderate Judaism is grounded in a cultural definition of what it means to be Jewish, whereas extreme Judaism is dictated by religion and nationalism. Below is a segment from the conversation that ensued:

> Molly: …what's the difference between religion and culture? Religion is between you and God and culture is […] everyone together…
> Julie: About what Molly said, that culture brings people together – that's because it […isn't] black and white. You are free to design your culture as you wish and choose which [customs] to keep and which not to keep…

Noa: I think that in ultra-orthodox families, parents coerce their children… if they didn't do that then those who become secular wouldn't be alienated from their families. It comes from a very extreme place…

Shelly: I can give an example about myself. Our family keeps shabbat, we are traditional. Let's say, my sister, at some point she stopped keeping shabbat. At the beginning she didn't talk about it – not because she was afraid of what people would say but out of respect. She comes and keeps shabbat with us, she won't be on her phone around us, but she will outside… Now I also stopped keeping shabbat. Not because I don't like it or because I was coerced, it's just really hard for me [to keep shabbat] with [secular] friends, preparing for exams… I'm sure that when I grow up, I will go back to it…//

Amos: //[*turns to Noa*] you spoke about how rigid religion is… let me phrase this as a question. Is religion *really* so rigid? Shelly is suggesting something else, right?... [*turns to Shelly*] how would you characterize the relationship with religion in your family?

Shelly: My sister stopped keeping shabbat but she does celebrate holidays. My brother and father keep shabbat and attend synagogue. Me and my mother and my sister don't, but we won't drive on shabbat, out of respect…

Julie: [*Talking to Shelly*] that's a great example [of moderate Judaism]! Because [the author] says it's all about what you include and what you forgo… the flexibility in your family means that you can choose what you want to do and how you see Judaism…

Amos: Note the correspondence between Shelly's example and the article…

A close reading of this segment shows how Shelly's developing non-religious identity offered a new take on the curricular content. Molly suggested that religion is an individual experience, whereas Julie argued that religion offers no room for individual choice. Shelly's example refuted Molly's position and strengthened Julie's. In her experience, religion is a family affair, not an individual one; and her choices positioned her as someone who had left religion behind. For Noa, Shelly's story provided a moderate alternative to a specific form of religious extremism – she initially focused on ultra-orthodox Jews who abandon their family when they leave their religion. But Shelly described a more moderate approach whereby religious and non-religious family members can sustain an atmosphere of mutual respect. Julie and Amos both drew a direct line between Shelly's story and the article.

In this case, Shelly's real-world experience directly influenced the knowledge advancement in a process that was mediated by several elements of the KBC's design. Amos selected texts that were pertinent to students' lives; and when the connection emerged, he drew attention to it. In addition, participant structures intentionally created an atmosphere of trust where learners were willing to share intimate details about their own lives.

Shared responsibility

Roughly halfway through the enactment, Amos and [Author] invited several guests, including the school principal, teachers, university researchers, and the director of an educational non-profit, to see the KBC in action. Although they agreed the stakes were high, Amos decided to share responsibility with the students as much as possible. One week before the planned visit, the lesson began – as it usually did – with a group meeting. After a few minutes of chitchat, which Amos encouraged, he outlined the goals for today's lesson.

Amos: As always, we will do everything together, so what we'll do now is divide into pairs; each pair will take a laptop and think and suggest how you think the [visit] should look or how we should present things. What needs to happen [during the visit]? How should it be done? Who should do it? We're thinking together.

The next 50 minutes were dedicated to brainstorming as students contributed 23 new notes and build-ons to KF. After a short recess, students reconvened to discuss their ideas and move ahead with planning the visit.

Amos: What shall we do next? Let's go over the notes, and organize them according to theme, ok? Wandering through the groups and notes, I saw that there was a focus on how we work, so one group will present that [*trails off*].
[*two students arrive late*]

Amos: [*addresses late students in annoyed and frustrated tone*] Why are you late? I'm already in the middle of the lesson; this is not ok! Please don't be late. [*addresses class more coolly*] Let them sit down, [*indicates with finger*] there's a spot. [*resumes explanation*] We will quickly read all the notes, and divide into groups according to theme, so one

> group will present the technology we use… another will explain how our lessons work. In one note I saw a comparison to a regular class so one group can work on that…

Over the next 45 minutes, students read their notes aloud, and discussed various strategies for how best to present their KBC. One question that emerged in the following notes, and came up again in the discussion was whether it would be worthwhile to play a game to make the visit entertaining (scaffolds are *italicized*):

> [note title] Ideas for the sample lesson
> [authors] Lia and Amber
> [date] 1/7/2019
> [note body] *My idea is*… to teach the lesson in a more active way, not sitting down or in front of the laptops – this is something we should do more often...
>
> [build-on note title] Problem!!!
> [authors] Ella and Neta
> [note body] *The problem with this idea* In our opinion we [feel the] need to mention that if we have an active lesson, it could give the wrong impression that our lessons are more like a youth movement. Also, most of our lessons aren't like that, so it could misrepresent what we do.

This exchange transcended the question of how to present the KBC to outsiders. Lia and Amber were proposing to make *all the lessons* more active, apparently because they were unhappy with the rigorous text-based norm. But in another note, Ella and Neta expressed satisfaction with the KBC as-is:

> [note title] Presenting the learning community
> [Authors] Ella and Neta
> [note body] … *Something important I want to share* it is important to share with the guests the benefits of learning this way. For example: formulating and expressing opinions, presenting diverse points of view, improved literacy, and ability to analyze texts…

In this interaction, Amos used participant structures and KF to distribute the responsibility throughout the class – everyone was able to contribute, critique, and voice their opinions, whether on KF or in the group meeting. Indeed, Lia, Amber, Ella, Neta and others all felt comfortable voicing their opinions about the design of the KBC, regardless of whether they were happy with the norms or not. However, this episode also illuminates two challenges facing KBC designers who are oriented towards problem-posing. First, sharing responsibility with students is unlikely to mitigate disruptions. In this case, Amos felt compelled to assert himself as an authority figure despite the communal atmosphere and his opening comment "we do everything together". Second, shared responsibility also means various ideas that cannot necessarily be reconciled. Although their status was officially equal, Ella was a more central figure than the other three students, and as a result, her views were most influential. Revoking authority from the teacher created a power vacuum but did not necessarily mean that the environment was more equitable. The KBC ended up being emancipatory for Ella, but perhaps less so for Lia and Amber.

Discussion: Directions for future research

Our findings show how the design of a KBC mediated the features of Freire's conception of students-teachers. In each of the three episodes, the content, participant structures, and technological affordances of KF worked in concert to mediate some concrete goals of critical pedagogy among students.

Yet, although our study was informative, demonstrating the efficacy of the KBC approach as a means for accomplishing ethical aims, the rich points that we analyzed left us with a series of lingering questions that must be further explored. While Freire's model aspires for a form of praxis that combines reflection *and* action, our analysis of how rising above mediated elevated awareness was limited to reflection, begging the question of whether KBCs might mediate action as well, and if so, how?

Mediation of the co-construction of knowledge and identity through the principal *real ideas and authentic problems* was achieved by means of content and participant structures but was not supported by the technological affordances of KF. What new features might be introduced to future versions of KF to support this kind of identity work, which is crucial for problem-posing?

And finally, relinquishing authority and distributing responsibility evenly between teachers and students was partial and problematic. First, because although the teacher intended to "do everything together", he felt the need to assume an authoritative role as soon as two students disrupted the lesson by arriving late. And second,

because the power vacuum that he left behind was not filled by the students in an equitable way, but rather enabled one student to claim a leadership role based on her charisma and determination. Thus, the question of how to distribute power equitably in KBC remains open and requires further investigations and contemplation.

Conclusion

The "political turn" in the learning sciences has led increasingly more scholars to recognize that their work should take ethical considerations explicitly into account. Indeed, some have concluded that in addition to advancing learners' knowledge, skills, or expertise, their scholarship should also focus on achieving ethical aims. But doing so does not necessarily require them to go back to the drawing board to design new learning environments from scratch. On the contrary, this paper shows how existing scholarship can be modified or repurposed to design educational innovations that seek to promote social justice and other values.

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A Lighter Shade of Black Boxes: Students' Interpretations of the Distinction Between Black Box Explanations and Unpacked Mechanistic Explanations

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Abstract: Scientific explanations rarely include all interactions and entities in a mechanism. Instead, some information is hidden in black boxes, keeping the focus on the explanation's essence. Studies show that navigating between black-box explanations and detailed mechanistic explanations perplexes students as they misunderstand the reasons for including or omitting mechanistic information. Therefore, we examined students' preference towards information allowing for the formation of either a black-box explanation or a detailed mechanistic explanation. Fifty-two 9th grade students read three scientific problems in three contexts. Students stated and justified their preference of information. Analysis revealed students based choices on problems' context and explanation's productivity. Students preferred black-box information when recognizing the need to make a prediction and detailed information when recognizing a need to control phenomena. Results suggest clear explanatory goals assist students' navigation between detailed and black-box explanations. This calls for a more explicit discussion around black boxes in the science classroom.

Introduction

The new mechanistic philosophy, explained by Machamer, Craver and Darden (2000; MDC), identifies mechanistic reasoning as a tool scientists can use to explain, predict and control phenomena. A mechanistic explanation is constructed first and foremost from a set of entities, the cogs and bolts of the mechanism. Each of these entities has its own activity, i.e., the thing the entity does and by that affects other entities in the mechanism. Furthermore, each entity has its own properties, i.e., essential characteristics of the entity, allowing it to perform its activity. As one describes the entities and their features (e.g. activities, properties), along with a description of how they are organized together, it can be shown that when they are organized together just so, they produce the phenomenon one is trying to explain (Craver & Darden, 2013, p. 65).

While mechanistic reasoning is an important part of the philosophy of science, it should not be considered a tool restricted to the use of scientists. Indeed, in the context of cognition, mechanistic reasoning has been described as a special case of causal reasoning, an inference about the causal relationship between two events, made in a manner that is not solely dependent on co-variation information (Ahn & Kalish, 2000). Research in the fields of cognitive and developmental psychology has taught us that this form of causal thinking is so natural to us that 4-years-old children are able to comprehend simple forms of mechanistic explanations (Lombrozo et al., 2018), that both young children and adults display a bias towards experts sharing mechanistic information (Lockhart et al., 2019) and that adults seek mechanistic explanations when trying to make sense of everyday events (Ahn et al., 1995).

While mechanistic reasoning seems to be performed at all ages, Perkins and Grotzer (2005) provide a review concerning the development of causal thinking, suggesting that mechanistic reasoning is a dimension of causal thinking that advances gradually. For example, while young students may provide surface level generalizations or token explanations when explaining a phenomenon (e.g. 'a trait is the result of a gene.'), more complex explanations, concerning underlying mechanisms are usually less common in such early ages. Following Russ et al.'s (2008) framework for analyzing classroom discussion, multiple studies have also highlighted the challenges students encounter while reasoning mechanistically in the classroom (e.g. Dickes et al., 2016; Duncan & Tseng, 2011; Haskel-Ittah & Yarden, 2017; van Mil et al., 2016). Furthermore, mechanistic reasoning has been included as one of the seven crosscutting concepts, listed as "Cause and effect: Mechanism and explanation", in the Next Generation Science Standards (NGSS) in the United States (NGSS Lead States, 2013). This inclusion contributed to the promotion of students' mechanistic reasoning as one of the goals of science education.

Although the ability to reason about mechanisms might be related to a person's age or developmental stage, research in biology education has taught us that students' ability to learn and reason about biological mechanisms also relies on disciplinary knowledge and specifically on students' familiarity with the entities in a mechanism. Such studies have also shown that students' mechanistic reasoning can be advanced by exposing students to information about these entities. For example, data suggest that third graders improve in their ability

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to reason about a mechanism in the context of ecology, as they iteratively conduct activities and are repeatedly exposed to the entities and entities' activities in the mechanism underlying a phenomenon (Dickes et al., 2016). In a similar manner, in the context of genetics, 7th grade students have been found to use proteins, the key entities in the learned mechanism, mainly when they are familiar with a protein's relevant activity (Haskel-Ittah et al., 2020). Likewise, undergraduate students' performance shows that they rely on their broader domain-specific knowledge of key entities to produce mechanistic explanations in novel contexts (Southard et al., 2017).

As studies focus on students' familiarity with entities in the mechanism, and as biological mechanisms tend to hold many entities, it becomes clear that the task of discussing all of these entities in the classroom becomes an immense one, to the teacher and students alike. Furthermore, considering the fact that some mechanisms can hold a vast number of entities and that every causal connection in a mechanism holds in itself a mechanism of its own, it can be argued that no mechanistic explanation is ever complete. Thus, we need to ask ourselves if we are paying as much attention as we need to the gaps in our mechanistic knowledge and mechanistic explanations.

It is not surprising to find out that most people work with partial understandings of mechanisms, as no human can actually hold in his mind the complete details of a complex mechanism (Keil, 2019). This means most mechanistic explanations intrinsically hold in them some knowledge gaps, points in which a causal connection in the mechanism is left unexplained. While knowledge gaps in a mechanistic explanation might make us question the correctness or completeness of the explanation, we must remember that mechanistic discourse acknowledges the existence of knowledge gaps, and has even objectified them by naming and focusing on them under the term of "black boxes". A black box, in the context of mechanistic reasoning, is a unit containing missing pieces, which we do not yet know how to fill in with entities and activities, in a way that it creates a gap between one step in the process to the next (Machamer et al., 2000). It should be emphasized that not every omitted or unknown detail in a phenomenon is a black box, just as black boxes are not simply forgotten details of a known mechanism. Black boxes are the parts of a mechanism for which we know the existence of a causal connection but are unable or indisposed to explain the nature of this causal connection. In other words, it is knowing that A causes B without explaining how exactly A causes B.

While it would seem like black boxes are the nemesis of any mechanistic philosophy, black boxes are regarded as a tool in scientific discourse. A good, well-known example of black boxes in biology would be the patterns and co-variation data produced by Gregory Mendel (1822-1884) in the 1860s, and rediscovered, during the beginning of 20th century, by Hugo de Vries (1848-1935), William Bateson (1861-1926) and others (Provine, 2001, p. 56). While Mendel was able to collect data in a precise, methodical manner, and use that data to detect inheritance patterns, he did not describe the underlying mechanisms of such patterns. The inherited factors of Mendel, later to be known as '*genes*', and gene variants, later to be known as '*allele'*, were never described in a mechanistic manner, but rather as part of a probabilistic model (Heim, 1991), meaning a model that allows for prediction, without explaining the underlying mechanisms, hence a black box. This black box knowledge, at the beginning of the 20th century, was enough to articulate several laws, such as the law of dominance and the law of segregation, allowing for the prediction of progeny population. Just as important, the acknowledgment of this probabilistic model as a black box (Morgan, 1909), which contains some unknown underlying mechanism that needs to be discovered, allowed scientists to focus their research on the entities inside this black box.

By the 1960's the scientific community was able to describe the entities and the entities' interactions within it (i.e., unpack the black box), a joint effort that has led to the accepted model of today's modern times, describing the activities of several entities such as the DNA, RNA and ribosomes (Cobb, 2015). In a similar manner, while the central dogma of molecular biology has been used a working model since the 1960s, the full structure of the ribosome, for which Ada Yonath was awarded the Nobel Prize for, was described only in the year 2000 (Weizmann Institute of Science, 2009). These examples go to show that scientists use and apply mechanistic explanations containing black boxes, in a productive manner, all the time. Furthermore, while this could be attributed to some kind of lack of choice (i.e., scientists have to make do with incomplete explanations), it should be made clear that even today, most mechanistic explanations concerning the central dogma would not benefit from the knowledge concerning the precise structure of the ribosome. Likewise, today, a genetic consultant can calculate, predict and explain the risk for the Tay-Sachs disease in one's family (an explanation containing the Mendelian black box) by considering the alleles in a family, without unpacking any details about the central dogma (i.e., the underlying mechanism). In summary, in scientific discourse, unpacking a black box when formulating a mechanistic explanation is dependent on the goal of the explanation, whether it is to explain the mechanism itself, predict the outcome of certain conditions or control a phenomenon by manipulating elements in its underlying mechanism (Machamer et al., 2000).

Although scientists accept and appreciate the existence of explanations containing black boxes, in the science classroom, science teachers usually hold the notion that while there might be different explanations using different amounts of detail and information, good explanations need to be as comprehensive as possible by

containing as many complex details as possible, in an effort to achieve a high a degree of similarity between the details in the explanation and the details in the phenomenon being explained (Justi & Gilbert, 2002). Furthermore, as demonstrated by a study in genetics education, students find it difficult to rationalize the co-existence of explanations including black boxes, alongside with explanations including that same unpacked black box. This has been specifically demonstrated in the context of genetics where black box explanations using information about Mendelian inheritance patterns co-exist alongside unpacked mechanism explanations using central dogma information (Gericke et al., 2013). While science appreciates the existence and productiveness of black box explanations, the focus, in the classroom, on an explanation's 'completeness', and the lack of attention to the productiveness of an explanation, is probably one of the reasons students often expect explanations to be 'complete' without any regard to their usefulness (Passmore et al., 2014). Accordingly, in the traditional biology classroom it might be difficult to find examples of students struggling with the idea of an explanation's productiveness, simply because they are usually required to give the most 'complete' explanation instead of choosing the most useful explanation or reason about the productiveness of their explanation.

While students' and teachers' tendency to search for the most 'complete' explanation can be attributed to a general bias towards detailed mechanistic explanations, it has been demonstrated that providing contextual cues concerning the goals of the explanation diminishes some of this bias. For example, Lockhart et al. (2019) demonstrated that while children and adults regard people providing mechanistic information about an object as more knowledgeable, they are more inclined to consult a non-mechanistic expert when they are informed that they need to sell an object. In a similar way, when adults are asked to rate the 'goodness' of mechanistic or teleological explanation, they prefer explanations that highlight the kinds of relationships that they expect to be useful for the task at hand (Vasilyeva et al., 2017). To make matters more complicated, it has been demonstrated that students reason about their choice of an explanation using several non-etiological reasons, such as the level of interest they find in the explanation and explanation complexity. For example, when students were asked to choose between a causal explanation or a teleological explanation to a phenomenon, some preferred a causal explanation because they viewed it as more 'interesting', while others preferred a teleological explanation because they viewed it as less 'complex' (Trommler et al., 2018).

Whereas the above-mentioned studies show that the choice between different explanations can be affected by contextual cues and that in some cases reasons for choosing an explanation can be non-etiological, all of them compare between epistemologically distinct explanations (e.g., mechanistic vs. teleological; mechanistic vs. functional). However, as previously discussed in this article, in some cases the difference between two mechanistic explanations can be the degree with which certain black boxes have been unpacked. While scientists determine whether to unpack a black box by evaluating the goal of the explanation, and specifically whether their aim is to explain, predict or control the phenomenon, it is not clear whether students can appreciate the existence of explanations containing black boxes when exposed to such goals.

In light of the above, it became of interest to examine whether students are able to appreciate the co-existence of explanations containing black boxes, alongside with explanations containing these same unpacked black boxes, when these explanations are presented in a context of different explanatory goals. To shed light on this problem, we strived to answer the following research question:

How do 9th grade students distinguish between the explanatory powers of black box explanations when faced with different contexts, containing different explanatory goals?

Methods

Research context and population

Ninth grade students in Israel are required to learn genetics. The mandatory curriculum includes chapters concerning the mechanism of meiosis, the mechanism of the central dogma and Mendel's principles. While Mendel's principles are essentially a black box which allows the prediction of traits in a progeny, the central dogma is the underlying mechanism which explains how exactly genes affect traits. Thus, while the appearance of traits can be predicted or explained by taking into account the existing alleles and using Mendel's principles, the unpacked central dogma mechanistic explanation allows detailing how entities, such as the DNA and RNA molecules, interact to produce such traits.

Fifty-two 9th grade students from two classes in the same school participated in this study. Both classes were taught by the same teacher, a science teacher with a M.Sc. in biology and on her 1st year of teaching. Students were taught about phenomenon and mechanisms in genetics, specifically the mechanism of meiosis, the mechanism of the central dogma of molecular biology and principles derived from the Mendelian black box, in that order. No explicit reference was made, in the classroom, to the term 'black box'. Furthermore, the teacher did

not pay any attention to the merits or constraints of using the Mendelian black box explanation vs. the unpacked central dogma mechanism.

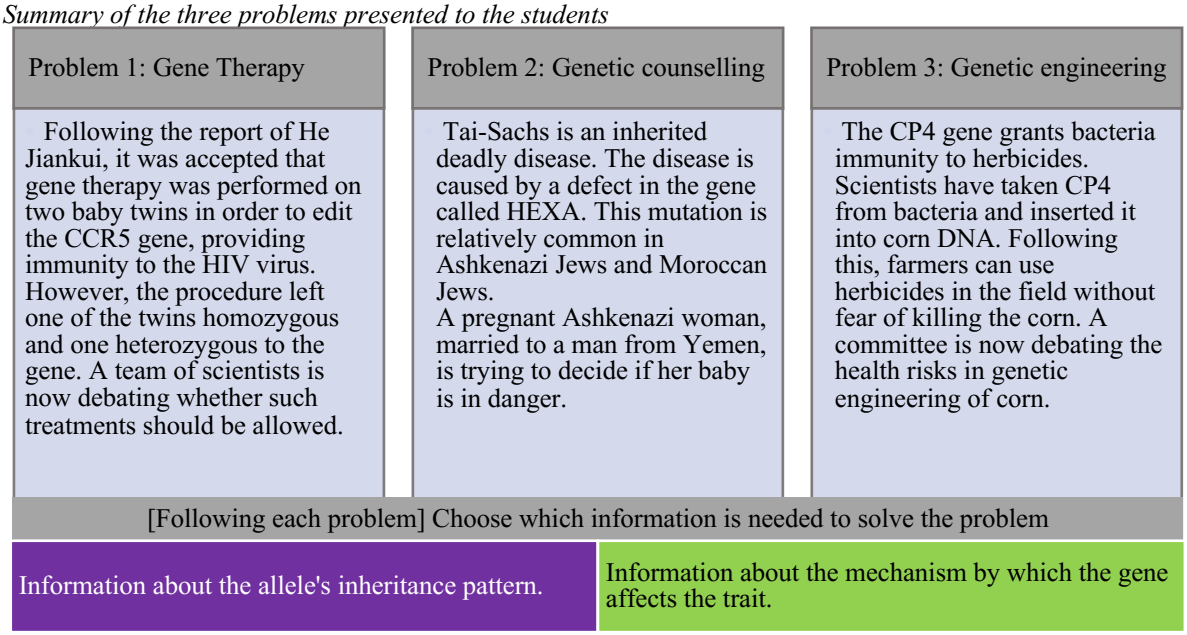
Research design

To examine students' preference of explanation in different contexts, each student read three scenarios in three different genetic contexts: gene therapy, genetic counseling and genetic engineering. Each scenario included a phenomenon in genetics lacking information about its underlying mechanism. The question at the end of each problem presented the students with a preference judgment task in which they were asked to choose which information is needed, in their eyes, to solve the problem at hand: a. information concerning the discussed alleles' Mendelian inheritance patterns or b. the mechanism by which the gene affects the trait. The three problems dealt with the issues of gene therapy, genetic concealing and genetic engineering as summarized in Figure 1.

We strived to minimize any effect derived from students' ability to use or come up with any explanations. Therefore, we asked students to choose which information they view as needed to solve the problem but did not ask them to solve it or even judge a written solution. We consider students' choice of option 'a' as a preference towards black box information and students' choice of option 'b' as a preference towards unpacked mechanism information. Thus, we use the term 'black box information' and 'unpacked mechanism information' to denote students' preference of either option 'a' or 'b', accordingly. This is not to suggest that students were aware of the type of information their answer is related to, but to classify students' choice of needed information to the type of explanation that can be constructed from that information.

Figure 1

Summary of the three problems presented to the students



After choosing an option, students were asked to justify their preference, before proceeding to the next problem. As each of the students provided three justifications, one to each problem, a total of 156 justifications were coded by two coders. Students' justifications were coded using an iterative bottom-up procedure, to reveal three categories: explain, predict and control. Justifications were coded as 'explain' when students wrote that the information they deemed as needed to solve the problem can be used to describe the phenomenon better or gain knowledge about it, without mentioning any other implications of this knowledge. For example, in the gene therapy problem, a student preferred to gain knowledge about the mechanism by which the allele leads to the discussed trait:

"Because I am interested in knowing how the defect in [the allele] CCR5 causes immunity."

The 'predict' code was used when students justified their choice by writing that the information achieved enables them to foresee the outcome of the conditions described. For example, in the genetic counseling problem, a student preferred to gain knowledge about the inheritance pattern of the discussed allele because:

"This will help the woman understand if her offspring will be sick."

The code 'control' was used when students claimed that the information can assist them in manipulating the outcome of the conditions described. For example, a student preferred to gain knowledge about the mechanism by which the allele leads to the discussed trait because:

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"Then we can make a cure."

Sixteen out of 156 justifications (10.3%) were coded as non-etiological or incoherent. Four justifications were omitted from analysis as they supported a rejection of both options (black box and unpacked mechanism). As a result, a total of 136 justifications were analyzed. Inter-rater agreement, between the two coders, concerning justification coding was 86% before peer discussion and 100% after peer discussion. Justifications were quantified and the rate of each category was calculated.

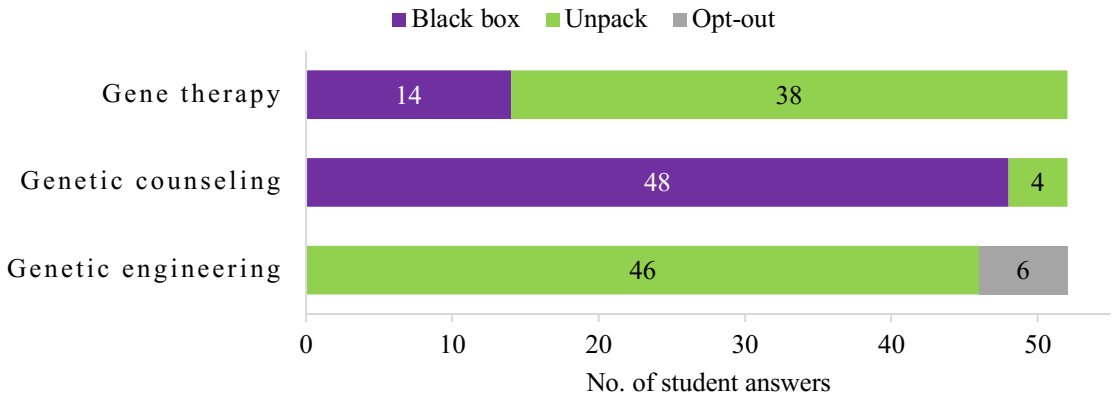
We wish to point out that as we focused on the contextual feature of productivity (predict, explain or control), our study did not include any analysis of other variables or discrepancies between the problems presented to the students. As such, we cannot determine whether other contexts, such as the organism in the problem, affected students' choices. It might be helpful to note that we were unable to identify justifications holding any reference to such variables.

Results

Choice of explanations was analyzed using a Chi Square test. As six students did not choose any of the options in the third problem and as an analysis of their justifications revealed they did not see any of the explanations as relevant to solving the problem, these students were excluded from the Chi Square test of the third problem.

Figure 2

Students' choices in preferance judgement task. n=52. Opt-out are students who did not write their choice.



Data analysis revealed a significant difference between the types of information chosen in the three different contexts (Figure 2). When faced with a problem in the genetic therapy context most students chose unpacked mechanistic information $X^2(1, N = 52) = 5.54$, $p<.01$. When faced with a problem in the context of genetic counseling most students chose black box information, $X^2(1, N = 52) = 18.62$, $p<.01$. Of the 46 students who made a choice when faced with a problem in the context of genetic engineering all students chose unpacked mechanistic information. Therefore, data suggest that students used the context of the problem to decide which type of information is needed, with a preference towards unpacked mechanistic information in the context of gene therapy and genetic engineering and black box information in the context of genetic counselling.

Distribution of students' justifications was analyzed using a Fisher's exact test. Data in Table 1 show that when students justified their preferences supporting black box information, 47 out of 57 were of the 'predict' kind, 7 were of the 'explain' kind and 3 were of the 'control' kind, revealing a significant relationship between the black box information choices and the type of justifications used by the students $X^2(2) = 28.3$, $p<0.05$. Examination of the residuals indicated that the 'predict' justification appeared in the black box category more often, while the 'control' justification appeared in this category significantly less (see 'Black box' row in Table 1). Therefore, it would seem that students associated black box information to its power of prediction. On the other hand, when students presented justifications coded as 'control', there was a significant association between this justification and the unpacked mechanism category (see 'Control' column in Table 1). Thus, it would seem that when students identified the problem as one that is linked with the need to control the phenomenon, they viewed the unpacked mechanistic information as needed in the context of the problem. It should also be noted that a relatively small number of justifications were of the 'explain' kind, 22 out of 136 justifications (16.2%). While Fisher's exact test did not reveal this low frequency as significant, it might be important to note that this can be the result of the context of the tasks, which did not merely require an explanation but posed problems that should be solved (evaluating a treatment, predicting and curing). Furthermore, while 15 out of 22 'explain' justifications (68.2%)

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were used to support unpacked mechanistic information, the difference between the two options (black box and unpacked) was not robust enough for drawing conclusions about differences between the choices.

Table 1

Distribution of students' justifications, sorted by justification type and the type of information the justification supported

	Explain	Predict	Control	Total
Black box	7	47	3	57
Unpacked mechanism	15	31	33	79
Total	22	78	36	136

Numbers indicate occurrence of each justification type.

Discussion

Scientists accept and appreciate the existence of explanations containing black boxes, as unpacking a black box when formulating a mechanistic explanation is dependent on the goal of the explanation: whether it is to explain the mechanism itself, predict the outcome of certain conditions or control a phenomenon by manipulating elements in its underlying mechanism (Machamer et al., 2000). However, in the classroom, teachers and students focus on an explanation's 'completeness' (Justi & Gilbert, 2002; Passmore et al., 2014). In the genetics classroom, students have access to both black box explanations and unpacked mechanism explanations. However, choosing to use the wrong type of explanation for the task at hand can lead students to incorrect conclusions (Gericke & El-Hani, 2018). Studies suggest that students struggle with understanding the differences between black box explanations and unpacked mechanism explanations (Gericke et al., 2013; Marbach-Ad & Stavy, 2000).

Our data points to a clear preference towards information needed for the construction of a detailed mechanistic explanation in the context of gene therapy and gene engineering. Furthermore, data points to a clear preference towards information needed for the construction of a black box explanation in the context of gene counselling. As students chose the type of information needed to solve the problem but were not asked to explicitly name each of the options, or even compare between them, it is impossible for us to determine whether they view each of the explanations as a black box explanation or a mechanistic explanation. However, our data does suggest that students were able to recognize some differences between the two explanations as they correlated each of them with different problems. Furthermore, students' justifications for choosing each type of information appear to point to their use of contextual cues embedded in the problems, a practice described in previous studies (e.g., Vasilyeva et al., 2017). Students referred to information concerning the underlying central-dogma-mechanism as one that allows control of the phenomenon, while referring to information concerning the Mendelian black box as one that allows for prediction. Therefore, our data hints at students' ability to classify each type of the offered information as different types of explanations, with different affordances towards their use in different problems. In that sense, it would seem that while previous research has demonstrated students' inability to rationalize the co-existence of central dogma explanations and Mendelian explanations (Gericke et al., 2013), providing students with contextual cues about the different goals achieved by using such explanations allows students to produce justified decisions in the context of this co-existence.

Although in this study students chose the content of information needed to solve a problem, they did not explicitly refer to the type of information (black box vs unpacked). However, we suggest that this is an important starting point to understand how students classify the information needed to formulate each type of explanation. According to our analysis, it would seem that students in this study perceived the provided black box explanations in a very distinct and consistent manner. When students faced a problem in the context of genetic counseling, almost all students in this study expressed a need for information about allele inheritance pattern, thereby taking a black box explanation approach. It should be noted, that the genetic counseling problem contained cues calling for the prediction of traits in the offspring population. The use of a black box explanation offers exactly this power. Therefore, students' preferences seem to reflect a very strong connection, made by the students, between the black box explanation and its application in explaining and predicting the distribution of phenotypes in a population of progeny. Supporting this claim are the students' justifications for their choices, as almost all students in this study expressed a wish to predict the outcome of the specified setup conditions. The above data suggest that students view black box explanations as explanations that are strongly connected to the ability to predict traits distribution in a progeny, and to predict the effect of an allele on a trait. While students acknowledged the black box explanation's power to offer prediction, it also became apparent that students perceived the unpacked mechanism explanation as one that allows manipulation of the scientific situation, in an exclusive manner (i.e., they did not view the black box explanation as one that offers a manipulation or explanation of traits).

Our analysis of students' justification to the use of each type of information leads to the conclusion that students judged the information presented to them in terms of productivity. Furthermore, while in a minority of

cases students presented justifications based on the need to explain phenomena, in most cases, students expressed a need to predict or control the outcomes of phenomena. We find this approach, towards the productivity of an explanation, concurrent with the way scientists view and use different types of information, as well as black box explanations (Machamer et al., 2000). Building on these students' intuitive understandings, in the classroom, may enhance students' distinction between different types of explanations and prevent conflation between a Mendelian black box perspective and a molecular mechanistic perspective, a known concern in the field of genetics education (Gericke et al., 2013).

In light of the above, our study supports the argument for explicitly teaching about the idea of black box explanations in the science classroom. We submit the idea that while classroom discussions tend to focus on the 'completeness' of explanations (Justi & Gilbert, 2002; Passmore et al., 2014), real life explanations are rarely complete. Rather than being complete, explanations can be productive and can be judged according to their productivity (Passmore et al., 2014). Our results suggest that students have the intuitive basis for gaining an understanding of the complex nature of various explanations. Therefore, explicitly pointing at different types of explanations and especially the presence of black boxes in explanations might be a way to help them establish a better understanding of the nature of different explanations. Namely, students understand that the need for unpacking black boxes is dependent on the contextual features of the problem. Thus, explicitly referring to black boxes in mechanistic explanations may help them understand what they can (and cannot) do with a given mechanistic explanation.

Lastly, this identified students' sensitivity to the relations between contextual features of the problem and the level of unpacking for a good-enough explanation calls for putting emphasis on the framing of questions and problems. It has been previously demonstrated that students who are unaware of the existence of a black box (e.g., the causal connection between genes and traits) find it harder to use new mechanistic information concerning the contents of that black box to construct a mechanistic understanding of the phenomena (Haskel-Ittah & Yarden, 2018). We submit that any mechanistic information discussed in the classroom should include not only an explicit discussion of the existence of the black box, but also a discussion of the reasons behind its unpacking. We view this framing as one that should include contextual hints on whether the problem requires an explanation, a prediction or a control of a phenomenon. As long as problems presented to students hold little or no contextual hints, discussion about the goodness of an explanation cannot be broader than the rote learning of details. However, once an explanation becomes a solution to a contextualized problem, other features of the explanation can be evaluated and a more authentic discussion can follow.

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Relevance of Students' Goals for Learning Engagement and Knowledge Gains in an Online Learning Course

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Abstract: Online courses are an important form of educational delivery worldwide, yet there are large differences in how well different participants learn from them. We strive to better understand these differences and investigate how they are related to participants' motivations and learning gains. Following an achievement goal approach, we distinguish between two mastery goals (task and learning goals) and performance approach and avoidance goals. We constructed an online course including 182 undergraduates and assessed their goals and prior knowledge before, and their knowledge gains after the course. Through learning analytics, we assessed learning engagement based on 9 indicators concerning usage, time, and clicks regarding the different course elements. Structural equation modelling showed that task goals were particularly beneficial for learning engagement, and in turn, learning gains. This paints a more nuanced picture of how mastery goals matter and illuminates how students' goals form a relevant premise for successful online learning.

Introduction

Online courses are a central element of educational systems and are becoming increasingly important. Over the last years, learning with online courses has rapidly increased and has been incorporated in all levels of educational systems (Castro & Tumibay, 2021; Lloyd et al., 2014). For example, in the USA in the academic year 2019-20, the percentage of students enrolled in distance education courses in postsecondary institutions was 51.8% (Hill, 2021)[1]. Adding to this, online learning is considered one of the most important forms of educational delivery in the world (e.g., Ng, 2016), and the recent shift to online teaching during COVID-19 provided a glimpse of what more is to come. However, this increasing trend of learning in online courses also comes with challenges, such as lower completion rates and participation (Ng, 2016; Simpson, 2013), making knowledge about how students differ in their engagement and learning within online courses crucial (see also Liu et al., 2009).

Despite the rising use and relevance of online learning, research on factors that drive students to learn successfully in such formats is still nascent. At the same time, knowledge about learning in traditional, face-to-face classroom settings cannot be readily transferred to online learning, as learning in classrooms and online courses systematically diverge: Besides format differences in terms of modes of interaction, accessible information, and (non-)linearity of design (Dettori et al., 2006), online learning is coined by more autonomy on the learner side and the requirement of high self-regulation in learning (Azevedo & Cromley, 2004; Kapp et al., 2015). While design and features of online courses such as social support are important for students' learning therein, learners' characteristics are also highly important and are considered as key competencies for successful online learning (Beaudoin et al., 2009). Within a given online course, there can be vast differences in the extent to which students engage. Consequently, to learn successfully in online courses, high levels of motivation and continuous learning engagement are required and need to be fostered (Simpson, 2008).

In the present research, we strive to better understand differences in learners' engagement in online courses and investigate how these are related to participants' motivations, as well as how they matter for learning performance. To this end, building on previous psychological and educational research, we conceptualize motivation using an achievement goal approach. Combining traditional data collection methods and learning analytics, we show that mastery goals are particularly beneficial for engagement, and in turn, learning gains.

Achievement goals and learning in online courses

Achievement motivation pertains to the energization and direction of competence-relevant behavior and describes why and how people strive toward competence and away from incompetence. As such, motivation is essential for how we experience and behave in achievement contexts, including learning in online courses. Moreover, motivation is dynamic and composed of personal as well as contextual aspects. Thus, for learning in an online course, it is especially important to consider the specific motivations regarding the upcoming course (opposed to general motivational characteristics). This does not (necessarily) reflect why individuals decide to participate in a given course, but rather differences in how they are motivated for this context. A prominent approach in educational psychology to describe such motivations is the achievement goal approach (Elliot & Hulleman, 2017).

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Achievement goals represent the "different ways of approaching, engaging in, and responding to achievement situations" (Ames, 1992, p. 261). They form cognitive representations of competence-related end states in achievement contexts that an individual is committed to approach or avoid (Elliot & Hulleman, 2017). Different types of achievement goals with which students approach a particular online course can be distinguished (de Barba et al., 2016). Given that these goals represent what individuals want to reach at the end of their learning, they act as a motivational basis for the interpretation of learning situations and self-regulation therein. Thus, close links with learning engagement and learning outcomes are to be expected. Indeed, previous research has shown that achievement goals are associated with self-regulated learning (Adesope et al. 2015; Zhou, 2013), learning engagement (Froiland & Worrell, 2016; Greene et al., 2004), and academic achievement (Church et al., 2001).

Following this approach, different types of goals have been suggested to matter in achievement contexts. While further distinctions have been discussed (for a contemporary overview see Daumiller et al., 2019), on a minimal level, three fundamental types of goals should be distinguished: mastery, performance approach, and performance avoidance goals. Mastery goals are characterized by a focus on task mastery and improvement. Based on their orientations, they can be distinguished further (see e.g., Daumiller & Zarrinabadi, 2020; Elliot et al., 2011; Hulleman et al., 2010; Korn et al., 2019), most notably depending on whether an individual is oriented at conducting tasks right (here termed *task goals*), or at the improvement of their own competencies (*learning goals*). Given these foci, mastery goals can be considered highly functional in learning contexts for engaged learning and learning gains, as they are focused on increasing levels of competence by acquiring the knowledge or skills that the task develops (Daumiller et al., 2021; Murayama et al., 2012; Payne et al., 2007; Wolters, 2004). It is worth noting that prior research typically assumes that mastery goals matter for learning outcomes through differences in students' engagement, but empirically, this proposed mediation has seldom been tested (Daumiller et al., 2021).

Opposed to mastery goals, *performance approach goals*[2] constitute a striving of wanting to be better than others, and *performance avoidance goals* are focused on avoiding doing worse than others. As such, performance approach goals combine a favorable approach-orientation with a focus on performance that serves to keep performance efforts channeled toward normative standards frequently eventuating in high levels of performance (Murayama et al., 2012). However, this might distract from deep learning, as reflected in a meta-analysis by Payne et al. (2007), where no associations with learning gains were found despite increased (adaptive as well as maladaptive) learning processes (e.g., Harackiewicz et al., 2000; Senko & Dawson, 2016). In contrast, performance avoidance goals combine two negative aspects (focus and valence), rendering clearly negative effects. Such goals are linked to anxiety, task distraction, and helpless engagement patterns (Elliot & Church, 1997) and have also been associated with reduced learning gains (Payne et al., 2007) and more maladaptive learning engagement of students in the form of more procrastination, surface processing and disorganization, and less deep processing (Diseth, 2011; Elliot et al., 1999; Elliot & McGregor, 2001; Wolters, 2004).

As described before, these general mechanisms of achievement goals may not readily transfer to online learning contexts (see de Barba et al., 2016). Regarding online learning, only few studies have yet investigated the relevance of achievement goals. However, accumulating evidence points to mastery goals mattering for online learning as well. For example, Xia and Huang (2014) investigated 132 students in a collaborative college-level online course and found that students pursuing strong mastery goals exhibited more frequent participation in online learning activities and reported to have learned a great deal from them. Yeh et al. (2019) found in a sample of 93 undergraduate and graduate students participating in various online courses that only mastery, but not performance goals, were positively related to supportive online learning behaviors and, by extension, expected grades mediated by an increased use of self-regulated learning strategies. Further, de Barba et al. (2016) found that for students participating in a MOOC (Massive Open Online Course), mastery approach goals assessed retrospectively after the course were associated with students' quiz attempts, and in turn, their final grades. In their study, de Barba et al. (2016) considered quiz attempts as one aspect of engagement, next to video hits.

Interpreting the current state of this line of research, three points should be considered. First, beyond research in the online learning context, mastery goals have typically been considered on a superordinate level in that they are not further distinguished into task and learning goals. Studies across different populations suggest different patterns of learning processes depending on whether individuals are focused on task or learning standards (Daumiller & Dresel, 2020; Elliot et al., 2011; Mascret et al., 2015b, 2015a; Yang et al., 2016). However, it is not yet clear how task and learning goals might specifically operate for such learning processes. As learning goals are focused on improving own competencies, they might be superior for learning processes compared to strivings focused on doing tasks right, as they may tie learning closer to one's self-worth. Conversely, task goals might be superior to learning goals in learning settings, as learning goals might distract learners from covering the full breadth of content to be learned (e.g., due to finding certain aspects particularly interesting and placing a focus on them), which might be especially the case in settings with high autonomy requirements (such as learning in online courses). As the research and practical implications drawn from these findings can differ substantially, further

investigations into the different facets of mastery goals are necessary. Adding to this, performance goals are still little understood in online learning contexts, where studies have either omitted them altogether (e.g., de Barba et al., 2016), or have not considered them relevant in remote learning contexts due to a lack of contact with peers (Sachs, 2001). More research is needed to determine their significance, especially as concerns about what others do may still be prevalent despite the actual presence of others. Lastly, in motivation research in general, self-reports are typically used to assess engagement. This can lead to a host of problems associated with same-source bias, desirable answering, and understandability (e.g., Karabenick et al., 2007), which need to be overcome by assessing engagement through other means. In the present work, we therefore consider learning engagement using a broad array of learning analytics indicators concerning how exactly students interacted with the online course.

Learning engagement and learning gains in online courses

Engagement can be defined as the time and energy students invest in educationally purposeful activities (Kuh et al., 2005). Research has consistently found engagement to be a key contributor to success in educational contexts. Importantly, learners who adopt a more engaged approach to learning are more likely to have increased learning gains (e.g., Froiland & Worrell, 2016). However, there is also variability in students' learning engagement, making it necessary to understand what individual factors might lead to different levels of engagement.

For examining learning engagement and outcomes in online contexts in particular, a unique opportunity to capture a more reliable understanding of these interrelations becomes apparent. Learning analytics paired with resulting log data from online courses represent a promising opportunity to measure and analyze how students engage with the different course materials in terms of specific interactions (e.g., views, clicks, posts, scrolls). Such objective indicators of engagement mark an important development within research on student learning, as they have the potential to overcome limitations from self-report measures and are minimally disruptive.

Indeed, several studies have found objective indicators of engagement within online courses to meaningfully represent students' learning involvement and persistence (e.g., Bonafini et al., 2017; de Barba et al., 2015; Phan et al., 2016; Pursel et al., 2016; Xiong et al., 2015). These objective forms of engagement have also been linked to different learning outcomes in theoretically sensible ways. For example, Bonafini et al. (2017) found that students who participated in a MOOC had a higher probability of course achievement when they completed more forum posts and watched more videos. Moreover, as previously noted, de Barba et al. (2016) defined students' engagement as their video hits and quiz attempts within a MOOC, which were positively linked to their interest and final grades. Adding to this, Xiong et al. (2015) assessed students' engagement in a MOOC as a latent variable through the indicators of: videos watched, forum posts, and number of assignments and quizzes completed—which was found to be positively predicted by motivation and resulted in higher student retention. To this end, construing engagement as a latent variable may be particularly advantageous to reflect the overarching psychological construct of engagement as opposed to only focusing on single indicators.

In terms of differentiating which objective indicators of learning engagement within online courses are better to investigate than others, a consensus within the literature has yet to be reached (see Agudo-Peregrina et al., 2014). Nevertheless, important criteria can be drawn from prior studies (e.g., Bonafini et al., 2017; de Barba et al., 2016; Xiong et al., 2015): To provide more comprehensive and reliable insights, several objective indicators of engagement should be simultaneously examined. Moreover, certain indicators—particularly page views, video views, and interactions with quizzes and assignments—have consistently been found to be meaningfully and significantly related to students' learning outcomes. These specific indicators are also commonly reported within studies investigating objective learning engagement in online courses and can therefore be more readily compared with existing research. Based on these considerations, in the present study, we considered the objective engagement indicators of page views (regarding core lessons, additional information, videos, and quizzes), clicks (within core lessons, additional information, assessments, and quizzes), and total time spent on the course.

The present research

As online learning continues to expand in higher education, the effects of pursuing different achievement goals on learners' engagement in online courses and the resulting learning gains need to be analyzed in more depth. In the present research, we aim to follow up on this research gap. Besides considering achievement goals in detail by distinguishing task and learning facets of mastery goals, we consider learning engagement based on multiple objective indicators. To test the relevance of achievement goals for learning engagement in online learning courses and how this consequently matters for learning gains, we put forth the following hypotheses based on the theoretical and empirical points previously discussed:

Hypothesis 1: Task and learning goals are positively associated with learning engagement.

Hypothesis 2: Performance avoidance goals are negatively associated with learning engagement.

Hypothesis 3: Learning engagement is positively associated with learning gains.

Given the unclear nature of performance approach goals, we did not formulate a directed hypothesis for this type of goal. Further, we presumed that both task and learning goals would result in positive effects, but tested for potential differences between these two facets of mastery goals on an explorative level.

Method

To answer our research questions, we constructed an online course on psychological research methods embedded in the curriculum of a psychology lecture and invited 182 students to participate in it over two weeks in November 2019. The study was conducted in full accordance with the Ethical Guidelines of the German Association of Psychologists and the American Psychological Association. Full anonymity of all participants was assured. We had no reason to assume that completing our survey would have any negative effects on the participants. We provide the online course used as an open educational resource and provide all data and code underlying this research in an open repository (https://osf.io/gp6h3/).

Participants and procedure

The participants of this study included students attending an introductory lecture on psychology. Typical for this population, participants were mostly women (135 identified as women, 45 as men, 2 as diverse), had an average age of 21.4 (SD = 2.6) years, and were in their first year of university. It should be noted that the students had not yet dealt with the topic of the online course (research methods) within their curriculum.

The online course contained 3 core lessons (including 10, 3, and 9 pages of learning content, respectively), 3 videos, 7 pages of additional helpful information, 16 quizzes, and 3 end-of-lesson assessments. It was constructed based on an earlier online course developed by Daumiller and Dresel (2019) and piloted regarding understandability, relevance of content, potential technological problems, and ease of use with five students. The average time spent on the online course was 122 minutes (SD = 70). When accessing the online course for the first time, participants were asked to complete a survey assessing their achievement goals and baseline knowledge. During the online course, we measured their learning engagement in the form of log data corresponding to the indicators of views, clicks, and total time. Directly after completing the online course, the students were required to participate in another knowledge test covering the topics within the course to gauge their learning gains.

Measures

We used the scale by Daumiller et al. (2019) to measure task approach (3 items; e.g., "… my goal is to fulfill the different requirements very well"; ω = .90), learning approach (4 items; e.g., "… my goal is to expand my knowledge as much as possible."; ω = .93), performance approach (4 items; e.g., "… my goal is to be better than the other students."; ω = .94), and performance avoidance (4 items; e.g., "… my goal is not to be worse than the other students"; ω = .94) goals. All items were directed at the online course (item stem: "In this online course…") and answered on a 8-point Likert-type scale ranging from 1 (*do not agree at all*) to 5 (*agree completely*).

As indicators of students' engagement during the course, we used log data concerning (a) the total amount of time students spent on the course, (b) how many times they viewed core lesson pages, (c) how many videos they viewed, (d) how many times they viewed additional information pages (containing supplemental information such as tips for reading research articles and a dictionary with key words), (e) how many times they viewed quizzes, (f) how active they were within the core lesson pages, (g) how active they were within the additional information pages, (h) how many answers they submitted within the assessments, and (i) how many answers they submitted within the quizzes. We modeled residual correlations between closely corresponding and partly dependent indicators (e.g., lesson views with lesson clicks). A CFA confirmed the presumed one-dimensional structure and supported modelling engagement as a latent factor (CFI = .97, TLI = .95, SRMR = .05).

We measured students' content knowledge concerning the online course by administering a slightly adapted and expanded multiple-choice test by Daumiller and Dresel (2019) containing 4 questions before the start of the course as well as the same questions along with 6 further, more difficult questions after the students finished the online course. Based on the proportion of correct items (pretest: M = .64, SD = .13, Min = .19, Max = .88; posttest: M = .65, SD = .11, Min = .38, Max = .90) we subsequently computed the residual change scores between these two knowledge test scores to describe students' learning gains during the course. Given that the post-test was more difficult than the pre-test, it should be noted that the change scores do not reflect the absolute amount of learning gains for each student (which we were not interested in), but instead allows us to quantify differences between the participating students with regard to their learning gains.

Analyses

We estimated a structural equation model in which learning gains were regressed on learning engagement (as a latent variable based on nine indicators) that was in turn regressed on the four achievement goals. We allowed for

direct effects from goals on learning gains. We estimated the direct effects as standardized partial regression coefficients and obtained indirect effects by combining the specified coefficients for direct effects; their statistical significance was tested with *z*-tests. The model was estimated in R version 4.1.1 (R Core Team, 2021) using the lavaan package version 0.6-9 and MLR as an estimator. There was no missing data.

Results

We present descriptive statistics as well as bivariate correlations between all variables in Table 1. In line with prior research on achievement goals, we found rather high levels of task and learning goals and lower levels of performance goals. All goals contained substantial amount of intra-individual variability, indicating that students started the course with different compositions of goals.

The results of the SEM (CFI = .96, TLI = .95, SRMR = .05) are visualized in Figure 1 and indicate that task approach goals had a positive, statistically significant effect on learning engagement, while learning approach goals and the two performance goals did not. Engagement in turn had a positive, statistically significant effect on learning gains. According to Acock (2014) both effects can be considered as moderate. Further, there was a small, statistically significant indirect effect from task goals via engagement on learning gains (β = .05, *SD* = .02).

Table 1

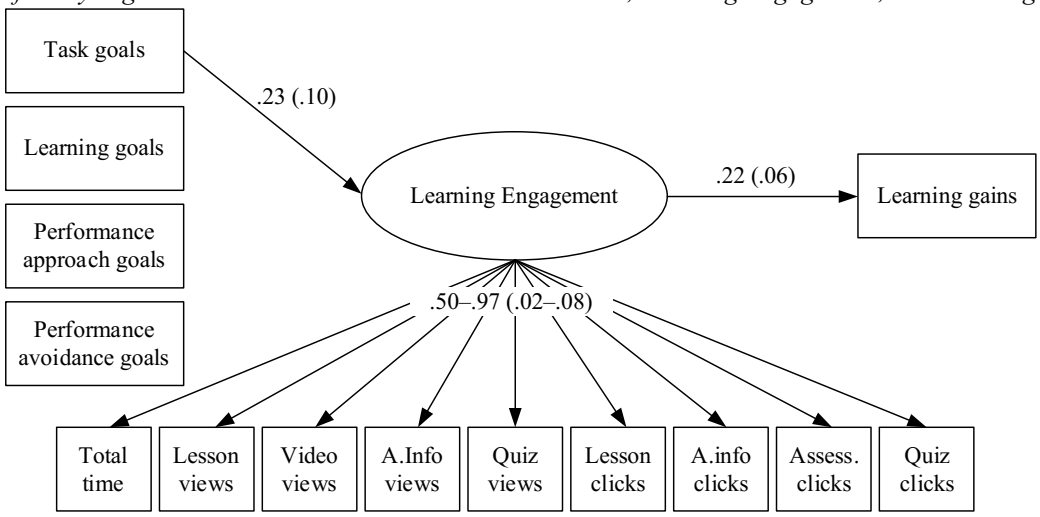
Descriptive Statistics and Bivariate Correlations

	M	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13
Achievement goals															
[1] Task approach goals	3.92	0.83													
[2] Learning approach goals	4.08	0.80	.69												
[3] Performance approach goals	2.15	1.00	.05	-.11											
[4] Performance avoidance goals	2.59	1.06	.15	.04	.74										
Learning engagement															
[5] Total time	122	70.3	.11	.04	-.02	.07									
[6] Lesson views	42.7	23.6	.08	-.01	-.07	.02	.54								
[7] Video views	1.75	2.27	.20	.07	.03	.05	.45	.48							
[8] Additional information views	9.27	8.74	.22	.13	-.05	-.04	.45	.38	.47						
[9] Quiz views	32.0	18.0	.10	.04	-.09	-.03	.45	.88	.51	.39					
[10] Lesson clicks	54.9	31.9	.09	-.01	-.06	-.01	.58	.95	.56	.45	.87				
[11] Additional information clicks	14.7	12.5	.20	.05	-.01	.04	.52	.65	.80	.66	.63	.72			
[12] Assessment clicks	13.4	10.3	.17	.07	-.04	.05	.43	.62	.49	.46	.75	.71	.60		
[13] Quiz clicks	25.7	14.3	.08	.03	-.10	-.05	.42	.87	.46	.34	.97	.83	.58	.57	
Learning gains	0.00	0.11	.07	.07	-.10	-.11	.25	.21	.18	.32	.18	.21	.12	.15	.17

Note. All $|r| > .14$ statistically significant at $p < .05$, $|r| > .19$: $p < .01$.

Figure 1

Results of Analyzing the Associations Between Achievement Goals, Learning Engagement, and Learning Gains



Note. Only statistically significant effects are visualized. Residuals and their correlations are not presented.

Discussion

As online courses are an important form of educational delivery worldwide, yet students vary substantially in how well they learn from them, we aimed to investigate differences in students' engagement and how they are related to participants' motivations and learning gains. Following an achievement goal approach, we distinguished between two mastery goals, namely task and learning goals, and included performance approach and avoidance goals. Besides this detailed view on students' goals, we expanded prior motivation research that primarily relied on self-reports by combining traditional data collection methods and novel learning analytics techniques, measuring learning engagement based on a broad variety of objective indicators. Our finding that especially task goals are beneficial for learning engagement, and in turn learning gains, paints a more nuanced picture of how mastery goals matter, and illuminates how students' goals form a relevant premise for successful online learning.

Confirming our expectations and in line with prior findings (e.g., Bonafini et al., 2017; de Barba et al., 2016), we found that learning engagement measured via objective indicators within the online course did indeed matter for students' learning gains. It should be borne in mind that our measure primarily focused on behavioral aspects of engagement; an increased relevance of engagement might have been found had we also considered cognitive and affective aspects more strongly. This highlights the importance of designing online courses in ways that spur engagement, as well as considering the role of personal learner characteristics that might impact learning engagement. Regarding the latter suggestion, our findings indicate that students' motivations expressed in the form of achievement goals constitute personal factors that impact their engagement within online courses.

In terms of the linkages with learning engagement, our findings support that across different types of learning environments, mastery approach goals are positively related to learning outcomes (see Belenky & Nokes-Malach, 2012). The finding that especially task goals (when compared with learning goals) matter for learning engagement and learning gains, requires a closer look into the relevance of mastery goals. Our findings imply that task and learning goals might indeed differ in how they matter for student learning (Daumiller & Dresel, 2020; Elliot et al., 2011; Mascret et al., 2015b, 2015a; Yang et al., 2016). Regarding learning processes, at least within clear learning contexts such as online courses, it might be the case that task goals are superior to learning goals, as learning goals might distract learners from covering the full breadth of content to be learned (e.g., due to finding certain aspects particularly interesting and focusing on them), which might especially be the case in settings with high autonomy requirements (such as learning in online courses). Here it should be considered that we designed the knowledge tests to operationalize learning gains by content-validly reflecting the full range of content within the course. This focus aligns with the notion that learning goals may foster deeper specialized knowledge gain, as opposed to an understanding of all relevant content to be learned. Future research might follow up on this by conducting interviews to inquire about students' learning processes in more detail. Another important take away is that although we also examined performance goals, no statistically significant effects were identified for this goal type with learning engagement or learning gains. This might be a function of the features of the online course, which included little opportunity for normative comparisons (e.g., no opportunity to compare quiz/assessment scores). Therefore, future research should consider a broad array of course features and how these might matter for the effects of performance goals.

When interpreting our findings, two key limitations need to be considered. Firstly, we considered a single online course with unique features, limiting generalizability and comparability of our findings. One way to address this could be extending the present study to courses with different designs. Second, we focused on engagement from an objective and behavioral perspective, however, additionally assessing emotional and cognitive facets of engagement would be an interesting and important direction for future research. Nevertheless, our findings already point to first practical implications. Specifically, task goals should be supported to allow for more successful online learning experiences. This may be facilitated through: (1) directly influencing these goals by stressing the importance of task mastery and putting the respective goals into writing; and (2) supporting these goal striving processes by an arrangement of contextual features emphasized in the online course (Lüftenegger et al., 2014).

In conclusion, our findings contribute to better understanding how established models of educational research can be applied to shed light on students' engagement and learning gains in the increasingly important context of online learning. While online courses may differ in design and support provided, personal learner characteristics such as their motivations should not be neglected. Our findings show that students' goals, and in particular, their task goals, are relevant for engaging more in online courses and taking more away from them.

Endnotes

(1) Given the aberrations of 2020 and 2021 data due to COVID-19, we rely on the data before COVID-19 as an indicator of how widespread the use of online learning courses has become (Hill, 2021).

(2) Similar to mastery goals, performance goals can be further distinguished based on whether they are directed at normative comparisons regarding performance (normative goals), or at competence demonstration (appearance

goals). For theoretical and conceptual clarity, we focus performance goals in the present work exclusively on normative comparisons (in line with Elliot & Murayama, 2008; Elliot et al., 2011).

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Genres of Discussion-based Social Emotional Learning: Emotional Inquiry and Inclusive Emotional Dialogue

Abstract: Social and emotional learning (SEL) scholars advocate discussion as a promising instructional method yet rarely specify how such discussions should be conducted. Furthermore, SEL literature contains contradictory discursive imperatives and typically overlooks the ways emotional experience and expression are shaped by culture, class, and gender. We addressed these issues in analyses of two primary language arts lessons drawn from a two-year ethnographic study. Each case study lesson illustrated a different interactional genre for discussing emotions: (1) inclusive emotional dialogue, in which students shared emotions experienced in their everyday lives; (2) emotional inquiry, in which students explored emotions and their social meanings. Both types generated informative discussions about students' emotions but put the teacher and students in challenging positions as students publicly exposed their hardships. Both types were also, at times, limited by norms of hegemonic positivity, gender-based assumptions, and teachers' promotion of a white, middle-class emotional code.

Introduction: Promoting discussion through social emotional learning

Social emotional learning (SEL) is widely promoted as a means to improve students' well-being, academic achievement, mental health, and civic engagement (e.g., Domitrovich et al., 2017; Jones et al., 2017). One strategy for advancing SEL is to integrate social, emotional and academic development (Aspen Institute, 2019), for example, by 'enhancing' the language arts curriculum with SEL (Collaborative for Academic, Social, and Emotional Learning, 2017). A central method for advancing these aims is discussion-based instruction (e.g., Assor, 2020). However, scholars advocating classroom discussions for SEL rarely specify how they should be designed and facilitated.

We explore discussions about emotions in the analysis of two case study lessons drawn from a two-year ethnographic study of a dialogic pedagogy intervention designed to foster productive classroom dialogue in the language arts. The two lessons were conducted in a primary school in a mixed Arab-Jewish socio-economically disadvantaged Israeli city. Each case reflected a different interactional form for discussing emotions: (1) *inclusive emotional dialogue* – a form of dialogue in which participants are expected to share their own emotions and to support others' sharing of their emotions; and (2) *emotional inquiry* – a form of dialogue in which participants are encouraged to explore emotions and how they and others experience and express them.

Social emotional learning discursive imperatives

SEL, like other educational trends, emerged within a certain cultural and historical context and should be understood as part of a broader therapeutic turn in education (e.g., Ecclestone, 2012). For present purposes, we focus on how scholars envision SEL discussions. We identify three main discursive imperatives:

'Don't bottle things up'

SEL guidance emphasizes that pupils should learn how to express their emotions (Collaborative for Academic, Social, and Emotional Learning, 2013; Jones et al., 2017; Merrell & Gueldner, 2010) and advocates sharing emotions as a desired practice (Department for Education and Skills, 2005; Merrell & Gueldner, 2010). Cameron (2000) critiques the imperative 'don't bottle things up', noting that its goal is limited to venting bottled up feelings, and does not include reflecting on those feelings: 'to speak them so that they may subsequently be spoken *about'* (p. 157).

Inclusiveness

SEL programs place a strong emphasis on sharing emotions. Students are guided to share their emotions and teachers are expected to encourage such sharing, without restriction or direction (Gillies, 2011). Wilce and Fenigsen (2016) conclude that 'emotion pedagogies evince a need to recognize—and, often, fully accept—all emotions, including "bad" or "negative" ones such as anger or shame' (p. 84). The authors point out that the idea of emotional inclusiveness is historically recent, as many cultures have traditionally tended to direct people toward desired emotions, while avoiding and even condemning the expression of others.

Hegemonic positivity

SEL programs tend to promote what Stearns (2017) calls 'hegemonic positivity', based on 'an assumption that children should feel good in school and about school' (p. 265). Hegemonic positivity is expressed in SEL by proclaiming the primacy of joy and by putting a strong emphasis on training pupils to control anger and stay calm. Gillies (2011) calls it a '"feel good" language... that deflects argument and disarms criticism' (p. 188).

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Hegemonic positivity, however, has been criticized: for example, Dutro (2008) writes, 'if wounds are not welcome, children will correctly sense that what school wishes to hear is the banal, the safe, the bland, and they will leave what matters most muted beneath a sterile, clean bandage' (p. 18).

Hegemonic positivity is in tension with inclusiveness and the call to accept all emotions. For example, teachers in a classroom observed by Stearns (2017) explicitly told students that bad feelings 'should only last for a certain amount of time' (p. 277). Stearns asserts that the directive to focus on positive emotions made teachers overlook students' considerable interest in discussing 'bad', difficult, emotional states.

SEL in context

SEL not only expects and promotes a certain emotional code; it also assumes a cultural world in which it wishes to operate, addressing and ignoring other social identities and discursive genres. Following Stearns (2017), who identifies a gap between the rare explicit mentions of race, class, and gender during SEL discussions and their 'ineffable presence' in them (p.152), we discuss here how emotional dialogues interact with gender and socio-economic status.

Gender

Evans (2017) shows how perceptions of gender roles generate different expectations for boys' and girls' participation in SEL. Girls are invited to 'suspend affect, and to engage in the intellectual exercise of analysing and articulating emotions … In contrast, boys [are] … permitted to passively participate, with their docile bodies serving as a signifier of success' (Evans, 2017, p. 198). Similarly, Wood and Brownhill (2018) show how teachers evaluate pupils' needs vis-à-vis gender, depicting boys, mainly those with 'anger problems', as needing strong boundaries.

Socio-economic Class

Hoffman (2009) criticizes the common SEL demand that 'children in the elementary grades should be able to recognize and accurately label simple emotions', arguing that 'not all cultures interpret emotional experience in the same way, nor do they assign the same kinds of regulatory or expressive responses (such as talk) commonly shared by the White, American middle class' (p. 540). Gillies's (2011) ethnographic study exposes a multilayered gap between the everyday needs of underprivileged pupils and the values promoted by the influential Social and Emotional Aspects of Learning (SEAL) program. The students she studied often discussed difficult events, such as local teenage stabbings, in a 'seemingly emotionless manner' (2011, p. 200). From an SEL perspective, such a response is 'indicative of poor social skills and low emotional intelligence' (ibid). Yet Gillies suggests the students used this emotional code to cope with a reality they could not affect or escape, and it 'effectively worked to defuse difficult feelings while fostering supportive social bonds' (ibid).

In sum, scholars call on teachers to use discussions to promote SEL but prescribe different and often contradictory discursive imperatives. How are such discussions enacted in practice in classrooms in diverse cultural contexts?

Research context and methods

The data were collected as part of a design-based implementation research project designed to foster productive dialogue in primary language arts classrooms. Participating teachers aimed to facilitate discussions that afford students opportunities to express their thoughts, build on others' ideas, and reason about their own and others' perspectives (Alexander, 2020; Authors, 2021a).

During the 2019-2020 school year, the program included ten schools, most of which were in underprivileged neighborhoods, including the school at the center of this paper. This paper focuses on lessons in two fifth-grade classrooms, documented in March 2020. The two classes shared similar demographics: most of the 31-32 students in each class were Mizrahi Jews, several pupils recently emigrated from the former Soviet Union, each class contained one Arab student, and 4-5 students were identified as having special educational needs. Both classes had balanced distributions of boys and girls. Most students came from lower-middle-class families and, according to the teachers, some experienced financial difficulties and domestic violence. The two classroom teachers, whom we are calling 'Miriam' and 'Osnat', were both highly respected veterans.

The first author conducted weekly observations at the school, documenting teacher team meetings and Hebrew language arts lessons in Miriam's and Osnat's classrooms. Our two case study lessons, taught in the two fifth grade classes, were dedicated to a preparatory discussion conducted prior to reading the short story 'The King Who Could Not Cry'. The story tells of a king whose kingdom is extremely prosperous and whose subjects are wonderfully happy. Yet one problem vexes the king: he cannot cry. The story follows the king's futile attempts to cry, helped by his advisers who try to make him cry by showing him sad sights such as a black

clouds, dry thorns, and a lizard that lost its tail. These attempts fail one after another. Finally, after many years, upon reaching old age, the king sees a young couple in love; this reminds him of his youth and evokes his tears.

We chose to focus our analysis on the lessons dedicated to 'The King Who Could Not Cry' as the classroom discussions revolved around crying and emotional states related to crying, thus lending themselves particularly well to SEL topics and aims. We applied principles and methods of linguistic ethnographic micro-analysis (Rampton et al., 2015) in analyzing the cases.

Contrasting two forms of classroom emotional dialogue

We examined how two classroom discussions unfolded vis-à-vis teachers' anticipations and SEL goals, cultural assumptions, and contradictory imperatives. In our data we identified two types of discussion relevant to SEL: *inclusive emotional dialogue* and *emotional enquiry*. In inclusive emotional dialogue students share their experiences and feelings with the teacher's encouragement, support, empathy, and approval. In emotional inquiry, teachers and students investigate their emotional experiences and perspectives through the use of open-ended questions, probing one another's ideas, weighing evidence, and drawing connections.

Each form of dialogue sheds light on different aspects of the challenges facing classroom discussions about emotions. Yet both types of discussions require that students share personal emotional stories and associated ideas about emotions and their expression. In this way they may expose gaps between SEL-preferred white, middle-class emotional codes and how students from diverse backgrounds experience and express their own and others' emotions.

Inclusive emotional dialogue in Miriam's class

Miriam opened the discussion by asking the class: 'Ok, is there someone who is willing to share when he cried last? And why?' Thereby she set in motion a round robin discussion in which students shared in turn their personal experiences of crying. Each turn was followed either by clarification questions or empathetic approval.

Miriam's question aroused the class, generating much chatter and attention. The first four students shared short anecdotes to which Miriam replied with playful banter, thereby signaling that the students' contributions were welcome. During these short dialogues, a girl remarked that 'boys cry because, when they lose in something'. A boy commented, 'I've never seen a boy cry". John, a fairly tough and popular boy, said that he cried on his birthday, when he heard that his friend's mother had a baby.

The sixth student to take the floor said she cried yesterday, just to let things out. Here, Miriam built on the student's talk to express a general argument: "You say that you had something, that was kept inside, very, very much, and you did not let it out. Not by talking or by crying, and it just came out. Because it was night. I can understand what she's saying. At night, it's quieter around us and we slowly, slowly gather into ourselves towards – towards the night and sleep and dreams, and then many thoughts well up within us." Miriam then returned to John: 'Wait a minute I want to go back to what I heard John say earlier, you [plural] were at John's birthday party right? And Zohar was there too, right? And then they told Zohar his mother had given birth? So why did this make you cry?' 'It's moving,' he replied.

In these two interventions, while abiding with the inclusive norms of sharing and approving, Miriam accentuated ideas that aligned with the emotional code she wanted to promote. The conversation with John also demonstrated that while the conception that boys don't cry was present in the discussion, some boys, including tough and popular boys, talked about crying openly, even in the traditionally feminine context of a friend's significant life event.

About seven minutes into the discussion Miriam gave Liron the floor:

1	Miriam	Yes, Liron
2	Liron	<I cried this morning>
3	Miriam	Why?
4	Liron	I get up in the morning, it's my birthday and everything-
5	Miriam	Happy birthday, yes
6	Liron	Then, when I come out, my mother gets upset with my brother because he keeps asking her for money
7	Student	Exactly like me
8	Liron	Then my mother drove anxiously to work, and then I said to him ah .. 'Dean why are you annoying her', then h:::e grabbed me, and choked me and told me, 'You bug me again I'll cut you with a knife.' [Laughter, indistinct chatter] And then he told me, and then I told him, 'leave me alone already' and .. that's it.

As Liron talked about the violence directed toward him, many of the students reacted, talking to others around them but not to Liron, the teacher, or the entire class. Liron's story was, in our eyes, troubling. In class,

Rasoul was the only participant who explicitly signaled unease, gasping loudly to mark his bewilderment (during line 8, above, after Liron said 'choked me'). Rasoul then looked around the classroom for clues on how to act. Seeing no other student overtly express a similar reaction, he quickly went back to behaving 'regularly'. At this point, Miriam stepped in and probed Liron's emotional state:

9	Miriam	So, was it out of anger or out of …?
…	…	…
12	Miriam	So basically-
13	Student	I wouldn't back down [a tune pupils sing to fuel disputes and fights]
14	Student	Out of anger
15	Miriam	Hush [[makes a silencing movement with her hand; the noise continues]] So basically, what we saw here, really, thank you very much for sharing, first of all, but what we saw here is actually that [1] crying can come from many reasons, it can be a matter of physical pain
16	Yali	Miriam, I cry every day
17	Miriam	We got hit, it could be from excitement, enthusiasm, joy, frustration, nerves
18	Yali	From anxiety, out of anger
19	Miriam	Nerves, anger, there really are lots and lots,
20	Lucy	Or you can cry with joy.
21	Miriam	wide range of emotions, a wide range of emotions following which we can, ah, a person can ah, come to cry.

Miriam's response distanced the discussion from domestic violence through two discursive moves. First, she focused on Liron's emotional state. This echoes one of the key principles of SEL and emotional knowledge: focusing on naming emotions and reflecting on them. By so doing, Miriam turned Liron's story into a story about his internal emotions as opposed to the external events to which he was exposed. Moreover, Miriam suggested Liron was angry, and anger made him cry (line 9), without considering more passive emotional states, such as sadness, fear, anxiety, distress, or sorrow, which would reflect an innate helplessness Miriam's interpretation of Liron's emotional state as anger might have been affected by a gender-based perception of emotions and their expression (Evans, 2017; Wood & Brownhill, 2018) which sees anger as an active masculine emotional response to getting hurt (although we cannot know whether Miriam would have treated a female student differently).

Second, Miriam built on her focus on Liron's emotional state to conclude the entire discussion by pointing to the range of emotions that may bring people to cry, one of the main goals of the discussion. Turning a story about domestic violence into a discussion on the varied emotions that may evoke crying may be thought of as a form of defensive teaching (McNeil, 1982), aimed to defend the teacher, as well as the students, from public exposure of and discussion about students' hardships.

Similar dynamics have been identified in the sparse ethnographic literature on SEL in other classroom discussions. For example, Coe and Nastasi (2006) documented a classroom discussion in which a student told her class that her grandmother 'sometimes used a stick or cable wire' to beat her. The teacher replied by asking her if the situation was really stressful and if she was upset. Miriam was not trained for SEL, but she used the same 'name-your-emotional-state' practice and by using it, like the teachers documented by Coe and Nastasi, overlooked and perhaps normalized a story about domestic violence (see also Gillies, 2011; Stearns, 2017). To understand why this happens, we need to examine the structural conditions of emotional classroom discussions; we return to this issue in the Discussion.

Emotional inquiry in Osnat's lesson

Osnat initiated her classroom discussion with the question: 'Imagine that I have a magic wand and everyone I touch will never cry again. Who wants me to touch him?' The question yielded eight responses, with students saying they did not want to stop crying. The first student who answered the question explained that we can cry because of joy or happiness. While she spoke, several students offered additional examples of positive experiences that generate crying. One said 'laughter', which the speaking student embraced and repeated, and at least two others said '[out of] emotions'. The students in effect followed the logic of the dominant cultural code, according to which emotions and emotional expression are good and, since crying is the product of emotion, crying is also good.

Students also addressed crying as a means of communication. The first speaker who promoted this line of thought said that if she did not cry, others would not understand how she felt. A boy who spoke after her said that when he cries, 'everyone rushes to me and asks me what happened', thus attributing a specific message to crying: it calls for and generates positive attention. This was supported by other students. The next student (male) to speak said, 'If someone does something to you then… crying says, like, leave me alone. I did not do

anything to you, and… uff, crying saves us sometimes'. He emphasized a different message: crying is a socially legitimate way to stop a fight or a quarrel. Once again, other students expressed support.

Although the students did not respond to one another directly, their answers built on each other's content (Alexander, 2020), and they jointly portrayed possible communicative meanings crying may carry: it may generate caring attention, and it may signal to others that aggression has reached its limit and should be stopped. These answers indicate that children use crying in a unique way that adults rarely use.

After eight turns of students indicating they would not want to stop crying, Yotam, a student who often expressed provocative positions during classroom discussions, offered a heterodox response:

26	Yotam	I actually (*davka*) do want because-
27	Osnat	To touch you?
28	Yotam	Yes. Because
29	Osnat	Okay, why?
30	Yotam	I am more sensitive
31	Osnat	More what?
32	Yotam	Sensitive
33	Student	He is sensitive
34	Osnat	You are sense:::tive. Wait a minute, try, try explaining to me
35	Yotam	Like, when, when others insult me, I like
36	Student	I have never seen you cry
37	Osnat	Wait a minute, but I cannot hear Yotam
38	Yotam	Because let's say uh I'm just saying, let's say that when others insult me so hmmm.. I kind of take it to the heart, I think that maybe it is true
39	Osnat	And then?
40	Yotam	And then I cry

Yotam's answer, as we understand it, touches on a fundamental question about the relationship between emotions and expression. Yotam cries when two things happen: others insult him, and he takes it to heart and believes what they say about him to be true. For Yotam, crying appears to be a transformative act, part of an internalization process. If so, then it follows that *not* crying indicates not internalizing others' offending remarks, and thereby he is able to defend himself.

This echoes Gillies' (2011) discussion about emotions vis-à-vis social class (discussed previously), and the need of some lower-class students to suppress rather than express their emotions, as their structural position grants them limited power to affect their realities. Gillies asserts that they use this 'suppressive' talk to defuse difficult feelings. Yotam said his self-esteem was sometimes hurt when he was insulted, and the strategy he developed was trying not to cry. Perhaps this is why a student said that he had never seen Yotam cry (line 36).

Yotam first said he wanted Osnat to touch him with her magic wand. But by using the word *davka* (line 26), he indicated that his choice contradicted something - the atmosphere in the classroom or the generally expected answer (for an account of the 'inherent counter-expectation' nature of Hebrew *davka*, see Ariel & Katriel, 1977). Yotam also described himself as never crying 'from excitement or anything like that', referring to what previous speakers had said and thus performing, for the second time, a rare act in classroom discussions: expressing a position which opposed a teacher-approved answer. Osnat encouraged Yotam's voice, which differed from those of the other students, thereby bringing into the discussion a different understanding of crying

Iris, a student who tended to adopt Yotam's ideas and follow him when he spoke in class, particularly when he challenged Osnat, raised her hand as Yotam's turn ended. After getting the floor, she said: 'I do want you (Osnat) to touch me... because when you cry, I think it's not for good reasons, for example, for example, if you are shouted at, you cry, then it is something that also hurts you... and I do not want to be hurt.'

Anat, the fourteenth speaker, a student Iris often mocked during classroom discussions, asked to respond to Iris. This was the only instance when a student directly and critically addressed a previous speaker during this classroom discussion:

80	Anat	Can I address what Iris said?
81	Osnat	Yes
82	Anat	So, she said that if she would stop crying others would stop hurting her, but if she would stop crying then they would hurt her more because they would think she did not care.
83	Rona	Most of the time it is the other way around
84	Anat	She said-
85	Iris	Like, I will not get hurt

86	Anat	In my opinion if I would stop crying, people would hurt me and think that I do not care that they say things about me so they-
87	Osnat	So with the help of crying what does she do?
88	Anat	She's like, telling people 'stop hurting-
89	Student	Like, she drags attention (*goreret tsumi*)
90	Osnat	Attention maybe, maybe attention (*tsumet lev*), maybe this is how she manages to better express her emotions, in this way, with the help of crying

Anat built on an understanding of crying that was already established in the discussion – a signal to others to stop hurting you – to refute Iris's argument. We want to focus on lines 83 and 89, however. Rona turned to Anat and said, 'It is usually the other way around' (line 83), meaning that usually if you cry when others hurt you, they do not leave you alone but bother you more.

Anat continued her answer, treating crying as an action that signals to others to stop hurting you, but when Osnat asked her, 'So with the help of crying what does she do?', one of the boy students said, 'She drags *tsumi*' (line 89), a slang phrase that indicates something along the lines of pitifully asking for socially undeserved attention. Although he did not address Rona directly, his train of thought continued hers, thus establishing something similar to a counter script (Gutierrez et al., 1995), as they together produced a coherent line of answers that was overlooked or even blocked by the teacher. Osnat transformed *tsumi*, a derogatory phrase, into 'asking for *tsumet lev*', a neutral phrase (sharing the same root) meaning 'asking for attention'.

The discussion shows how emotional inquiry can produce valuable emotional knowledge. First, the students thought of crying as a means of communication, even a social request, but each student attributed a slightly different meaning to this request: making others react to how I feel, making everyone rush to me and ask me what happened, or signaling to others to leave me alone as 'crying saves us sometimes'. Second, students highlighted the relationship between expressing emotions and feeling them when they said they preferred not to cry so as not to get hurt. Third, the inquiry produced an opportunity to further discuss crying as communication while distinguishing legitimate and illegitimate social requests embedded in crying.

Discussion

Genres of classroom discussions about social and emotional issues

Discussion is seen as a favorable instructional method for SEL, but we found the term 'discussion' was too vague in the SEL literature. We identified in our data set two very different types of discussion, each with distinct goals, norms, affordances, constraints, and challenges.

In *inclusive emotional dialogue,* students were encouraged to narrate personal, sometimes difficult stories, thereby enabling the sharing of emotions as experienced in students' everyday lives. However, as indicated by Liron's story of how his brother choked him on his birthday, this genre can put teachers and students in a challenging position. On the one hand, sharing personal stories entails exposing fears and hardships in the class plenum, an environment in which it is hard to ensure that students receive the appropriate response to such exposure. On the other hand, if the teacher glosses over these issues, she implicitly conveys that such issues are either not important or unsuitable for discussion, should be kept secret, are not the school's business, and so on (Dutro, 2008).

Emotional inquiry promoted exploration of children's understandings and expressions of emotions. It generated informative discussions about emotional states related to crying and their diverse social meanings and may thus be considered especially compatible with SEL (as well as other pedagogic) goals. However, norms of hegemonic positivity can limit or silence the expression of emotions that deviate from official school expectations.

Faced with these challenges, the teachers we observed reacted in various ways. One reaction was to casually acknowledge the content of students' experiences by thanking them for sharing, indicating that what they shared was important, or by playfully bantering with them, thereby suggesting the sharing was in and of itself the end goal of the discussion. However, when sharing does not lead to reflection, SEL's effectiveness is questionable (Cameron, 2000; Nils & Rimé, 2012). A second reaction was to probe students' responses, figuring out together what made them cry or why they wished to continue or give up crying. A third reaction was to emphasize and generalize certain answers, thereby endorsing these answers as the teacher's and school's official position. Finally, in some cases, the teachers held back and chose not to discuss sensitive issues such as domestic or school violence.

SEL's cultural assumptions reflected in the classroom discussions

We found the *white, middle-class cultural code*, critically identified with SEL (Hoffman, 2009), conflicted with many students' cultural codes. For example, the SEL literature emphasizes inclusiveness (Wilce & Fenigsen,

2016). From this perspective, crying is encouraged. For Yotam, however, crying entailed internalizing bad things others had said about him, which gave him a solid reason to refrain from crying (see also Gillies' (2011) discussion of anger). Yotam was strong enough to insist on his perspective, and the classroom culture allowed him to take a critical stance on the teacher's position. In other instances, students may learn that their emotional code is inadequate, even when it serves important goals in their lives. This case thus serves as additional support for culturally relevant SEL (Mahfouz & Anthony-Stevens, 2020).

Our findings indicated *gender-based assumptions* can interact with classroom emotional dialogues. The conception that 'boys don't cry' was present in the classroom discussions and was even expressed directly. However, many boys actually reported having cried, and some even reported crying in stereotypically 'feminine' contexts, such as the birth of good friend's baby brother. The findings thus demonstrate that the classroom reality produces diverse manifestations of the relationship between gender, age, and the way emotions are talked about. Gender was also evident in the way Miriam constructed Liron's emotional state after he was attacked by his brother, calling it anger (a stereotypically masculine emotion), not sadness or helplessness.

We found the teachers were guided by *hegemonic positivity* (Stearns, 2017, 2018), in that they avoided talk about negative experiences and emotions and attempted to (re)interpret these as positive or neutral events or feelings. This phenomenon was manifested in several ways. First, a teacher's response to a student's story about domestic violence, while aligned with the SEL agenda of focusing on students' emotional responses, did not touch on some disturbing aspects of his story - his brother fighting with his mother over money and then choking the student for interfering. Second, in an instance of teacher-pupil miscommunication, a student's description of crying as 'asking for *tsumi*', a slang phrase that indicates pitifully asking for 'socially undeserved attention', was reframed by the teacher as 'asking for *tsumet lev*', a neutral phrase meaning 'asking for attention'.

The contradiction between hegemonic positivity and inclusiveness was reconciled by the general insistence that crying is essentially good. Teachers and students repeatedly addressed crying as desired using two main arguments: we also cry because of joy, and by crying, we 'let things out'. This may indicate a broader trend to affirm all emotions; if emotional states which initially seem bad are ultimately deemed positive, then naturally we need to accept and include them.

When hegemonic positivity and inclusiveness were disregarded, the teacher took a negative position on a student's stance (Osnat and Anat). This generated a classroom discussion in which students jointly inquired into the social meanings of crying. This finding suggests SEL could benefit from taking into consideration the pedagogic potential of encouraging conflicting voices when discussing emotions in the classroom (Authors, 2013; Authors, 2016).

Conclusion

Miriam and Osnat are both highly dedicated and experienced teachers who care deeply about their pupils. Why didn't Miriam develop the discussion on Liron's story of domestic violence (much like the teachers documented by previous ethnographers, such as Coe & Nastasi, 2006; Gillies, 2011; Stearns, 2017)? Why did Osnat miscommunicate with her students and transform *tsumi* into *tsumet-lev*?

Classroom discussions, particularly discussions in which pupils express original and unexpected ideas, complicate teaching. They increase uncertainty as the students' thoughts and ideas are expressed in them, not just the teacher's (Cohen, 2011). In emotional dialogue, which aims to discuss students' emotional codes, it is not only students' thoughts and ideas but also the content itself that is determined by students. In these discussions, almost any topic can emerge. The study shows that emotional dialogue requires teachers to facilitate extremely challenging discussions while encouraging students to share, supporting them when they share difficult stories, and defending them from exposure to criticism, threats to their status, and other social implications. To exploit the full potential of discussions, teachers also need to identify when students express emotional codes that differ from the teacher's and to encourage these expressions.

Overall, the findings indicate that integrating SEL into the 'regular' curriculum can enhance it (Collaborative for Academic, Social, and Emotional Learning, 2017. p. 2). They also shed light on some of SEL's blind spots and suggest that while SEL may enhance language arts, language arts instructional methods may also enhance SEL.

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Locating as a Temporally-oriented Practice for Noticing Data for Improvement

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Abstract: This study examines how practitioners look at and make sense of improvement data through the lens of *noticing*. Conceptualizing noticing as a practice performed through talk, we examined data conversations in a teacher preparation networked improvement community and found that practitioners engaged in the noticing practice of *locating* data. In particular, we found that practitioners' noticing practice of locating was shaped by their temporal orientations, where attention to past, present, and/or future guided where and how they placed data within their own contexts and settings. We also found that practitioners located data either under their own or others' purviews or within the experiences of their students. One contribution theorizing noticing as a practice and applying noticing to improvement data as a material resource. Attending to how practitioners *notice* data can generate insight into the kinds of noticing practices that produce productive insight from improvement data.

Introduction

Networked improvement communities bring practitioners together around shared problems of practice to generate solutions that are usable in local contexts. In the context of improvement, the collection and analysis of data serves an important role. Unlike data for research that seeks to answer questions to advance a scholarly knowledge base, data for improvement intends to develop usable measures that provide real-time feedback that enable practitioners to take action (Bryk et al., 2015; Shah, 2019). When using data for improvement, the goal is to create a small number of measures that can be collected frequently and shared in data displays to allow the network to examine if it is improving over time and enable decisions to be made about how to improve. We focus on data use for improvement because of the increased interest in education research to examine how practitioners (e.g. leaders of schools, districts, and other educational organizations) can engage in systematic inquiry into the performance of their systems (Coburn & Stein, 2010; Datnow & Park, 2014). While data plays a central role in the improvement process and has emerged as a tool for facilitating improvement, we know little about how practitioners look at and make sense of data in the context of improvement efforts. In this study, we seek to understand how practitioners use data for improvement by conceptualizing the sensemaking of data as being expressed through *noticing practices.* The construct of noticing has been taken up to understand how teacher educators attend to and make sense of material resources (Amador, 2021; Kazemi et al., 2010). Traditionally, noticing has been taken up as a cognitive construct to examine how teachers look at and make sense of classroom video data (Sherin & Russ, 2015). We bring a noticing lens to help us understand how practitioners use improvement data, a different kind of material resource than classroom video. Additionally, we conceptualize noticing as a *practice* that is performed through action, of which talk is one kind. By examining practitioners' noticing *practice*, we focus our study on *how* practitioners engage with data, as opposed to *what* practitioners notice about data.

Our study takes place in the context of a teacher preparation networked improvement community. We study data use for improvement in this context for a few reasons. First, research in teacher education is often isolated to one course, in one context, limiting the field's ability to make progress in understanding whether and how particular pedagogies of teacher preparation prepare candidates for teaching (Cochran-Smith et al., 2015). In addition, current measures of teacher education are often used to make summative evaluations of program quality, such as meeting state credentialing or accreditation requirements (Bastian, 2018; Peck & McDonald, 2013). Such measures do not capture the process by which teacher education programs are designed over time to prepare candidates on particular aims.. Therefore, we know very little about how the organization of a program and the sequence of coursework and field experiences prepare candidates to learn the practice of teaching.

Though there is limited research on teacher education program data use, the limited body of work shows promise for using data to improve. Prior research on data use in teacher preparation shows how teacher education program stakeholders can use summative data, namely teaching performance assessments, to generate insight into program quality. For example, Peck and McDonald (2013) highlight how one program successfully used these summative data to learn about program quality via teacher education program staff's participation in scoring their candidates' teaching performance assessment portfolios. Further, Davis and Peck (2020), examined the various *organizational* practices that teacher education programs engaged in that enabled regular and productive data

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conversations. The authors found that programs that were successful in using data for program improvement held regular meeting times to discuss data and integrated data conversations into existing routines. While this line of research offers insight into the organization of data use conversations, questions remain about how teacher educators look at and make sense of data - what do they focus on, how do they engage with data, and how does their engagement with data inform improvement efforts. In this paper, we begin to explore these questions by illuminating teacher educators' *noticing practices* to understand *how* teacher educators look at and make sense of improvement data. To do this, we focus on one noticing practice that emerged as a dominant practice in our analysis: the noticing practice of *locating.* We illuminate how studying this particular noticing practice a) enabled teacher educators to make sense of data, and b) revealed the different places they located data.

Theoretical Framework

We draw on two broad lines of research to frame our inquiry into how teacher educators work with and make sense of data: noticing and practice theory. Together, these bodies of literature situate teacher educators' data use as a practice they enact to both attend to and reason about the problem of practice and the enactment of solutions. We elaborate on each framework below.

The construct of noticing captures what educators attend to, how they understand what they see, and the broad range of decisions they consider that inform the actions they take in practice (see Blomeke et al., 2015). In the context of teaching, researchers have sought to understand the nature of teacher noticing and how it can be developed to support more responsive, equitable instructional practice (Sherin et al., 2010; Schack et al., 2017). As this work has developed, researchers have argued for the active nature of teacher noticing. For example, van Es and Sherin (2021) propose a framework that defines teachers' noticing as three interrelated actions teachers take to gain deeper insight into student thinking in the context of classroom instruction. This is consistent with others who explain that noticing is driven by the activity system of which teachers are a part, where teachers are attending to and making sense of phenomena that is guiding their decision-making and thus provides new experiences for noticing (Erickson, 2011; Hand, 2012). Together, this line of research suggests that noticing is not passively observing, but rather, entails actively seeking out information and trying to understand the phenomenon under one's purview. We extend this research to propose that noticing is a practice that is being performed moment to moment through action, primarily discursive practices. Rather than conceptualizing noticing as a cognitive process, we position noticing as an action that is shaped by activity systems and in turn (re)shapes those activity systems.

To understand noticing as a practice, we draw on practice theory. Practice theory conceptualizes practice as simultaneously situated and situating action, where actions produce context and context constrains and enables action (Feldman & Orlikowski, 2011). We used practice theory to see how teacher educators performed noticing of improvement data in data conversations through talk. In our examination of how teacher educators looked at improvement data, the practice of *locating* emerged, where teacher educators placed data in temporally diverse ways. To understand this temporality in teacher educators' locating of data, we turned to Emirbayer and Mische's (1998) conception of agency to understand how teacher educators were *temporally oriented* as they engaged in locating data. Emirbayer and Mische view agency as a "process of social engagement" that is informed by orientations to the past, present, and future (p. 963). For Emirbayer and Mische, actions and the capacity to act are simultaneously influenced by past, present, and future, where actors may be more or less oriented to one over others at any given time. This view of agency helped us understand and see the varied ways temporality shaped teacher educators' data-locating practice.

Study Context and Research Methods

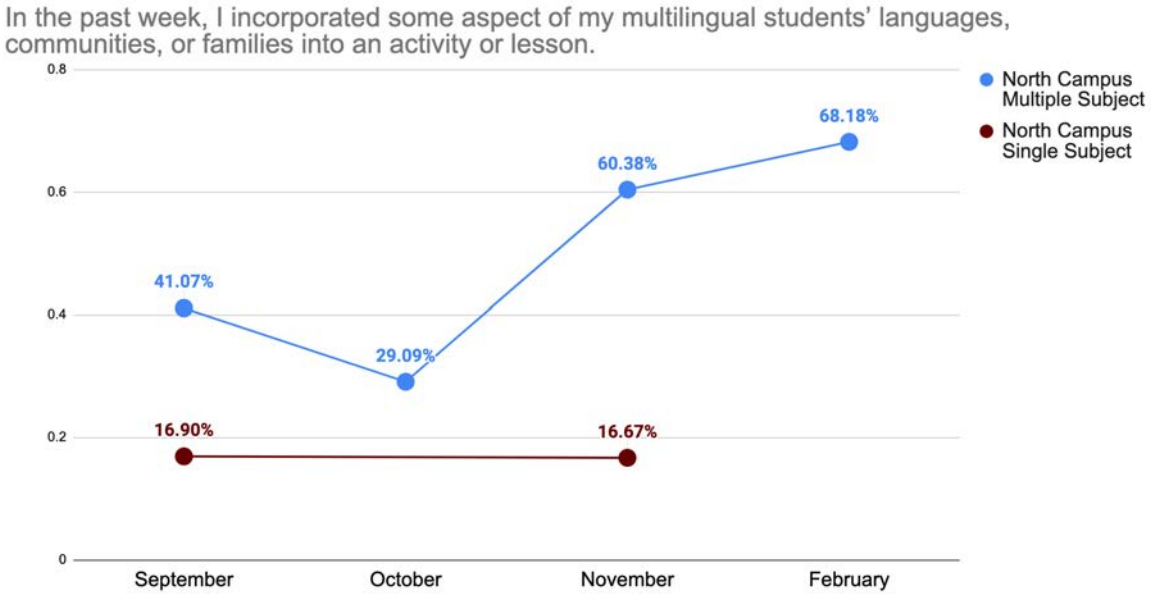
The study took place in the context of a broader research effort to understand the design and improvement of teacher education (cterin.ucop.edu). We developed a networked improvement community (NIC) consisting of eight teacher education programs, who are all part of a larger university system. The directors of these programs come together twice a year to share efforts to respond to state-wide policy mandates, to discuss local problems of practice and seek out support and advice on these issues, and to develop strategies to advocate for support for teacher preparation at their local campuses, across the university system, and within the state legislature. Because of their shared commitment to understanding and improving teacher preparation, this group became the site for launching a NIC.

The improvement project that is the focus of the study includes nine campuses in the NIC who collectively identified the preparation of candidates to support multilingual learners as the shared problem of practice (see Sandoval & van Es, 2021 for a description of launching the NIC). The measurement system the NIC developed included a survey consisting of 15 items that were both quantitative and qualitative in nature. These items asked questions about whether candidates learned about their multilingual students' backgrounds; whether

candidates considered multilingual students' experiences and backgrounds in their instruction; and whether candidates navigated school systems to advocate for their multilingual students. The network established a routine for making sense of these data across the network and within campuses. This routine included teacher educators administering the data to teacher candidates in their program coursework; improvement facilitators generating data displays from the data, typically in the form of line charts that showed the percent of candidates who said they engaged in particular activities in their placements (see Figure 1); and having teacher educators review and reflect on the displays.

Figure 1

Example of improvement data display



Data consist of audio and video recordings of data conversations with teacher educators. Additionally, data includes artifacts that were generated for and from these conversations, such as data displays, spreadsheets where data were stored and manipulated, drafts of and notes on the survey, and our memos about these data conversations that we generated in the moment. For this analysis, we selected six data conversations across five different teacher preparation programs and four different campuses over three academic years. Collectively, 12 teacher educators participated in these data conversations. We chose these six data conversations from the 17 data conversations we conducted in this network because they represented a variety of campuses, programs, and moments in time.

Data analysis was qualitative in nature. Informed by interaction analysis methodology (Jordan & Henderson, 1995) and research on noticing (van Es & Sherin, 2008; Sherin et al., 2011), we started by having the three authors collectively analyze one data conversation together, where we each highlighted what teacher educators noted in the data - what they thought was interesting or noteworthy in the data displays and in candidates' qualitative responses - as well as how they interpreted what they saw. As we reviewed the data, we observed that the teacher educators were engaging with the data displays in different ways, such as making requests to compare the displays to ones they viewed previously and talking with each other about how the displays reflected what was happening in their programs at different points in time. We then added an additional focus for our analysis that included capturing how teacher educators interacted with the data. We then viewed a second data conversation together, each capturing what teacher educators highlighted as noteworthy, how they reasoned about these highlighted elements of the data and how they interacted with each other and with the data. We each generated analytic memos that captured the noteworthy ways they engaged with the data and summarized key observations and insights they generated from the analysis of data. We then compared our individual memos and discussed any discrepancies in our analyses. Using this same process, we each analyzed one additional data conversation—with the exception of the first author, who analyzed two conversations—along the three broad categories, generating analytic memos for each one. We then conducted a cross case discussion, among all the conversations we analyzed. At this point, we identified the practice of locating as something that all the teacher educators were doing as they

interacted with the data. In the final round of analysis, we returned to the data to generate evidence for locating and to characterize the various ways teachers engaged in this noticing practice in data conversations. We now turn to present our findings.

Findings

Examining teacher educators' noticing practices revealed that teacher educators engaged in the practice of *locating.* Locating refers to how teacher educators' situated improvement data within a range of contexts to make sense of it. TEs located improvement data within their own program and within their own or others' purview. This practice of locating improvement data within varied contexts was also influenced by teacher educators' varied temporal orientations, where some TEs were more oriented towards the past while others were more oriented towards the future or present.

We begin by describing how teacher educators located improvement data within their teacher preparation programs, such as program structures and activities in which teacher candidates engaged. We surface a series of exchanges in February 2020 among teacher educators at a teacher preparation program around improvement data from an item that read: "In the past week, I incorporated some aspect of my multilingual students' languages, communities, or families into an activity or lesson." The data display had shown that 29 percent of candidates had responded affirmatively ("Yes, in my fieldwork" or "Yes, in my coursework and fieldwork") in October 2019; 60 percent responded affirmatively in November 2019; and 68 percent responded affirmatively in February 2020. The facilitator prompted teacher educators about the increase:

> Facilitator: I'm curious what you all think, because it seems to be—it went up to 60 percent. It went from 29 to 60 percent, which is a huge jump, and then it went to 68 percent.
>
> Oscar: They're also taking two language courses. During that time during the fall, they're taking the Language for the Chicano Child [course]. And then in the winter quarter, they're taking a course on [English Language Development].
>
> Rachel: Well, and then for us, there also may have been the pulse-off thing going on. So if it was given in October in the second week of a pulse-off, then anyone who was pulsing off would say no. If given in the first week of a pulse-off, those people would have been in their classrooms the prior week. This has to do with "in the past week" language. So just "the past week" part could account for some of that difference as well.

Both Rachel and Oscar located the data within what program activities and structures candidates were experiencing as they completed the survey, evidence for what we argue is a pronounced orientation to the past. For example, when asked about the changes in data from October to November and February, Rachel points to the "pulse-off" program structure; TEs would later explain that "pulse-off" referred to a routine that occurred throughout the winter and spring quarters where candidates worked in their student-teaching placements for two weeks before taking a two-week break. Rachel explained how candidates may not have had opportunities to incorporate multilingual students' families, communities, or languages into an activity or lesson if they were "pulsing-off," or taking a two-week break from their student-teaching placement at the time the survey was administered. Rachel's locating of data was influenced by her orientation to past program structures, evidenced by her recollection of what candidates were experiencing at the time that may have influenced the data.

TEs' locating of improvement data within program structures and activities were not always influenced by an orientation to the past, however. TEs also located data within program activities and structures in ways that were influenced by a closer attention to the present and future. During the same meeting, Oscar suggested adding follow-up questions to the survey to gain insight into how candidates responded relative to particular program structures, while another TE in the room, Maria, built on Oscar's suggestion.

> Oscar: Or even at the end of this, like, [can we ask a] follow up that shows the graph and ask them, to what to what do you attribute this growth in your opinion? They can say I attribute it to Lisa's class. And we can kind of see how many folks attribute it to Lisa's class. How many folks attributed it to their resident teacher?
>
> Maria: Could it be a menu? Like, coursework, and then we can list the classes? Or resident teachers, and we can list the supervisors?

> Oscar: Or, you know, we can call it like [student-teaching placement]? Your classes? I don't know.

Oscar and Maria located the data within program structures and activities—in this case, coursework, resident teachers, and student-teaching placements—but with more of an orientation to present and future than past as was surfaced in the previous exchanges. This time, Oscar and Maria were *imagining* how candidates might respond and generating ideas for new follow-up items to understand what program structures were influencing how they might respond. We note that, in alignment with Emirbayer and Mische (1998), Oscar and Maria's exchanges were at once temporally oriented to the past, present, and future. However, we argue that their exchanges are evidence of a more resonant orientation to a) the future, where TEs are imagining the possibilities for candidates' responses, and b) the present, where TEs are generating ideas for items that can be added to the survey to gain insight into candidates' responses. In this meeting, TEs engaged in the practice of locating primarily to situate data within program activities, and their temporal orientation shaped how they made sense of data and the ways in which they responded to data. How TEs located data within program activities and structures changed drastically based on whether they were oriented more towards past, present, or future. In this case, TEs moved from finding explanations for why improvement data looked the way they do to ideating new items to gather more information about improvement data.

We turn to describe how TEs located data within their own or others' purview, situating improvement data as someone's responsibility to look at and respond. We argue that this particular way of locating was also influenced by TEs' orientations to past, present, and future. We illustrate this first by examining segments from a data conversation with Alicia, a teacher educator primarily responsible for leading the single-subject program at her campus. During this conversation, Alicia located the data under her own purview, viewing data as something she was responsible for and could control. In April of 2021, Alicia reviewed improvement data and noted that 45 percent of candidates responded affirmatively to the item "In the past week, I incorporated some aspect of my multilingual students' languages, communities, or families into an activity or lesson," remarking that she "expected more" candidates to respond affirmatively. Following this remark, Acacia began to generate ideas for how she wanted to respond to the data and landed on changing a form teacher candidates are required to use and complete when preparing for observations from supervisors.

> I got this thing where I'm just like… the long term goals are just not working with me. Lately, I've been thinking, okay, Alicia. What can you do now? Right, like I'm thinking of like immediate changes… It doesn't have to be voted on by the steering committee. We don't have to analyze all this data. Like I could just do it now, right? And so, because they have 12 observations, this is something that I could change. I can add, you know something about, "How do you incorporate? Like, what was the question? I can add, "I am incorporating some aspect of my multilingual students' languages, communities, or families by doing the following."

Alicia's comment that the "long term goals are just not working with me" and that she asked herself what she can "do now" suggest that Alicia's temporal orientation foregrounds the present by locating the improvement data as something she is capable of acting on and responding to "immediately." Her focus on "something that [she] could change" was evidence that she located improvement data by placing it under her purview as something to which she ought to respond. We also argue that Alicia's orientation to the future and past were simultaneously influencing how she located improvement data. Alicia's comment that changes do not "have to be voted on by the steering committee," and that she could make these changes immediately suggest that Alicia was attending to the *future* by imagining the trajectory of a "change" would be, while drawing on her *past* experiences with the process of making changes in the program. While Alicia was at once simultaneously oriented towards the past, present, and future, we viewed her comment as having a tone that was more aligned with a present orientation, with an emphasis on making a decision about what she can do immediately.

We contrast this noticing practice of locating data within one's own purview with an instance where a teacher educator located improvement data under someone else's purview. We surface a data conversation that occurred in January 2019 with Janice, a teacher educator in the multiple-subject program at Alicia's campus. We highlight here how Janice located the data as being under someone else's purview, primarily because, at the moment, Janice was teaching a class on teacher inquiry. During this data conversation, the facilitator first showed Janice descriptive info about how many candidates responded and how long it took them to complete the survey. The facilitator then asked Janice to review the data displays. Janice reviewed and commented on each display. Halfway through, Janice reviewed an item in the survey that read, "In the past week, I reflected on how schools enforce the use of Standard English." Teacher candidates were asked to choose one of four responses: "Yes, in

my program coursework," "Yes, in my fieldwork," "Yes, in my program coursework and fieldwork," or "No." Janice was presented with a bar chart that displayed that twenty-one of the 53 candidates who responded answered "No," one candidate responded "Yes, in my program coursework," 23 candidates responded "Yes, in my fieldwork," and eight candidates responded "Yes, in both my coursework and fieldwork." After pausing to review these displays, Janice responded:

> Janice: I keep going back and forth with these, like, I'm wondering like in this middle one here, I reflected on how schools enforce the use of standard English. Why are some things... do we do it [in my class]? Because that would fall into a particular class. I don't see myself doing that in [my inquiry class] necessarily. Like, only if it was a discussion. Like I wouldn't necessarily... like I see that as…
>
> Facilitator: Like, really specialized?
>
> Janice: Yeah, like it wouldn't necessarily fit in my content. I can see there are other courses that it would totally fit into, right.
>
> Facilitator: This seems like you're saying… like oh, that actually is sort of course dependent, right. That's not something that we necessarily have to talk about throughout. Whereas some of these are important to sort of bring up sort of—
>
> Janice: Yeah, or if it's different. Schools enforce the use of standard English—so I could see that. Well. I guess I'm having a harder time of how I would connect to that in [my inquiry class], but maybe because I'm just thinking about it from that lens. But having taught math methods, I think that's a huge one that we would talk about.

In these exchanges, Janice is locating improvement data as something that does not exist under her purview given that her class is focused on inquiry. Janice's comment that she did not "see myself doing that in [my inquiry class]" illustrates how she located improvement data as something over which she had no control. For Janice, data from this item is relevant to "other courses" and not something she would talk about in her course. We viewed these exchanges as being influenced by Janice's pronounced orientation to the past, drawing on her past experiences of what her class does and does not emphasize. By orienting to how her class on inquiry has been conducted, Janice is locating data on candidates' reflection on the enforcement of Standard English outside of her purview. While Janice is locating specific improvement data outside of her own purview, we are not making the claim that Janice is absolving herself of responsibility for the data broadly. In these exchanges, Janice mentions that the topic of enforcing the use of Standard English would be a "huge" point of discussion in her teacher preparation program course on math methods. Additionally, in prior exchanges during this meeting, Janice reflected back on whether she led any activities related to the items and wondered why she did or did not do so, indicating she viewed improvement data as something for which she holds some responsibility. What we argue, instead, is that TEs engaging in the noticing practice of locating improvement data served to place data within some people's purview at particular times, and thus shaped how they looked at and responded to improvement data.

Our findings illuminate how teacher educators performed noticing of improvement data and focused on one specific noticing practice that emerged as prominent as TEs looked at improvement data: locating. Teacher educators engaged in the practice of noticing in a range of ways, namely locating improvement data within program structures and activities and locating data under some teacher educator's purview and outside of others' purview. Additionally, we argue that the practice of locating data was influenced by the temporal orientations of teacher educators, where orientations to the past, present, and future shaped where and how teacher educators located data and what teacher educators did once they located data. Having illuminated how TEs located data and how that was influenced by TEs' orientation to past, present, and future, we turn to discuss implications for teacher preparation and improvement data use.

Discussion and Conclusion

This study is significant in three ways. First, our study stretches conceptualizations of noticing by viewing it as a practice that is performed through discursive moves and in relation to artifacts under one's purview. Second, we contend that examining how practitioners *notice* data can enable those leading and studying improvement science-driven efforts to examine how data conversations can be led to engage in noticing practices that are productive

for doing improvement. Finally, our study examines the use of data for improvement in teacher preparation, a field where data use, and improvement data use in particular, are not well-understood.

Our findings build on prior research to propose that noticing is not only a cognitive process, but also a practice that is enacted as educators work with and analyze artifacts of practice. Elsewhere, van Es and Sherin (2021) describe how teachers actively work with students' ideas to shape interactions in order to gain deeper insight into students' mathematical thinking. In doing so, they position noticing as a process that is mediated through interaction in classroom activity. Here, we extend this research to conceptualize noticing as a practice that is performed, through talk, as teacher educators interact with artifacts of practice, in this case, data displays. By characterizing the ways teacher educators enact *locating* we see that noticing not only entails what and how individuals and communities attend to and reason representations of practices (e.g. video, student work) but also involves how individuals and communities interact with these artifacts in order to attend to and understand their meaning. By shifting our lens to how teacher educators engage with artifacts, we begin to expand theory of construct of noticing in educational contexts.

We also contribute to improvement-focused research by examining how practitioners make sense of and use improvement data. Although there exists numerous studies examining practitioners' data use and sensemaking (e.g., Datnow & Hubbard, 2015; Horn et al., 2015), our study focuses on how practitioners use data designed specifically for continuous improvement and situated within an improvement effort. Because improvement data differ from data for research or accountability (Bryk et al., 2015), we argue that understanding how practitioners make sense of improvement data is critical for enabling productive data conversations. Unpacking the noticing practice of locating helped to unveil how and where practitioners place data temporally and specific to their own contexts and settings. Understanding how teacher educators located data helped us to see that improvement data were enabling particular acts of locating. For example, for some teacher educators, reviewing improvement data enabled them to locate the data as being something for which they are responsible for, while enabling other teacher educators to locate data as someone else's responsibility. We argue that attending to the varied performances of locating can help those leading improvement efforts design data conversation activities and protocols that enable certain kinds of locating.

Finally, our study adds to a small but growing body of research on data use in teacher preparation. To date, very few studies have examined the use and sensemaking of data in the context of teacher preparation. Those that do examine data use in teacher preparation focus on how teacher preparation programs can organize themselves to enable the collection and use of data for program improvement (e.g., Davis & Peck, 2020). Our study gets inside data conversations to reveal how teacher educators engaged in the noticing practice of locating to situate improvement data within program activities, coursework, student-teaching placements, and instruction. Unveiling the varied ways that teacher educators located improvement data help reveal teacher educators' conjectures about what program activities are pertinent to improvement efforts. Additionally, understanding how teacher educators make sense of improvement data can help to conceptualize efforts to make improvement data more useful relative to specific improvement efforts.

We conclude by arguing for closer examinations of how practitioners notice improvement data. We argue that doing so can enable those leading improvement efforts to examine how they organize improvement data conversations to make them more productive. Taking a noticing lens enables improvement-focused researchers to get inside data conversations to inform how they organize data-driven improvement efforts. We argue that examining how data conversations unfold is a critical step in improving how improvement work is carried out.

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Modeling-based Learning in Pre-School Science: Affordances of Different Types of Children-Constructed Models

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Abstract: Despite its proven added value, Modeling-based Learning(MbL) in science is not commonly incorporated into early grades science education. Following a growing body of research on using MbL in early grades, this multi-case study seeks to provide detailed descriptions of the implementation of MbL with 3 groups of pre-K children engaged in the study of three different phenomena, taught by 3 different teachers participating in a professional development program of pre-school science education. Findings across the different cases suggest that participating pre-school children were successfully engaged in authentic MbL activities and developed several different types of models using knowledge and experiences, as well as a variety of features of both analogical and mechanistic reasoning. I use this evidence to argue that (a)different MbL tools may afford different learning opportunities; (b)pre-school children have modeling resources that can use to utilize different tools using MbL in natural ways of young children learning (e.g.,playing).

Introduction

Within the larger context of inquiry-based learning, models and the process of modeling are considered integral parts of science learning, providing students opportunities to understand and explain natural phenomena (e.g., Gilbert & Justi, 2016). The authors of the Next Generation Science Standards (NGSS Lead States, 2013) define modeling as a practice that involves the development, revision, use, and evaluation of models aiming at predicting and explaining physical phenomena (Appendix F, p. 6). Externalized through various means and representation tools, a student-generated model along with the process of its development becomes a learning tool enabling students to understand the mechanism underlying natural phenomena (Schwarz et al., 2009). This helps students develop concrete representations of their understanding of a structure, a process, or a natural system, as well as to use models as tools for engaging in scientific reasoning. Recognizing the process of modeling as a key component of learning in science, NGSS Lead States (2013) suggests that learning science should include developing an understanding of natural phenomena through the construction and refinement of models (Louca & Zacharia, 2015), as well as learning the processes of developing and refining those models (White & Frederiksen, 1998). In this respect, models and modeling are considered integral parts of science learning, primarily because they provide the means for students to represent, describe, examine, understand, predict and explain natural phenomena (e.g., Justi & Gilbert, 2016).

Theoretical framework

Modeling-based Learning (MbL) has been widely advocated as an approach that meaningfully engages students in authentic practices of learning of and about science (e.g., Louca et al, 2011; Louca & Zacharia, 2015). Despite this emphasis, only a limited number of studies have investigated MbL among K-6 students (e.g., Louca, 2021). As part of their efforts to enhance our understanding of MbL with young learners, Louca et al (2011) developed a framework for analyzing student-constructed models of natural phenomena. Aligned with other research on MbL in science (e.g., Clement, 1989; Gilbert, 1995; Glynn & Duit, 1995; Ingham & Gilbert, 1991; Penner et al, 1997; Penner, 2001), the Louca et al framework includes five elements of student-constructed models: representation of (i) the phenomenon's physical objects, (ii) the phenomenon's physical entities, (iii) the physical processes, (iv) the interactions among physical objects, entities, and processes, and (v) the accuracy of the phenomenon depiction. This framework provides a coherent system for analyzing and evaluating student-constructed models based on their structural components, it can capture the model's sophistication across the 5 structural components, and it may provide a picture of model progress over time during instruction.

Louca et al's (2011) application of their framework suggested, for example, that the students in the study tended to move from simplistic representations of physical entities to more sophisticated ones. Further, in the case of the representation of object behavior(s) elements, the findings suggested that students' initial models used more non-causal or semi-causal representations of the objects' behavior, as opposed to their final models, in which they used more causal representation of the objects' behavior. Such a framework is particularly useful for providing a picture of how students' models, as well as their learning, progress (e.g., Lehrer & Schauble, 2006; Lesh et al., 2000; Metcalf et al., 2000; Windschitl et al. 2008). Moreover, the framework reveals

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differences among different modeling tools, which could enable teachers and curriculum developers to select the more appropriate environment for the construction of models for a specific physical phenomenon.

Models as student representations of their understanding of a structure, process, or system in science, are directly related to the representation of causal, coherent explanations of the target phenomenon, that is, causal mechanisms. Ke and Schwarz (2019) explain that "developing and revising models that address the mechanism of phenomena lies at the core of the scientific endeavor" (p. 183). In this respect, successful modeling should result in models that include the underlying mechanism of the phenomenon or system. Russ et al (2008) developed a scheme of 7 components of mechanistic reasoning. Those components include (i) descriptions of the target phenomenon (what we see happening), (ii) identification of the set-up conditions that are necessary for the phenomenon to happen, (iii) identification of entities (conceptual or real objects that play a particular role in the phenomenon, (iv) identification of the entities activities, (v) identification of the entities properties, (vi) identification of the entities organization, and (vii) chaining (talking about what had happened prior to a phenomenon and what will happen). Limited research on MbL with young learners, however, has highlighted that they are able to engage in MbL, develop a number of different types of models, using various features of analogical and mechanistic reasoning (Louca, 2020).

MbL also involves analogical reasoning, namely a way of thinking that relies upon an analogy (May et al., 2006). Individuals use analogical reasoning to present commonalities between two phenomena or systems to support predictions or explanations for one of the systems while drawing information from the second system, which usually is more familiar to them. In this sense, analogical reasoning is an important ingredient for causal and scientific thinking because it supports the transfer of knowledge from a well-known or better-known phenomenon or system to a less well-known one. For example, in an attempt to explain how the heart works, individuals may use as an analogy a pump. In this view, expert mechanistic reasoning (Ke & Schwarz, 2019; Russ et al., 2008) involves the generation, use, and evaluation of analogies (May et al, 2006) because analogies can be valuable tools for constructing one's own understanding in a variety of contexts. Unlike most of the research about analogies (focused almost exclusively on their pedagogical value in curriculum materials and teacher explanations for promoting conceptual change in students (May et al, 2006)), we are interested in students' abilities for analogical reasoning that includes (i) the generation of analogies (that includes a target case (unknown), a base case (known) and a relation that maps elements from one case to the other), (ii) the evaluation of the validity of an analogy and subsequent refinement (that includes identification of the key features of an analogy and its limitations), (iii) the use of analogies to create new knowledge by making new inferences about the target case and creating abstract generalizations and (iv) the use of analogies to communicate ideas in science to others (Clement, 1998; May et al, 2006).

Purpose

This is a qualitative multi-case research study seeking to provide detailed descriptions of the different ways pre-K children may engage in MbL using a variety of modeling tools and representation media as well as the types and characteristics of the models they constructed. With an emphasis on the representation of the mechanism of natural phenomena, in this study, I analyze evidence from 3 case studies to comparatively describe the different ways that pre-school children may use different modeling and representation tools while learning in science through MbL. I use this evidence to argue that (a) different modeling/representation tools may afford different learning opportunities; (b) pre-school children have modeling resources (Louca & Zacharia, 2019; Louca, 2020) that can use in order to utilize different modeling/representation tools using MbL in natural ways of young children learning (e.g., playing); and (c) educators may find it productive to choose among these tools depending on children's prior modeling experiences and the mechanism(s) to be represented.

Methods, data sources, and analyses

Following a multi-case study approach (Yin, 2017), this study involved the analysis of data from 3 different groups of pre-school children (age range: 4,5-6) in Cyprus taught by 3 different teachers. All 3 teachers participated in the same professional development (PD) program organized by the author over the duration of a school year. The cases selected for this study were the teachers' first attempt to implement an MbL-in-science unit. Teachers developed their modeling unit from scratch after they participated in PD sessions about inquiry-based learning and teaching science in preschool, and MbL in pre-school science. For the purpose of this study, all lessons (about 40-minute duration) in each case study were videotaped and transcribed for analysis. Children's work (models) was also collected for analysis. Table 1 presents an overview of the data collected.

Since this study involved children aged 5-6, I adopted the approach of drawing-based modeling as used by various researchers in the field (Ainsworth, Prain, & Tytler, 2011; Brooks, 2009) in which children use annotated drawings to represent their models. Thus, when in this study children created drawings, 3-D structures

or used gestural/bodily representations as their representations of the phenomenon under study (Gilbert, 2004), they also accompanied their models with oral descriptions or annotations of their model.

Table 1
Overview of data collection.

Case	Number of children	Number of meetings	Rounds of MbL cycles	Types of model representation		
				Paper & Pencil	3-D structure	Physical representation
Case 1. Plant parts & functions	20	5	4	X	X	
Case 2. Solution of substances in water	18	3	2	X		
Case 3. Shadow formation	25	5	3	X		X

Modeling discourse Analysis: Derived from the videos, transcripts of student conversations served as the primary source of data. The analysis of modeling discourse builds on analyses of children's conversations in science (e.g., Ball, 1993; Gallas, 1995) focusing on the interest of the science education community in classroom discourse (e.g., Kurth et al., 2002; van Zee et al., 2001). This analysis uses transcribed children's conversations as a gateway to children thinking and learning experiences (Edwards & Mercer, 1995). From the videos, I selected and transcribed all conversations that included children's presentations and discussions of their models. These discourse data were coded along with the artifact data (see below) using a coding scheme developed in a previous study (Louca et al, 2011), which codes student talk for: physical objects, physical entities, physical processes, and physical interactions. Then, I used the discourse findings to develop detailed accounts of the context and the content of the modeling conversation describing the student contributions towards MbL. Lastly, I also carried out a coding in terms of the representation of the mechanism in children models and their descriptions, using the Russ et al (2008) coding scheme (see theoretical framework).

Artifact Analysis: To support the discourse analyses above, I also analyzed student-constructed models using artifact analysis adopted from Louca et al (2011). Codes from this analysis included the ways that children represented different elements in their models: physical objects, physical entities, physical processes, and physical interactions.

Findings

Below I briefly present an overview of each of the three cases and then turn into a discussion about common emerging themes from all the 3 case studies.

Case study 1: Plant parts and their functions

For the first lesson, children working in 4 groups identified similarities and differences among several wild plants they collected. In a whole classroom discussion that followed, they agreed that all their collected plants shared the same 4 parts: roots, stem, leaves, and flowers. They also identified that despite those similarities, their plants were different in the type of roots they carried, the shape and the size of their leaves, and the color, the size, and the petal shape of the flowers. In the second lesson, the teacher asked children to draw their findings in order to show them to the children of the next-door classroom. Each group chose a different part of the plants, which they drew independently and put together at the end, making a large poster (model 1) as depicted in Figure 1a. At the end of the session, children compared their poster with one of the real wild plants they collected, identifying a series of disadvantages, mostly related to the way they depicted the information they knew about all the plants into a single drawing. This, children suggested was helpful for letting others know about that information provided, but on the other hand, it was misleading in terms of what a single plant looked like. Thus, children spent lesson 3 revising their first model. Their teacher, however, proposed to work on a 3-dimensional structure as their second representation, using materials that they were familiar with (Figure 1b). This time, each child developed their own model. The comparative evaluation of their models identified a different number of limitations, this time focused on the ways they represented each part of the wild plant and the selection of the materials used for the representation of the plant's parts. In lesson 4, each child worked on a revision of their model, still using 3-dimensional materials. The lesson took place after an investigation of the process of transpiration, using experiences and collecting evidence from an experiment carried out in their schoolyard. This time, their models were substantially revised (see Figure 1c) utilizing materials for their representations that had implications for the plant part functions such as roots showing uptake of water, leaves represented in a way that implied the process of water retention and transpiration, and the stem as a vehicle for water transportation from roots to the leaves. During the evaluation of their models, children agreed that despite their models' revised representation of the plants' parts, their representations contained little information about

the process that takes place inside the plants' parts. Thus, they collectively decided to develop a new model, that would contain information about those processes (e.g., water uptake, water transportation, transpiration), and they discussed how 3-dimensional models had limitations in representing this information. Thus, during lesson 5 they decided to revert to a single, collective paper-and-pencil model, having their teacher noting in words their explanations about their drawings of the processes (Figure 1d).

Figure 1
Children's models of plant parts and their functions

1a. Model 1

1b. Example of Model 2

1c. Example of Model 3

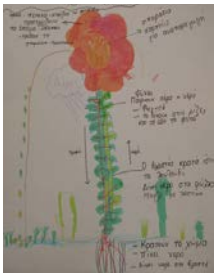
1d. Model 4

Table 2 presents artifact analysis findings regarding the models developed by children in case study 1. Findings suggest that the first two models were of similar nature, with the second model having a better representation of the physical objects involved in the phenomenon. For instance, in model 1 children included multiple representations of the same physical objects (e.g., roots), whereas in model 2 they represent only one type of root which was similar to each child's plant. In model 3 the root representation gets better with children choosing particular materials to represent the root, which they thought were related to the functions of the root, and in model 4 they were fully depicted (e.g., water is also presented) and orally discussed how the different objects involved in the phenomenon. In terms of physical entities, processes, and interactions, these were more-or-less absent in models 1 and 2, whereas in model 3 children started making connections to the physical entities, related to the fact that the representation of the physical objects took into consideration the objects functions (processes and interactions). The representation for physical entities, processes, and interactions got better in model 4, with physical processes involved in the phenomenon coded as fully represented.

Table 2
Artifact analysis of Case 1 children models

	Model 1 (one for all)			Model 2 (individual children)			Model 3 (individual children)			Model 4 (one for all)		
	L. 1*	L. 2*	L. 3*	L. 1	L. 2	L. 3	L. 1	L. 2	L. 3	L. 1	L. 2	L. 3
Physical objects	100%				100%				100%			100%
Physical entities	100%			100%			80%	20%			100%	
Physical processes	100%			100%			65%	35%				100%
Physical interactions	100%			100%			55%	45%			100%	

*Level 1 - Limited representation, *Level 2 - Partly represented, *Level 3 -Fully represented

Case study 1 children started addressing the mechanism underlying the phenomenon in model 3, possibly, possibly due to the investigation of the process of transpiration that preceded this modeling round, as well as the 3-D materials that they were using to develop their model 3. Based on the Russ et al (2008) scheme, children's 3rd model and their descriptions included descriptions of the target phenomenon and identification of entities. In their fourth model, students also discussed the identification of the entities' activities, the entities' properties, and their organization possibly due, among others, to the change of the modeling medium.

Case study 2: Solution of substances in water

The first lesson of case study 2 focused on describing how different substances behave in water in an attempt to operationally define the phenomenon: some substances dissolved in the water (e.g., instant coffee, flour), while others did not (e.g., small rocks, beans). In the second lesson, children collected data from the following experiment: In a clear glass of water, they placed a drop of brown food color at the bottom of the glass. Every 2 minutes, children recorded on a piece of paper what they observed in the glass. After collecting the observations, they gathered into the whole class setting, and the teacher displayed children's drawings in the sequence they

were recorded on the whiteboard to talk about what they had recorded, specifically focusing the discussion on the changes in the water. Through this discussion, children reached a consensus that by the last drawing, the water became brownish, although it was not as brown as the initial drop of the food color that they had recorded in their first drawing. The teacher decided that this drawing could play the role of children's first model and used it to ask for interpretations of the data collected to be incorporated in a revised model by asking: "Suppose you are in the water. What would you see happening?" Children went back to their group tables, were provided a clean sheet of paper, and asked to draw that story. This drawing was the children's model of the phenomenon under study. In the third lesson, children presented their 18 models to the rest of the class, talked about them, and discussed their differences and similarities. Figure 2 presents 3 examples of children's models that differ in the way they represented the phenomenon. The first one is a sequential approach, in which children focused on presenting in their paper-and-pencil model a sequence of drawings in an effort to represent sequential scenes of the phenomenon. A second type of model depiction included all these scenes of the phenomenon happening over time in a single drawing. A third type of depiction simply provided the final scene of the phenomenon, with the brown "pieces" randomly distributed in the water. This third type of model does not include or refer to any mechanism of the phenomenon under study. More details about this case can be found in Louca (2020). Due to time limitations, children in this case study did not work on further revisions of their models. They simply talked about the similarities and differences of their models, in an effort to identify the advantages and disadvantages of their representations.

Figure 2

Examples of representations developed by the children

2a 2b 2c

The artifact analysis of model 1 (Table 3)suggested limited representation of all components of the model - physical entities, processes, and interactions were completely absent from the model. The artifact analysis of their revised models (model 2) suggests that children presented and talked about physical objects represented in their models (e.g., the water, the dye drop, the water and the dye pieces (aka molecules)), physical entities (e.g., "pieces" being the smallest possible unit of the substance, the "pieces" having the same color properties as the substance), physical processes (e.g., molecules moving, each molecule being able to behave independently of the rest of molecules; the random movement of the colored molecules), and interactions among physical objects and physical entities. Table 3 provides an overview of the artifact analysis of the models. These findings suggest that although all of the children-constructed models included all the physical objects of the phenomenon under study, only 58% of them had fully represented the various interactions between physical objects, entities, and processes. In terms of physical entities, only 32% of the models fully included them. 68% of the models had fully represented the physical processes involved.

Based on the Russ et al (2008) mechanistic reasoning scheme, for their second model children used a number of elements of mechanistic reasoning. 82% of the models presented were accompanied by mechanistic explanations. The data suggest that level 1 representation (limited representation) for all components had a mean of 7%, level 2 (partly represented) 38%, and level 3 (fully represented) 55%. All the children provided a full description of the target phenomenon. 68% of the models also included a level 3 identification of the set-up conditions necessary for the phenomenon to take place; 66% fully identified the entities (conceptual or real objects) that played a particular role in the phenomenon. 65% of the children models included entities' activities, whereas 10% of the total models had limited representations of the entities' activities; I have found a similar picture regarding the description of the entities' properties. The last 2 components were much less addressed in children's descriptions: no fully described the identification of the entities' organization (19% level 1, and 81% level 2); only 30% of the models fully included chaining, whereas 60% of the models had chaining represented as level 2.

Table 3
Artifact analysis of Case 2 children model 2

	Model 1			Model 2		
	L. 1*	L. 2*	L. 3*	L. 1	L. 2	L. 3
Physical objects	100%					100%
Physical entities	100%				68%	32%
Physical processes	100%			10%	22%	68%
Physical interactions	100%			10%	32%	58%

*Level 1 - Limited representation, *Level 2 - Partly represented, *Level 3 -Fully represented

Case study 3: Shadow formation

Case study's 3 lesson 1 started with children investigating the conditions under which a shadow is created. To resolve this, children designed an experiment during which they found that in order to create a shadow they needed a light source, an object, and a screen to get the shadow on, in that order. In the following lesson, children worked on figuring out how to increase the size of a shadow. They experimented with materials and identified 2 different ways to change the size of a shadow. In the 3rd lesson, the teacher asked the children to develop a representation of how they thought the shadow is created, asking them to reflect on their experiences from experimenting with shadow in the last two lessons. This resulted in their first model (Figure 3a). During the comparative evaluation of their models, one common issue identified was the ways children used the light rays as a conceptual idea playing a critical role in the process of creating a shadow, as well as the characteristics of the shadow produced. These were extensively discussed and revised in most of the drawings/models 2 during lesson 4 (Figure 3b). In lesson 5, the children along with their teacher got outside their classroom, into an open-air patio, which was always windy. The teacher asked children to think about ways to represent the shadow formation, as they represented it through their previous models. Children had to think/invent ways to represent the various physical objects taking place in the phenomenon, the physical entities (such as light rays) that are involved, and the interactions between them that resulted in the physical processes of the phenomenon. This discussion resulted in their collective model 3 (figure 3c and 3d) in which some children function as the "light-production cells", holding long paper stripes as the light rays. One child was the object for creating the shadow (wearing a red piece of cloth) and a child wearing a black piece of cloth represented the shadow created. Figure 3c represents the lights-off situation and Figure 3d represents the lights-on situation.

Figure 3
Examples of representations developed by the children

3a. Model 1 3b. Model 2 3c. Model 3 3d. Model 3

Table 4
Artifact analysis of Case 1 children models

	Model 1 (individual children)			Model 2 (individual children)			Model 3 (one model for all)		
	L. 1	L. 2	L. 3	L. 1	L. 2	L. 3	L. 1	L. 2	L. 3
Physical objects		100%			100%				100%
Physical entities	40%	60%		20%	80%			100%	
Physical processes	32%	58%		16%	68%	16%		100%	
Physical interactions	16%	68%	16%		84%	16%		100%	

*Level 1 - Limited representation, *Level 2 - Partly represented, *Level 3 -Fully represented

The artifact analysis (Table 4) suggests that the representation of the physical objects was partial for Model 1 and model 2, whereas model 3 had a full representation. For the rest of the model components, there was an increase in the quality of representation from model 1 to model 2 and then to model 3, although the level 3 representations of physical processes and interactions were lost in model 3 possibly due to the change of the modeling medium and the fact that children worked together to develop a single model.

In terms of mechanistic reasoning, children in case study 3 started addressing the mechanism of the phenomenon from their model 1 by providing descriptions of the target phenomenon, identification of the set-up

conditions that are necessary for the phenomenon to happen, and identification of entities (conceptual or real objects that play a particular role in the phenomenon, even though the entities activities and properties were never fully represented. With the improvement of the representation of model components from model 1 to model 2 and then to model 3, there was an improvement in the children's description of the mechanism of the phenomenon. All the children described the target phenomenon and some identification of the set-up conditions necessary for the phenomenon to take place; they also identified the entities (conceptual or real objects) that played a particular role in the phenomenon as well as the entities' activities, and their properties. The same applies to the last 2 components of the mechanism in children's descriptions: although no full description was provided, children were able to describe the entities' organization as well as the chaining.

Discussion

My purpose in this multi-case study was to provide detailed descriptions of the different ways pre-K children may engage in MbL focusing on the variety of the modeling tools and representation media used by children. Agreeing with prior studies suggesting that pre-school children are able to represent mechanisms underlying natural phenomena (e.g., Louca, 2020), data from this study suggest that, overall, pre-school children are also able to use a variety of modeling representation media such as paper-and-pencil, 3-dimensional materials or physical/body representations to represent that mechanism. In at least 2 of the cases presented, children in the study were able to talk about the possible different ways of representing their models, engaged in a conversation about different ways' affordances in terms of their representational power, and collaboratively decide which way better suited their representational needs. Thus, I contend that some evidence suggests that children as young as pre-school may be able to move from one type of representation to another, with the possibility to invoke what Louca & Zacharia (2019) have suggested as modeling resources in order to utilize different modeling/representation tools. While I do not suggest that these children were experts in MbL, these findings may further suggest that educators may find it productive to choose among these tools, depending on children's prior modeling experiences and the types of mechanism(s) to be represented. Future research should further investigate this direction.

Towards this direction, it is also important to highlight children's abilities not only to use different modeling media, but also to choose among different modeling media, in terms of enabling them to show aspects of the mechanism underlying the phenomenon. Although this needs further investigation, I suggest, it might be related to epistemological implications of the MbL as described by Schwartz (2019) in terms of epistemic considerations within the disciplinary norms of the scientific community, which includes the nature of the knowledge provided by the model, the justification of that knowledge, its generalization and the audience of the model. Lastly, I contend that the findings I describe in this study may prove useful for educators seeking to engage pre-school children to MbL in science by helping them choose among different modeling/representation media depending on children's prior modeling experiences and the mechanism(s) to be represented.

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International Society of the Learning Sciences

Illuminating Supports for Representations of Science through Examining Modes of Reproduction

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Abstract: Knowing how to move towards scientific literacy for all requires an understanding of how science is represented within classrooms. Patterns in science representation range across a continuum from science as isolated truths to an integration of knowledge, practice, and conceptualization that creates holistic science representations. This action research case study examines science representations across this continuum within a science course for elementary education majors at a minority serving institution and how these practices of representation are supported across multiple levels of the educational system. Findings presented summarize overall course patterns and supports and give details of a pattern that leads to suggestions for reform efforts towards the goal of scientific literacy for all. The need to look beyond single-level changes is evidenced by how supports acted at a multitude of levels and how supports that sustained holistic representations of science interplayed with those that supported non-holistic representations.

Introduction

As science education works towards the goal of scientific literacy for all, it is important to examine how science is represented in classrooms, but simply characterizing science representations within a classroom is insufficient. There is a need to understand how and why science classroom practices beneficial to student learning are or are not implemented (Gardner et al., 2021). It is only by understanding how content is represented within a web of systematic supports that lasting change can be enacted (Cobb et al., 2009). This requires knowing how those representations are supported both within the classroom and across the complex, multi-leveled education system that situates the classroom.

In this study, I examine science representations within a science content course for future elementary educators studying at a minority serving institution and preparing to teach in urban schools. I ask two questions: (1) How did practices of science representation manifest in this course, and (2) how are patterns in these practices supported in a way that sustains them across the course? To do this, I use methods based on the MoRe Institutional Framework to engage in a multi-leveled analysis of the supports that sustain both ideal and non-ideal practices (Anderson & Colyvas, 2021; Zeller, Under Review).

Parts of Science

Lederman and Lederman (2020) discuss that there are three parts of science that are integral to developing scientific literacy: scientific knowledge (SK), scientific inquiry (SI), and the nature of scientific knowledge (NOSK). SK is the facts and knowledge that have resulted from science (e.g. Newton's Laws, the Big Bang Theory, and the density of water). SI is the practices of scientists, the process by which SK is created (e.g. experimentation, data analysis, and analyzing claims). NOSK is characteristics that are inherent to SK and set SK apart from opinions and unsubstantiated claims (e.g. empirically based, tied to human creativity and culture, and changing/tentative). In order for someone to be scientifically literate, they need to have an understanding of all three parts of science.

In this study, I operationalize "holistic science representation" to mean a collection of representations that showcase all three parts of science. This holistic representation is one end of a continuum, the other end of which has science as isolated facts that are taken as total truth. Along this continuum are various gradations of non-holistic representations that combine parts of science, such as SK and SI coupled together but not showing NOSK within classroom materials and activities.

It is important to note that looking at science representations in the classroom is only an initial step towards creating learning environments that develop scientific literacy. Specifically, research shows that students do not learn NOSK through simple exposure and that learning NOSK requires explicit instruction (Lederman & Abell, 2014; Marchlewicz & Wink, 2011). Looking at representations, however, lays the groundwork by looking at how NOSK is present within classrooms before specific efforts have been made to implement explicit instruction on NOSK.

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MoRe Institutional Framework

In order to expand my view beyond simply what is happening in the classroom, I utilized the MoRe Institutional Framework (Anderson & Colyvas, 2021). This framework is rooted in institutional theory, starting with Jepperson's (1991) definition of institutions as continually reproduced "social patterns" that are sustained by "self-activating social processes" (pp. 144-145). Anderson and Colyvas (2021) discuss these self-activating processes as modes of reproduction and how they manifest in observable ways at multiple levels of complex systems. They present categories of modes of reproduction that the literature shows are prominent in education, including policy, framing, stakeholder interests, learner identities, roles, assessment, routines, and professional norms. Modes of reproduction are the key to understanding why a pattern of practice continually occurs within a classroom.

What makes the MoRe Institutional Framework powerful for investigating classroom practice is looking beyond a single, idealized pattern of practice by examining modes of reproduction supporting both ideal and non-ideal practices. These practices are often conflicting. Practices do not often manifest in binaries, one practice or the other. Rather, it is better to conceptualize the range of these practices as a continuum that creates space to investigate complexity. Looking at how institutionalized patterns of practice manifest along a continuum illuminates the interplay between opposing practices. It is possible that one practice may even act to support the very practice it is trying to replace (Anderson, 2017).

Methods

This work is part of a larger study conducted within the methodologies of case study and action research (Zeller, Under Review). Case study effectively allowed me to look in depth into the patterns of practice within a single classroom and develop rich, detailed descriptions (Yin, 2006). Utilizing action research, through having the author as part of the instructional team, afforded access and insider understanding of situated processes and evidence that are not available within observational studies (Roth, 2001). Case study and action research methodologies require specific tools for data analysis. In this study, the MoRe Institutional Framework provides those methodological tools, including categories and coding strategies that were used to create the case descriptions. Within this paper, I pay attention to the particular ways that the MoRe Institutional Framework facilitates description of practices of science representation and how these practices were supported.

Context and participants

The course examined in this study was a science content course for elementary education majors during the Fall 2020 semester. The course ran a single lecture section of 72 students and three lab sub-sections synchronously online. The course is a required class for the major in elementary education, which focuses on preparing students to teach in urban schools, at a large, R1 university in the Midwestern United States. The university is classified as a minority serving institution. The course covered physics, space, and earth sciences topics and is one of two required science content courses.

The course team consisted of two co-instructors and two teaching assistants (TAs) and is traditionally taught by one professor from the physics department and one from the earth sciences department. In the semester of the study, the earth sciences instructor was the professor who had taught the class in years past, and the author, a graduate student in learning sciences with six years' experience teaching high school physics, filled the role of physics instructor of the course. For clarity within this paper, I refer to myself in the first person as a researcher and in third person as an instructor. A graduate student from the physics department was the TA for one of the lab sections while a graduate student from earth sciences was the TA for the other two sections.

The course is unique within the university as it is taught by staff from two separate departments of the College of Liberal Arts and Sciences and is a required course for undergraduate students within the College of Education. Each co-instructor earns a full course teaching credit for the course, regardless of co-instructing. It is extremely unusual for a course to be co-taught like this, especially across departments at the university. The TAs for the course are regularly hand-picked, before other appointments are made in the departments, to select graduate students who are interested in teaching and fit the role of working with education majors. One artifact of these special conditions is that the instructors have more freedom and flexibility, which leads to the instructors regularly using the course as a place for innovation.

Data collection and analysis

Data analyzed for this study included course materials as well as reflections and interviews from the course team members. The course materials included the slide decks for both lecture and lab, activity documents and poll questions used during lecture, lab assignment documents (prelab assignments, instructions, activities, and conclusion questions), and summative portfolio assessments. Interviews were semi-structured and focused on

individuals' experiences within the semester. The course team reflections were completed before each interview and used to inform some of the interview conversation. I conducted three rounds of reflection/interview with each other team member. A separate research associate conducted two rounds of reflection/interview with me, as the physics instructor. The data was initially grouped into two strands: practices data and supports data. Utilizing the structure of the MoRe Institutional Framework to illuminate the complex web of supports and patterns in the classroom, I empirically investigated both patterns of practice and modes of reproduction (Zeller, Under Review).

The analysis of the data for practices focused on patterns of science representation in the course. Codes were developed out of Lederman and Lederman's (2020) descriptions of the three parts of science. Table 1 details the codes and sub codes. Heatmap tables of codes within and across documents were used to identify patterns along the continuum between representing science as isolated facts and holistically representing SK, SI, and NOSK. I then used the coded data to build descriptions of how these patterns manifested.

Table 1

Definitions of sub-codes within each part of science

Sub-Code	***Definition***	***Example from Case***
Scientific Knowledge (SK)		
Truth Statement	Statements of how things are or what something is (e.g. scientific law, definition).	Presenting the definition of force and various types of forces.
Mechanistic Explanation	Statements of why things are the way they are (e.g. scientific theory, cause/effect).	Presenting how igneous, metamorphic, and sedimentary rocks are formed.
Applying SK	Use of knowledge within a scenario or phenomenon (e.g. solving problems).	Completing practice questions by creating energy bar charts for given scenarios.
Scientific Inquiry (SI)		
Doing Science	Students are engaged in scientific inquiry/practices.	Creating a model of the earth and sun showing the causes of eclipses and moon phases.
How to Do Science	Teaching about how to engage in scientific inquiry/practices.	Presentation of how to analyze a model, such as a motion graph.
Doing Science to Teach	Using scientific inquiry as a demonstration tool within instruction of content.	Demonstrating how to use equations for energy to understand different types of energy.
Inquiry as Pedagogy	Students doing science as learning tool (with learning outcomes other than doing/understanding inquiry).	Students building understanding of circuits through guided exploration of a simulation.
Nature of Scientific Knowledge (NOSK)		
Human Creativity	The human part of science (e.g. starting with a question, choice, creativity, collaboration, or inference making).	Labs asking students to write questions about phenomena before knowing what the outcome should be.
Empirical	Discussion of data/observations that back up scientific knowledge or the use of data/observations in scientific thinking.	Discussion of the evidence that shows that the solar system is heliocentric, not geocentric.
Changing/ Tentative	Discussing scientific knowledge changing over time, acknowledging skepticism within science, or considering multiple theories for the same phenomenon.	Discussion of the recent shift in acceptance from continental drift theory to plate tectonics theory.
Socially Embedded	Connections between science and everyday life, especially where one seems to directly affect the other, including discussing diversity in science.	Presenting the history behind the adoption of alternating current over direct current and its connection to the world's fair.
Subjective/ Theory-laden	How scientific theory shapes how we do science and how we explain scientific knowledge.	Discussing the direction of conventional current and how it is still used even through electrons move the other direction.

The analysis of the data for supports focused on the categories of modes of reproduction from Anderson and Colyvas (2021). First, the broad, category codes of policy, stakeholder interests, framing, learner identity, roles, assessment, routine, and professional norms were applied. I then reviewed how the categories occurred within each segment and developed codes for specific supports within each category.

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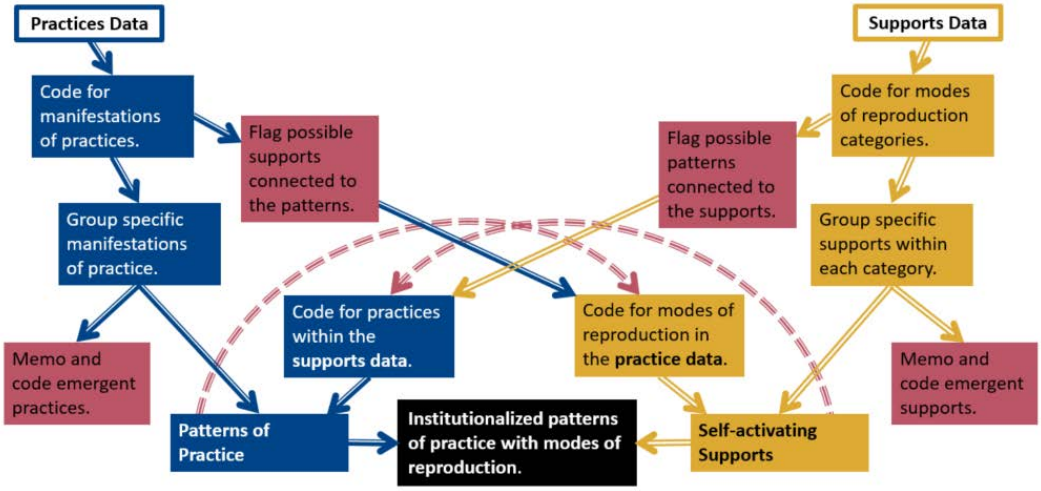
Once the practices and supports data were coded for practices and modes of reproduction, respectively, I went back and cross-coded to capture more detail. Through micro-rounds of iteration and focusing on specific practices in turn, I created groupings of modes of reproduction that supported each pattern of practice.

The flow of the analysis process is summarized in Figure 1. The blue boxes and arrows in Figure 1 show the analysis of practices data, looking for patterns across the continuum. The yellow boxes and arrows show the analysis of supports data using the categories of modes of reproduction. The pink boxes and arrows show the iteration of cross-coding that occurred between the two sets of data to form complete account of patterns and supports that were assembled into groupings of institutionalized patterns of practice with modes of reproduction.

Figure 1

Flowchart of data analysis



Findings

The data showed both overall and nuanced patterns across the continuum of science representations within the course. Figure 2 shows heatmap tables of SK, SI, and NOSK within the lecture, lab, and summative assessment for each unit, shown in order of instruction. The scales for each lecture, lab, and summative assessment indicate the frequency of each part of science within each unit. The gradient scales for lecture and lab were each normalized based on the number of meetings per unit. The included numerical scale matches the color gradients to make the data more accessible. The darkest boxes of each color scale (1.00) indicate the unit-part of science combination that had the highest frequency. White boxes (0.00) indicate coding for that the part of science did not appear within that unit.

Figure 2

Heatmap tables of science representations of SK, SI, and NOSK within lecture, labs, and summative assessments (portfolios) by unit of the course

	Lecture			Lab			Summative Assessment		
Course Unit	**SK**	**SI**	**NOSK**	**SK**	**SI**	**NOSK**	**SK**	**SI**	**NOSK**
Physics: Motion	0.78	0.59	0.03	0.45	0.41	0.19	0.82	0.73	0.09
Space	0.85	0.36	0.81	0.53	0.33	0.22	0.91	0.55	0.18
Earth: Geology	0.73	0.25	0.51	0.78	0.44	0.28	0.64	0.55	0.36
Physics: Electricity	1.00	0.32	0.21	0.55	0.19	0.16	1.00	0.27	0.18
Earth: Climate	0.45	0.26	0.30	1.00	0.47	0.34	0.64	0.36	0.36
Physics: Waves	0.53	0.18	0.00	*no lab this unit*			0.36	0.27	0.09

As evidenced in Figure 2, all three parts of science were represented within each part of the course, but NOSK was less prevalent and sometimes missing within units. Some units are strongly holistic, while others only weakly represented some parts. No units, however, appeared at the end of the continuum of representing science as isolated facts as they all included representation of both SK and SI. When looking between units, there is a distinct difference in the amount of NOSK representation within the physics units versus the earth and space units.

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The supports for the overall pattern and variation by discipline patterns are presented in Table 2, grouped by mode of reproduction category. The first pattern describes the science representation of the course in general and is provided to give the reader a brief idea about how the course was shaped as a whole. I present the details of the pattern of variation of science representation between disciplines below, exploring both how this was seen within the course and how it was supported at various levels. I first describe the patterns of practice and then the supports.

Table 2
Patterns of practice of science representations and their corresponding supports

Patterns of Practice	Support Category	Specific Supports within Categories
SK and SI representation with limited NOSK representation.	Policy	The university offered this course specifically for urban education majors. The college specified this as a lab course. State standards shaped what is included in a course for future teachers.
	Routine	The course lab structure included NOSK across whole semester.
	Stakeholder	There was interest in preparing the students to be educators.
	Identity	The students were identified as future educators.
	Assessment	The assessments used in the class created opportunity for rich inclusion of SI.
	Framing	The course team thought scientific literacy was important.
	Roles	Neither instructor had training in teaching NOSK.
Science representation variation by discipline.	Roles	The physics instructor was trained in and valued Modeling Instruction. The earth sciences instructor saw the goal of general education science courses to be building general appreciation and understanding of science.
	Framing	The physics instructor thought learning goals should focus on the integration of scientific knowledge and practices. The earth sciences teaching assistant thought of science as understanding mechanisms.
	Professional Norms	Earth and space sciences have theory shifts accessible to this course. Physics courses traditionally focus on algorithmic solving.
	Policy	The university set the contact hours for the course.

Patterns of science representation variation by discipline

Here, I give a detailed account of how science representation varied by discipline within the course structures of lecture, lab, and assessment. The earth and space science units included more NOSK than physics units. In lecture, physics units mostly presented science as just SK and SI while the earth and space units represented science more holistically through the additional inclusion of NOSK. All units included representations of SK and SI, but two of the three physics units lacked representations of NOSK in lecture. Only the electricity physics unit represented NOSK significantly, by discussing electricity within the socially-embedded context of how electricity is embedded within everyday life and the theory-laden way historical decisions (e.g. the direction of conventional current flow) affect how we interact with and study electricity. The earth and space units, in contrast, all represented NOSK. Earth and space units consistently made ties to the history of science and the human aspect of theory development. This represented science as including human creativity and being theory-laden. The space and geology units also strongly represented science as changing/tentative and empirical because they discussed historical shifts in theory: heliocentric to geocentric and continental drift to plate tectonics. Overall, the earth and space unit lectures provided more holistic science representations by including more representations of NOSK along with the SK and SI that was well represented across all units, while physics had fewer NOSK representations.

For the labs, all units, across earth, space, and physics, represented NOSK. This was directly tied to the routine lab structure. Labs that specifically represented NOSK the most were the labs on plate tectonics (in the geology unit) and climate. The plate tectonics lab repeatedly represented science as changing/tentative, theory-laden, and empirical through the discussion of the shift from continental drift theory to plate tectonic theory. The climate lab represented science as empirical through the analysis of longitudinal data sets to identify changes in

atmospheric carbon and global temperatures. Overall, the labs more consistently represented NOSK across units than lecture, but the earth and space units still had more representations than the physics units.

For the summative unit assessments, SK and SI were generally well represented but NOSK was minimally represented across units in both disciplines. The earth and space assessments still had a slightly higher representation of NOSK through socially embedded questions and empirical data sets provided for interpretation. The first two physics assessments included unspecific connections to everyday life and analysis of a provided data set, providing weaker, but still present NOSK representations. The last physics assessment, however, completely lacked representations of NOSK and included the least SK and SI of any unit assessment. This assessment covered the shortest unit and focused more on reflection on learning over the whole semester than the content of the final unit. Even with the general lack of NOSK representation across all summative assessments, the earth and space assessments still generally represented it more than the physics assessments, matching the pattern seen across lecture and lab.

Supports for science representation variation by discipline

To understand why the difference in science representations between disciplines persisted across the semester, I developed an account of the supports that reproduced this pattern. More holistic science representation in earth and space units than in physics units was supported by modes of reproduction at the individual, course, and scientific-field levels. At the individual level, the framing and roles assumed by members of the instructional team shaped the focus of various units. Disciplinary professional norms drove different practices within each unit, and course-level policy in the form of learning goals further connected course practices to professional norms.

The general lack of NOSK in physics was connected to a strong focus on SK and SI. This focus was supported at the individual level by how the physics instructor's training in Modeling Instruction (Wells et al., 1995) for high school physics permeated their teaching of this course. This pedagogy focuses on students learning through developing and using scientific models and shaped the physics instructor's framing of student learning goals. The physics instructor reflected on how Modeling Instruction shaped their instructional choices:

> I really felt strongly that, um, the tools of modeling that I've learned from Modeling Instruction and using visual models to help build conceptual understanding of the concepts is more important than 'plug and chug and get an answer'… So I tried really hard to focus on these models, using graphs and force diagrams and bar charts and different semi quantitative models, to talk about the concepts of motion force and energy (Physics Instructor, Interview 1).

This meant that the physics units, especially the motion unit, were more focused on the integration SK and SI, which is evidenced by the strong SK and SI representation across the first unit. Although Modeling Instruction does not specifically exclude NOSK, it caused the physics instructor to focus more specifically on inclusion of SI. This focus also likely contributed to the absence of socio-cultural connections because of the difficulty students had in mastering the graphical and mathematical models of motion, leaving less space for NOSK representation through rich, socially embedded context. The way the physics instructor implemented Modeling Instruction supported rich representations SK and SI, to the neglect of NOSK.

Supports for the inclusion of NOSK in earth and space units came from the individual level through the earth sciences instructor seeing their role as a general education instructor as helping students build a general appreciation and understanding of science. They talked about this in an interview:

> A lot of [the goal of the course] for me is just passing on interests in science and excitement about science and being able to share that with their students… I think [this course] is trying to cultivate interest and feeling more confident in their science skills (Earth Science Instructor, Interview 1).

This understanding of their role helped reproduce the inclusion of NOSK representation through connecting with students' interests with highly contextualized examples in the earth and space units, including the assessments. This supported socially embedded science representations across earth and space units.

The earth sciences TA's individual-level framing of science as focused on understanding the mechanistic explanations for phenomena supported inclusion of NOSK. This TA helped design the earth and space labs and therefore had more impact on those units than the physics units. They said that for lab redesign and instruction they, "wanted to communicate these mechanisms and such, and that being a big point, but the practice of actually trying to get them to understand and check-in with them as we go" (Earth Science Teaching Assistant, Interview 2). The earth sciences TA also had a background in planetary science and was a guest lecturer during the space

unit. Therefore, their framing especially reproduced the NOSK representation of science as empirical in the space unit's discussion of helio- vs. geocentrism through the focus on evidence that supports each theory.

The specific content of this course, which created the base structure for inclusion of SK, SI, and/or NOSK, was reproduced by the semi-formal policy of course learning goals. These goals, however, are tied to higher-level traditions of what is taught in introductory earth science and physics courses. Although the specific content of this course is also influenced by state-level, K-12 science teaching standards, these too are descended from the field-level traditions of Physics and Earth Sciences. The professional norms of each discipline reproduced variation in how each unit represented science. These norms include both field-knowledge development and traditions of what is included in introductory courses.

Within the earth and space units of the course, professional norms reproduced representations of NOSK through the examination of theory change and the examination of large, longitudinal data sets. The pervasive focus on theory shifts in the earth and space units was supported by professional norms at the scientific-field level, reproducing representations of science as changing/tentative. Classic introductory earth and space topics, include models of the solar system and the earth's crust. These two topics are imbued with NOSK representation because of the major historical shifts in theory related to them. This is especially true for the earth's crust since the shift from continual drift theory to plate tectonics theory happened quite recently. Science was also represented as empirical through the traditions of using large, longitudinal data sets to analyze climate change. The nature of the content traditional to earth sciences courses supported pervasive representation of NOSK.

Introductory physics courses traditionally focus on motion (including kinematics, dynamics, and energy). Within the scope of an introductory course, the theory for motion has not recently changed. Additionally, this content is often taught in an algorithmic, fact-based fashion, which focuses on computing the correct answer to a question. These traditional approaches are SK forward, neglecting the SI and NOSK opportunities. The physics instructor's framing through the lens of Modeling Instruction contributed to more representation of SI, but as previously discussed, not NOSK. Although many reforms (e.g. Modeling Instruction) try to disrupt these patterns, field-level professional norms are inherently institutionalized and taken for granted as something that just is, which makes them strong modes of reproduction.

Discussion and Implications

Examination of the findings in this study illuminates information about how holistic and non-holistic science representations are reproduced within this classroom and points towards efforts that could help reforms aiming for scientific literacy. The interplay between modes of reproduction for holistic representations and those that only reproduced inclusion of SK and SI and how these supports manifest at many levels show that reform efforts need to look beyond just what the teacher is doing, or other single-level changes.

Within the overall course findings summarized in Figure 2 and Table 2, NOSK is the part of science that was least represented and reproduced. Modes of reproduction influencing how science was represented in the course spanned levels from individual to scientific field, emphasizing the need to consider action beyond teachers. However, at the individual level, framing and role based modes of reproduction acted through the course team, emphasizing that although there is a need to consider the wider system, the instructors are still central to classroom practice.

The findings also show examples of how this course uniquely involves cross-department and college collaboration which affects what policies and professional norms reproduce classroom practices. Specifically, the freedom and flexibility within this course for instructors to innovate creates a diverse web of modes of reproduction that affect practice.

When looking at the specific example of NOSK being represented more within earth and space units than within physics units, more detailed conclusions emerge. The specific background and training of the physics instructor provided the example of a specific past reform effort, in the form of Modeling Instruction, permeating into a space other than the original intended setting based on instructor transfer. This transfer, however, was constricted by the new classroom environment, causing the instructor to focus narrowly on specific goals. In this case, the focus on integrating SI and SK meant that NOSK was not supported within the physics units, especially the motion unit.

The split between earth and space and physics units' representation of NOSK also brought to light the deep institutionalization of professional norms from the different science fields. Things that are most taken for granted can most stand in the way of reform. For example, one implication of this study is that, after the investigated semester was over, I discussed possible changes in the motion unit with the regular physics instructor of the course and we decided to cut some very traditional content in order to be able to make other content more accessible. This challenged the professional norms of introductory physics content and opened the door for changes in classroom practice.

The variation between the science disciplines also exemplifies that the specific classroom context and goals must be considered when formulating plans for implementing reforms. What comes easily in one discipline may be difficult in another. This pairs with the difficulty in transferring Modeling Instruction pedagogy between educational settings (i.e. high school physics to an undergraduate, interdisciplinary science course) to show how influential the specifics of the classroom and surrounding system are to classroom practice. This shows how important it is to use research methods, such as the ones used in this study, to deeply look at what is supporting classroom practice and understand the complexity of implementing change.

Together, the findings suggest that, in order for this course to implement reforms towards the goal of scientific literacy for all, particular attention is needed towards consistency in the representation of NOSK across disciplines. Possible actions include writing formal course goals and learning objectives that connect to NOSK, especially in the physics units by showcasing how historical work by scientists exemplifies NOSK, then examining content coverage and how this aligns with course goals. These actions would attempt to establish course-level policies that balance out the lack of higher-level policy support of NOSK inclusion and create space for challenging taken-for-granted field-level professional norms.

These findings also have important implications for wider study of the complex, interlacing web that institutionalizes practices in the classroom. The current findings provide insight into supports of science representations manifesting on the timescale of a semester, but can also inform conceptualization and investigation of issues outside of the single course or semester. Changing the unit of analysis from within one semester to looking at change across school years would provide a different view with different affordances towards wider change. What is considered unchanging or transient depends on the timescale of analysis (Lemke, 2000). Therefore, within a longer-term study, multiple snapshots of a longitudinal reform effort focusing on patterns and modes of reproduction could result in better understanding of the process of constructing and deconstructing modes of reproduction in service of lasting change.

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High School Science Education in a "Post-truth" Society: Confronting Confirmation Bias with Students and Teachers

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Abstract: Incorporating the goals of a comprehensive epistemic education into K12 curricula is increasingly critical. In this study, we worked with high school biology students and teachers to evaluate how to enact strategies to counter confirmation bias while engaging in scientific modeling. We used a video-cued method in interviews with participants and then applied the AIR model to analyze responses. Findings show that most could identify biased epistemic processes. Additionally, teachers listened to some of their students' evaluations and were surprised by what they heard. This suggests noticing students' epistemic cognition in the classroom is difficult and engaging students in video-cued discussions about reliable scientific practices around a familiar activity may allow for learners' thinking to become more visible.

Keywords: Epistemic Cognition, Metacognition, Scientific Modeling, Biology Education

Introduction

Science denialism has become increasingly prevalent, with the internet allowing for the exponential spread of misinformation on important socioscientific issues, such as vaccine safety and climate change (Sharon & Baram-Tsabari, 2020). Individuals' tendency towards *confirmation bias* is likely one important underlying cause of this worrying trend (Gorman & Gorman, 2021). One manifestation of confirmation bias is the evaluation of evidence to favor one's prior beliefs, as when evidence supporting one's beliefs is considered accurate and reliable, whereas equally relevant and sound evidence against one's beliefs is dismissed as false or erroneous (Nickerson, 1998). As a result, processing new information with an open-mind and demonstrating the ability to change a belief in light of contradictory evidence can be extremely difficult (Gorman & Gorman, 2021). Thus, the repercussions of unconfronted confirmation bias and its effects in propagating anti-science beliefs will continue to have detrimental effects on global public health and safety (Gorman & Gorman, 2021).

Given the gravity of current socioscientific issues, it is imperative that science educators improve students' abilities to critically evaluate evidence and distinguish well-justified and accurate information from false and misleading claims (Chinn et al., 2021). This involves emphasizing epistemic educational goals for students, among which, include increasing their awareness of cognitive biases, as well as helping them to develop and implement strategies that can counteract those biases (Barzilai & Chinn, 2018; Hofer, 2016). Such educational goals have emerged from research on *epistemic cognition*, which can be defined as people's ways of knowing—including cognitions and practices used to establish, critique, and use knowledge within disciplines (Greene et al., 2016). Research has revealed that teachers need support in developing the best ways to cultivate a comprehensive epistemic education given the complexity of the topic; however, we are still limited in our understanding of the best ways to design and enact such supports (Fives et al., 2017; Sandoval et al., 2016).

In this study, we investigate how students and teachers are working with well-developed modeling curricula from the perspective of their epistemic performance, specifically as it relates to confronting confirmation bias in evaluating evidence. Using a video-cued interview method (Tobin, 2019), we identified a case of confirmation bias occurring in previously collected video footage of past high school biology students engaging in a modeling unit and then asked current students and their teachers to evaluate the epistemic performance of the students in the clip. In an effort to contribute to research and design that promotes effective epistemic education in science classrooms, we addressed the following research questions: 1) How did current students and their teachers evaluate the epistemic performance of past students working with the modeling curriculum? 2) How did teachers respond and react to hearing some of their own students' evaluation of the epistemic performance exhibited in the video clip?

Supporting teachers in promoting an epistemic education

The complexity and relevance of epistemic cognition in science teaching is critical to address, yet current instructional practices tend to fall short of developing students' capacities in this way (Chinn et al., 2020; Elby et

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al., 2016). Indeed, multiple contextual factors are likely to affect teachers' abilities to focus on epistemic performance goals in the classroom, as teachers are likely to hold a multitude of goals for their students (both epistemic and non-epistemic) simultaneously (Fives et al., 2017; Buehl & Fives, 2016). Furthermore, the contextualized nature of epistemic cognition demands that teachers attend to the specific tasks and learning environment of a given activity, as well as to become proficient in teaching across various knowledge domains (e.g., biology and scientific modeling) (Sandoval, 2014). This means that teachers must be able to notice and assess their students' epistemic cognition to better understand how to support it; yet the development of such an awareness and assessment requires significant time (Fives et al., 2017).

Indeed, the best ways to support teachers in promoting a successful epistemic education have not yet been clearly defined (Muis et al., 2016). For example, more research examining the links between various aspects of teacher practice (e.g., specific instructional designs, pedagogy, student agency in the classroom) and how they can lead to successful epistemic performance when learning science is needed (Sandoval, 2014). As a start, science classrooms need to incorporate activities that allow students to engage in the real practices of scientists (Gorman & Gorman, 2021). In addition, teachers must also be able to identify and assess their students' knowledge about these scientific practices and then use this information to improve instruction (Fives et al., 2017). In the next section, we describe a pathway (situated within the context of scientific modeling in high school biology) that would allow teachers to begin investigating ways of noticing and assessing their students' epistemic cognition.

Epistemic performance within the domain of scientific modeling

To promote the goals of an epistemic education (Barzilai & Chinn, 2018) in high school science classrooms, we adopted the AIR model of epistemic cognition as a framework to evaluate learners' epistemic performance as they engaged in scientific modeling (Chinn et al., 2014). The AIR model establishes three main components of epistemic cognition as being: Aims, Ideals, and Reliable processes. Aims refer to the specific goal of inquiry, whereas Ideals are the standards or criteria that an individual uses to determine whether epistemic aims have been met. Reliable processes denote the strategies (individual or collective) that people use to successfully achieve their aims. Because this study focuses on participants evaluating how past students engaged in modeling during their science class, we emphasize identifying only the ideals and reliable processes related to this particular learning activity. Therefore, for the purposes of this study we analyze learners' *epistemic performance* in terms of the reliability of the epistemic processes used, and the appropriateness of the ideals applied, to the modeling task being evaluated. Indeed, previous research has shown that students need support in understanding both how to think like scientists and why scientific processes are reliable (Elby et al., 2016).

Table 1.
A Selection of Ideals and Reliable Processes to Promote Successful Epistemic Performance During Modeling

Epistemic Performance to Promote in the Complex Systems Modeling Curriculum	
Ideal 1 •Rigorous fit with evidence that is relevant, ample, systematic, and conclusive	
Reliable Processes (RPs)	• Multiple hypotheses. Consider multiple hypotheses (even if it is just a hypothesis and its negation). Make predictions based on these alternative hypotheses and test them together. • Multiple trials. Run multiple simulations to establish average phenomena under the same starting conditions. • Revise explanatory models when there are small or large discrepancies with evidence.
Ideal 2 • Has plausible, well-established underlying biological process (or mechanism)	
RPs	• Incorporate underlying biological processes into models to explain phenomena. • Examine interactions of elements in simulations carefully and systematically to grasp underlying processes.
Ideal 3 • Fit with prior (well-established) knowledge	
RPs	• Use previous science to evaluate and understand phenomena being modeled. • Evaluate whether ideas are consistent with well-established prior knowledge.

The AIR model can be used as a lens to examine the thinking strategies within a domain and to analyze various reasoning problems in the public sphere, such as those associated with confirmation biases (Chinn et al., 2014). As an example, biased epistemic performance could involve aiming to preserve one's prior beliefs. The biased ideals associated with this aim could include aligning beliefs with flawed or limited evidence. The biased processes associated with this ideal could then include cherry-picking data, dismissing contradictory evidence, or only seeking out supportive information. In contrast, unbiased epistemic ideals and processes could include aligning beliefs with evidence that is ample and conclusive and then using the reliable process of fairly weighing evidence on multiple sides of a question and developing arguments with thorough evidence-based reasons. This general example using the AIR model to understand how to mitigate against cognitive biases can be applied towards evaluating students' epistemic performance as it relates to the modeling curricula being studied here. Table 1 consists of a (non-exhaustive) list of ideals and reliable processes that can be applied while

engaging in scientific modeling that can lead to successful epistemic performance. This list emerged from two main sources: 1) a review of the literature on the epistemology of scientific modeling (e.g., Schwarz et al., 2009) and 2) a previously validated coding manual that emerged from the analysis of past student groups engaging in the modeling units. Next, we describe how Table 1 guided this analysis, as it includes strategies that can support an individual in learning to reason in rigorous, unbiased ways.

Methods

Context and participants

In this exploratory study we used previously collected video footage from students working with complex systems modeling curricula that combine experimentation with data analysis to generate discussion about epistemic performance with current students and their teachers. We asked students and teachers to evaluate a clip of a pair of students engaging in a modeling unit where they were investigating the effects of enzymes on the breakdown of starch to sugar (see Table 2).

Table 2

Transcript and the Research Team's Analysis of Video Clip Shown to Study Participants

Dialogue between Student A and B (regular font) with contextual descriptions of the scene (italics)	**Epistemic Processes Identified by the Research Team**
The clip begins with Student A reading the worksheet instructions aloud to partner, Student B. The students are trying to understand how varying the starting amount of substrate (starch) will affect the amount of product (sugar) produced in the absence of enzymes. **Student A:** Hypothesize: If you started with 60 starch molecules, how many sugar molecules would you expect to form? Use your graph to help make a prediction. Use the simulation to test your prediction...Group prediction I'm gonna say about like 50…50… **Student B:** 55? **Student A:** 55. Alright now we have to run it. Ready? Are you ready? *Student A then runs the simulation.* **Student B:** Why does is say hashtag? Oh wait, it says number of sugar molecules. **Student A:** *Laughing at her partner's comment. Once the simulation is finished running Student A points to the counter indicating the number of sugar molecules formed and says,* "It only produced 31!" **Student B:** That's fake. **Student A:** Can we do it again? **Student B:** Yeah. *They run the simulation a second time without speaking. The output after this run again reads 31.* **Student B:** That's so fake! **Student A:** *Laughing as speaks.* We said 55….We're doing it one more time. (*The student then runs the simulation a third time using the same starting conditions).* **Student B:** It was the same number every time, it's obviously going to be the same number. **Student A:** No, see (*pointing to the sugar output counter on the simulation)*, look, no. It's 49! This is cray. **Student B:** F-a-a-a-k-e. **Student A:** Can we do it again? **Student B:** No, just do 49. It's fine. *This student chooses to report the number that is closest to their initial prediction.* **Student A:** *Pointing to the sugar output counter in the simulation, student says,* **"**Hold on, I'm doing it one more time." *The simulation runs as in previous trials but the output from this run reads, "34".* **Student B**: The simulation result was 49! **Student A:** Relax, relax. I'm doing it one more. *And student runs the simulation with the same initial conditions for the 5th time. At the end of the run the sugar output counter reads, "43".* **Student A:** This is so inaccurate. **Student B:** It's called randomizer [sic].	• Did not appear to use prior knowledge (e.g., data from previous runs to justify their prediction) to better understand the experiment (less reliable) • Did not articulate multiple hypotheses, only considered one prediction (less reliable) • Believed contradictory evidence to be "fake" and "inaccurate"; could have been more open-minded (less reliable) • Ran multiple trials using the same starting condition (more reliable) • Could have looked to see what was going on in the simulation (e.g., did not observe how the molecules were moving and interacting during the runs) (less reliable) • Did not compute averages of data points collected, tried to cherry pick the result that matched their prediction most closely (less reliable) • Could have addressed whether their initial prediction, or overall understanding, was correct (i.e., did not try to understand why their results were different from prediction) (less reliable) • Student B eventually seemed to recognize that randomness/ stochasticity could be contributing to their results (more reliable)

While the clip in Table 2 was filmed in 2013, the unit used has remained largely unchanged since, and was therefore familiar to the participants. The clip was chosen because it demonstrated a clear case of confirmation bias. We employed a video-cued ethnographic method (Tobin, 2019) with the intention of eliciting participants' metacognition to gain contextualized insight into the learning practices they enact during modeling. This allowed us to measure aspects of their *metacognitive knowledge* (or the knowledge about how to perform an activity that will result in knowing) of the modeling task and the strategies used (Barzilai & Zohar, 2014). Table 2 also details our a priori analysis of the epistemic processes observed in the clip and whether we considered them less or more reliable. Our identification of these processes and assessment of their quality is directly aligned with the selected list of the more general ideals and reliable processes outlined in Table 1. Of the 8 processes identified, 6 were categorized as less reliable, while the remaining two were considered more reliable.

Table 3

Coding Examples Illustrating the Less and More Reliable Processes Noted in Student and Teacher Responses

RPs Observed in Clip	Coding Examples
Making Only One Prediction- Did not articulate multiple hypotheses, only made one prediction (less)	"Only one approach was considered." (Teacher Hanna, 4 Aug 2021) "Didn't consider another hypothesis." (Teacher Rachel, 4 Aug 2021)
Cherry Picking Data- Picking one specific result that matched their prediction most closely (less)	"If you're looking for a specific result, you can make the data match that. For example, as soon as they saw the result that there's 49, they went with that." (Focus Group with Cindy's students, 10 May 2021)
Dismissing Opposing Evidence- Believed contradictory evidence to be "fake" and "inaccurate"; could have been more open-minded (less)	"When they got answer that they thought didn't make sense, they freak out a little bit…not freak out, but they just kind of dismiss it in way." (Focus Group with Lindsay's students, 21 May 2021)
Not Reconsidering Mental Model- Could have addressed whether their prediction (or mental model) was correct; did not try to understand why the results were different (less)	"I think they should've thought about why they were getting 31 or whatever instead of the 55. Maybe put some thought into why it was incorrect." (Focus Group with Cindy's Students, 10 May 2021) "Students are unwilling to adjust their initial beliefs even when the same evidence arises multiple times." (Teacher, Cindy, 4 Aug 2021)
Not Observing the Interactions of Agents within the Model- Could have examined the model more closely; did not observe how the agents were interacting (less)	"I also think it would be important for them to possibly look at how the things are moving in there a little more too. Because I know sometimes in the ones we've done, we've had things disappear. We've had things bounce off and things and it might just be interesting to see if it does any of that in this." (Focus Group with Catherine's students, 13 May 2021)
Not Applying Prior Knowledge- Did not appear to use prior knowledge (e.g., data from previous runs to justify their prediction) to better understand the experiment (less)	"I don't know how they came up with the number 55 [as their prediction] at all, so I think they should've talked it over more, use more of the experiment's data." (Focus Group with Elizabeth's students, 11 May 2021) "Student makes argument that 55 starch molecules will occur, based on no evidence-based reasons (that they articulate)." (Teacher Catherine, 4 Aug 2021)
Running Multiple Trials- Ran multiple trials using the same starting conditions (more)	"I think their strategy was decent because they ran the simulation many times to see, does [sic] the numbers change." (Focus Group with Rachel's students, 15 Jun 2021)
Noting Randomness Occurs in Biological Systems- Student B eventually seemed to recognize that randomness/stochasticity could be contributing to their results (more)	"They attempt to explain the different numbers by hinting that there is a touch of randomness." (Teacher Elizabeth, 4 Aug 2021) "Well, I think they didn't understand that it was randomized at first. And then they found out that it was randomized and they were like, 'Oh, it's randomized, it's not fake.'" (Focus Group with Rachel's students, 15 Jun 2021)

In the 2020-2021 academic year, we interviewed 37 ninth grade biology students and eight of their teachers. Participation in student focus groups was voluntary, so only self-selecting students participated; however, teachers indicated that the participating students represented a broad range of students with respect to performance level. Half of the students interviewed attended private, college preparatory schools and the other half attended large suburban public schools in the north or southeastern U.S. The eight teachers were selected for this study as they represented teacher experts with respect to the modeling curricula being studied (i.e., they had implemented the curricula multiple times already and helped to facilitate other teachers' uptake of it). These teachers participated in a virtual professional development (PD) summer workshop with the larger goal of becoming design collaborators in modifying the existing curricula to better promote epistemic performance. The teachers, on average, had 10 years of teaching experience, with a range of 5–18 years at the time the workshop occurred.

Data sources and analysis

To address research question #1, students and teachers were prompted to examine and reflect on the epistemic performance demonstrated in the video clip. Student data was collected in end-of-school-year focus groups (April-July 2021). We conducted 11 semi-structured focus groups consisting of 2 to 4 students, each lasting approximately 60 minutes. As part of the interview, students were shown the video clip, asked to describe the strategies they observed the students in the clip enacting, and then asked to evaluate whether they thought these were good strategies in terms of better understanding the scientific phenomenon being modeled. Teacher data was collected as part of an activity in a summer PD workshop (August 2021). Evaluation of the video clip by teachers occurred once they had already been explicitly introduced to Ideal 1 (rigorous fit with evidence) and its associated processes (see Table 1) and were ready to begin exploring its applications in the modeling units (this occurred on Day 3 of the ten-day workshop). Once teachers viewed the clip, they responded to similar questions as the students; however, teachers first engaged in individual reflection and then participated in a large group discussion about their reflections. To address research question #2, teachers next listened to select audio clips of some of the students' responses to the clip. Teacher data regarding their responses on hearing their students' evaluations of the clip was collected via asynchronous group discussion posts on Canvas as part of the PD. In their posts, teachers were prompted to identify and react to the more—or less—reliable epistemic processes they heard their current students articulating in their evaluations.

To guide this analysis, we used the 8 epistemic process codes previously identified in relation to the video clip (see Table 3, column 1) and recorded them as being mentioned or not within any single focus group response of students or within any individual teacher response upon viewing the video clip. This list of epistemic processes related to this modeling curriculum were generated by a modified method of interaction analysis (IA) by all the authors (Jordan & Henderson, 1995). Author 1 then initially coded the student and teacher responses and then conducted interrater reliability analysis on 20% of the coded enactments with Authors 4 and 5; this returned a Cohen's kappa = 0.94. Regarding the analysis aimed at addressing research question 2, we identified and summarized the salient themes that emerged in the teachers' Canvas discussion posts as they reacted to hearing some of their own students evaluate the video clip. Here we used a constant comparative method of analysis, where the first author read the first discussion post and recorded overall emergent themes, and that information was then compared to and triangulated with each subsequent discussion post to validate that a particular response emerged from multiple teachers (Glaser, 2008).

Results

Below we first present the percent presence (scored as being noted in any of the 11 student focus groups or in any 8 teacher responses) of the focal reliable processes for students and teachers and elaborate on key ideas from their responses. Second, we include teachers' reflections upon hearing the audio clips of some of their own students responding to the video clip. In asking teachers to evaluate their current students' scientific epistemologies in this way, we gain insight into how teachers understand their level of epistemic performance.

Table 4

Presence of 8 Epistemic Processes in Student and Teacher Responses

Less and More Reliable Processes Coded As Present Within the Video Clip	Student % Presence	Teacher % Presence
Making Only One Prediction	0%	50%
Cherry Picking Data	91%	88%
Dismissing Opposing Evidence	82%	88%
Not Reconsidering Mental Model	82%	50%
Not Observing the Interaction of Agents within the Model	36%	0%
Not Applying Prior Knowledge	73%	63%
Running Multiple Trials	100%	100%
Noting Randomness Occurs in Biological Systems	27%	63%

Students' and teachers' evaluation of epistemic performance in the video clip

Table 4 shows that student groups at some point noted almost all (7 of 8) of the epistemic processes that had been used to code their responses. However, students more rarely identified several reliable processes, such as *Noting Randomness Occurs in Biological Systems* and *Making Only One Prediction.* In addition, the fact that students frequently identified the processes *Cherry Picking*, *Dismissing Opposing Evidence* and *Not Reconsidering Mental Model* demonstrates that many of them readily recognized some of the less reliable processes underlying the confirmation bias evident in the clip (although no one labeled it as such). For example, a student in Catherine's class noted that "one thing that…people do a lot is when they…want to be right and think that they're right, they

just disregard other things." Another student in Elizabeth's class pointed out that "after running it three times, they actually ran it more than three times. But instead of averaging their data, they cherry pick the one that was closest to their prediction, which is just not being a good scientist."

However, in one instance a student in Catherine's class seemed to articulate the value in the tendency to want to stick to one's original hypothesis, "I think that it shows the trust they have in their predictions and their hypothesis. It's kind of a good thing how much they trust it." To which a classmate responded, "I feel like they need to realize that…at a certain point, you have to realize that the simulation might be right, and your prediction might be wrong. And instead of…saying it's fake, or whatever, just say maybe our prediction's not quite accurate and…why is it not accurate." In this example with Catherine's students, one student indicated that trusting in your original hypothesis is a "good thing", whereas another cautioned that at some point it is important to consider that you could be wrong. In fact, most students regarded the students in the clip as displaying less reliable strategies in continuing to believe their prediction was correct despite mounting evidence.

Beyond recognizing the pitfalls of disregarding or cherry-picking data, some students pointed out that falsification of hypotheses happens often in science and is something you "shouldn't be upset about." One student in Elizabeth's class astutely noted that falsification should be discussed more explicitly in classrooms: "I think in general, more of what needs to be done in…science classrooms…is that it's fine for the data to negate your predictions. Because I think so often students are discouraged by data that disproves what they previously thought, but I think it should be more normalized." Therefore, this student not only evaluated the clip but further suggested an instructional strategy that could improve students' epistemic performance in science class. These findings show that student groups were able to articulate their metacognitive knowledge of working with the modeling units and demonstrated a solid understanding of some of the more reliable epistemic processes related to it.

Teachers' individual responses to the clip also aligned closely with the epistemic processes that the authors had previously identified (see Table 4). Teachers noted almost all the pre-identified epistemic processes (7 of 8) with high frequency (50% or greater), with the exception of *Not Observing the Interaction of Agents within the Model* (0% noted this). Also, the frequent mention of the processes *Dismissing Opposing Evidence* and *Not Reconsidering Mental Model* (88% or 7 of 8 teachers noted these) in their responses demonstrated that, like students, most teachers readily recognized the biased processes evident in the clip. Moreover, while *these* students overall demonstrated the metacognitive awareness of the need to correct for confirmation bias, many teachers (4 of 8) pointed out that while when implementing the modeling units in their classroom, they have also experienced similar situations to what they saw on the clip. For example, Linda recalled, "Doing this the first time with my students, this exact simulation, and I had a group of girls that were like in a panic, calling me over, 'it's broken, it's broken, it's not working.' And I said, 'What's broken?' They [said], 'we keep getting different numbers.' And they were so adamant it was broken, and since it was the very first time that I was doing it, it hadn't really occurred to me that they would have that immediate response." Hanna also mentioned that her students "struggled a lot with the idea of not getting the same results again and again." These responses show that current teachers are indeed noticing instances of confirmation bias during modeling. Many students seem to doubt the probabilistic nature of the simulation and whether it is "right" because they have yet to learn about the authenticity of such scientific processes firsthand. Therefore, these modeling curricula could be an important tool needed in science classrooms to redress the misconception that scientific knowledge is absolute.

Teachers' reflections on hearing students' evaluation of the video clip

After evaluating the clip, teachers then listened and reacted to some of their students' evaluation of the epistemic processes they had observed. Overall, teachers were surprised at how thoughtfully students commented on the reliability of the epistemic processes they noticed, and they noted some contextual variables (e.g., performance goals, societal pressures) that can influence students' epistemic performance. When teachers listened to a clip from Elizabeth's class, which included the observation a student made about "cherry picking" data and another that made a point about normalizing falsification in science class as described above, they mentioned being "really surprised," "astounded," and "completely blown away" at how "insightful" these students were in assessing epistemic performance. In fact, Elizabeth recognized her students' voices and described her amazement in hearing their evaluation of the clip: "One of the speakers who identified several apt practices completely threw me! She was struggling all year, was very quiet, and often seemed to lose focus. I found it very interesting that she was still able to glean some of these practices (I was pretty shocked)! This was very interesting for me to hear."

In addition to being surprised, teachers agreed that their students' insights were "extremely thoughtful" and that "encouraging acceptance of being wrong in your hypothesis was great!" Linda further elaborated that "it always interests me how [students] can have such great understanding of the right practices to use, but in the classroom, they often get focused on that 'task completion' and don't follow through!" This comment suggests that while this video-cued method might elicit some surprisingly insightful reflections, these may be more difficult

for students to enact during science class, when performance goals (e.g., task completion, or getting a good grade) may affect the processes students use. The second audio clip teachers listened to was from Catherine's class and included the observation a student made about how it is good to "trust in your prediction," as described above. Teachers identified this response as less reliable, and Julie even suggested it was "possibly a reflection of being a teenager in this country—it seems like there's a lot of messaging about being confident and trusting in yourself and your ideas. So, in a way [this student] seemed to reflect that cultural idea." Catherine agreed adding that "I think that it is likely that societal ideas about confidence and trusting yourself are seeping in."

Finally, after engaging in this activity, teachers were intrigued by what they heard and eager to hear more from their students regarding their focus group responses. Lindsay elaborated, "Listening to the student samples was insightful. As a teacher…we hear from the student groups we are working with at a particular moment, but often their dialogue is biased towards what they think we, the teacher, want to hear. It was nice to hear their candid conversations." Teachers also agreed that having *all* of their students evaluate the epistemic performance of other students working with the same models (as their focus group students did) as a classroom activity would be beneficial in promoting more reliable scientific modeling processes in the classroom. Lindsay added that this activity "would be a great way to spark the conversations about [more and less reliable processes] and how students can identify when they are putting less productive strategies in play and how to correct them." Taken together, these teacher reflections on some of their students' responses to the video clip demonstrated that they uncovered some very surprising and otherwise hidden aspects of epistemic performance that they were not seemingly unaware of prior to this activity. This revelation underscores the prevalence of a major barrier towards teachers' ability to promote the goals of an epistemic education in their practice: being positioned to notice and accurately assess their students' epistemic cognition.

Discussion

In this study, we used video-cued discussions with students and teachers to uncover their metacognitive knowledge regarding scientific modeling. All participants noticed and discussed at least some of the 8 previously identified epistemic processes at work in the video clip. Many of the biased processes observed in the clip included some hallmarks of confirmation bias (e.g., cherry-picking); thus, students and teachers were aware of confirmation bias and were able to accurately identify some aspects of it in practice. However, engaging students with effective curricular tools, such as the modeling curricula investigated here, is likely only one of many important factors leading to the development of more sophisticated epistemic cognition (Muis et al., 2016). While these modeling units probably contributed to the successful epistemic performance exhibited by students in focus groups, more explicit instruction regarding ideals and the justification of reliable scientific processes could also improve student outcomes, as teachers pointed out that they had seen these kinds of biased processes playing out in their classroom.

The second part of the study, when teachers listened to students identify the epistemic processes from the video clip, revealed that teachers were not necessarily attuned to their students' epistemic cognition. Teachers were "astounded" and "surprised" by the metacognitive knowledge their students articulated regarding modeling. This is problematic because perceiving this and then using it to inform future instruction is a critical aspect involved in promoting an epistemic education (Fives et al., 2017). Furthermore, teachers also accurately pointed out that students' epistemic cognition is shaped not only by cognitive biases, but also by factors such as social and cultural influences, performance goals, and attitude towards learning (Elby et al., 2016); therefore, the video-cued method used to invoke metacognition around a familiar activity was powerful in revealing this kind of thinking. In fact, multiple teachers agreed that showing their students a clip such as this would be a fruitful classroom activity. Because we know teachers need better supports for incorporating epistemic educational goals in instruction (Muis et al., 2016) and more activities that elicit metacognitive thinking are needed to address this (e.g., Chinn et al., 2020), we suggest using this type of method directly in the classroom. Our findings here indicate making this kind of metacognitive knowledge explicit in science class could contribute positively to the epistemic climate of the classroom (Muis et al., 2016). Future studies might then address how an intervention like this might affect epistemic performance across knowledge domains and/or compared to other better-known interventions, such as those that involve reading and responding to persuasive texts (e.g., Porsch & Bromme, 2011).

In conclusion, even though it is well established that teachers need to notice their students' epistemic performance, this is difficult to achieve, and it is likely there are biased processes going unnoticed and perhaps inadvertently being reinforced in science classrooms. Incorporating more metacognitive thinking into science classrooms to redress this is not a new suggestion (e.g., Barzilai & Chinn, 2018; Hofer, 2004) but this study provides support for the value of using a video-cued evaluation of familiar classroom practices as a method to help elevate learners' thinking into the metacognitive realm. Additionally, it seems necessary to make these types of ideals and reliable processes more explicit to students, as this could provide a mechanism for transfer of the

more domain-general aspects of successful epistemic performance towards everyday decision-making regarding current socioscientific issues.

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An Assessment Framework for Complex Systems Understanding

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Abstract: Complex systems understanding is crucial for understanding the sciences of the twenty-first century. Helping students with the principles of complex systems is thus both a challenge and an opportunity. In order to investigate the effectiveness of complex systems learning activities, we would like to have an assessment instrument which we can ultimately use as pre and post-test to assess the learning gain. In this paper, we developed an assessment instrument as a questionnaire containing five scenarios related to key concepts of complex systems understanding. After validating the understandability of the questions, we collected answers from 37 participants including experts as well as non-experts. We finally propose a scoring scheme based on fuzzy logic. This approach results in a general procedure which is compact, automatic and human legible to quantify expertise in complex systems concepts.

Introduction

Order, regularities, and patterns are ubiquitous around us. A flock of birds winging in the sky, the self-organization of social insects, or the synchronized blinking of fireflies are examples of natural complex systems where "macro" patterns arise from the interaction of "micro" agents. Complex systems can be defined as "an interdisciplinary field of research that seeks to explain how large numbers of relatively simple entities organize themselves, without the benefit of any central controller, into a collective whole that creates patterns, uses information, and, in some cases, evolves and learns" (Mitchell, 2009, p. 4).

Not only is this an important domain to learn about on its own, but it actually consists of a "powerful idea" (Papert, 1980) that cuts across disciplines and can lead to the understanding of a large class of physical and social phenomena taught as conceptually different subjects. Researchers argue that different complex systems in nature, such as insect colonies, brain activity, immune systems, economies, the atmosphere, and human social interactions, have much in common. In fact, understanding complex systems is fundamental to understanding science, and it is becoming one of the essential cognitive skills needed for the twenty-first century (Reed, 2020). It is therefore not surprising that the Nobel Prize in physics in 2021 was awarded for groundbreaking contributions to our understanding of complex physical systems.

An active research area within the teaching and learning of complex systems is that of developing computational tools and resources for facilitating the learning of complex systems concepts. These are mostly based on agent-based modeling environments such as StartLogo or NetLogo that help students construct a connection between the interactions of micro-level particles/agents and the emergent complex macro behaviors. These learning environments are based on the assumption that whenever students have the opportunity to take the point of view of an atom, an electron, a sheep, a fish, an ant, or a trader, they are more ready to conceive complex systems (Wilensky & Rand, 2015). Repenning et al. (2010) developed "Collective Simulations" that help students to learn about the intricacies of interdependent complex systems by engaging them through social learning techniques in the classroom along with networked computers. Similarly, participatory simulations, such as Hubnet (Wilensky et al., 2006), were developed as a type of role-playing activity used in classrooms to explore how complex dynamic systems evolve over time through individual elements acting. In order to evaluate the effectiveness of these resources, it is necessary to assess the learners' complex systems knowledge, which is challenging given its cross-disciplinary nature and vastness of its underlying concepts. Therefore, an important area of research consists of developing instruments to assess complex systems understanding.

In this paper, we focus on this second research goal. We develop a general assessment instrument, freely publicly available, assessing the five essential complex systems ontological concepts, discuss its validation and provide an automatic, human legible general scheme to classify expertise in complex systems concepts.

Theoretical Background

Complex systems are present everywhere in nature, and many are commonly observed or experienced by all of us during our daily life. However, experts and novices think and build their knowledge about complexity in significantly different ways. Hmelo-Silver (2007) found that novices focus on the visible and static structures of the subsystems involved while experts incorporate structures, causal behaviors, and functions. Similarly, Jacobson (2001) documented that the differences between experts and novices lie in the cognitive and ontological ways of

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thinking. Novices were committed to believe that systems work in a centralized, predictable and reductive ways, while experts tend more to describe systems as decentralized, nonlinear, and nonreductive.

Learning about complex systems is challenging (Hmelo-Silver, 2006), and many studies investigate the difficulty that humans have in understanding and grasping complex systems, alongside common misconceptions about them. Resnick (1994) discusses students' bias to generally assume that the behavior of a system is controlled by lead - a leader orchestrating the system's patterns, or by seed - a single pre-existing entity in the environment, rather than resulting from decentralized interactions. This inclination toward centralization is referred to as Deterministic-Centralized Mindset. Moreover, probabilistic non-deterministic behavior in systems is also found to be a challenging concept to comprehend (Wilkerson-Jerde, 2015). Similarly, people tend to assume immediate effects instead of indirect cascading effects (Grotzer et al., 2015). Chi et al. (2005) have also shown that a process is generally thought of as a direct static phenomenon rather than emergent. An assessment instrument for complex systems understanding should therefore be designed to detect the presence of these misconceptions.

Yoon et al. conducted a study where they analyzed students' responses to one open-ended question in an ecology context concerning the effects of the arrival of geese on a park ecosystem. Results showed that the most difficult ideas to grasp are those related to the decentralized organization of the system and the unpredictable or non-deterministic nature of effects. They then proposed a learning progression to systematize the pathways students undertake to enhance their conceptual competence in complex systems. In another context, Wilensky and Abrahamson (2006) studied the student learning of the spread of diseases in a participatory simulation activity. Their findings identified several reasons for students' incorrect interpretation when explaining the agent-to-aggregate (i.e. micro to macro) relationship. These include proportional and linear reasoning, randomness-determinism confusions, disregarding feedback loop effects, and anticipating emergence from agents' rule-based interactions. Their assessment was composed of questionnaires and interviews where the situations, modeling, and representation tools relate thematically to the disease spread context. The students were provided with a modeling kit (stationery, Lego, strings, etc.) and data-charting tools to give them a choice between either modeling the process itself with concluding their response based on this, or directly charting quantitative data without thinking through the process. The key items in the questions were the spread of a mold on a moldy piece of bread, the scattering of people in a gym class, the spread of a rumor in a class, and the disease spread.

Hmelo-Silver et al. (2007) suggested a framework based on structure-behavior-function theory to represent how people think about complex systems, in particular, in a biological context. Structures refer to the elements, functions to the role of an element, behaviors to mechanisms of how the structures achieve their function. The case study included two biological complex systems: the human respiratory system and an aquarium ecosystem. To assess complex systems understanding, interviews were conducted, including drawing and open-ended questions. These were then coded by the presence and absence of the target concepts (structures, behaviors, functions). Jacobson (2001) developed another framework depicting multiple categories of complex systems concepts based on ontological and epistemological "component beliefs". Multiple studies then followed and adapted this framework (Jacobson et al., 2011; Yoon, 2011, 2019). Jacobson et al. (2011) refined this framework to focus on five main concepts that we also rely on in this work (more details later). They developed a hypermedia learning environment consisting of five NetLogo agent-based models: foraging of ants, traffic jams, self-organization of slime molds, social segregation, and wolf-sheep predation. Interactive scaffolding was introduced related to declarative knowledge of the complex ontologies as well as problem-solving exercises to compare and contrast the different aspects. Ontological shifts were observed, which further confirms and validates earlier results concerning the main concepts comprising complex systems.

In the literature discussed above, many studies explored the importance of as well as the difficulties encountered when learning about complex systems, and defined and validated its main concepts. However, there is no instrument available to objectively score a learner's understanding across different concepts of complex systems, in addition to different contexts. The contribution of our paper is motivated by this limitation. Based on and inspired by the findings above, in this paper, we compose a general assessment instrument that can be used to assess expertise within complex systems. The instrument requires participants to answer questions related to five different scenarios which are then scored to extract their competence in five ontological concepts required for complex systems understanding. More specifically, our research question is: can we quantify the expertise in complex systems based on answering questions targeting related ontological concepts?

Method

Materials

The instrument is designed as a questionnaire consisting of five scenarios related to key concepts of complex systems understanding. These concepts, identified as core complex systems characteristics, used and validated in

prior research (Jacobson, 2001, Jacobson et al. 2011, Yoon et al, 2019) are the five ontological categories of complex systems understanding — Order (Centralized, Decentralized), Causes (Single, Multiple), Actions effect (Linear, Nonlinear), Agents effect (Predictable, Random), and Processes (Static, Emergent). The scenarios draw inspiration from literature and are: Traffic Jam (Resnick, 1994), Scattering (Wilensky and Abrahamson, 2006), Flock of Birds (Jacobson, 2001), Butterfly Effect (Jacobson, 2001), and Robots and Gold (Resnick, 1994). For each scenario, the questions were formulated with a mix of Multiple Choice Questions (MCQs) and open-ended questions. They were written in an appropriate way to be answered by both experts and novices alike. No formal declarative concepts were used. The detailed questions can be found here. Whereas the last two scenarios (butterfly effect and robots and gold) are thought experiments, the first three scenarios include familiar (scattering, traffic jam) or naturally observed behaviors (flocks of birds). Moreover, we distinguish two types of questions: whether it involves explaining the behavior of a system (e.g. *How is it that the birds fly in a flock?* in the third scenario) or defining rules to enact it (e.g. *How should the robots move in order to find the gold?* in the last scenario). Finally, the questions, even in the same scenario, can tackle different perspectives: local (agent perspective, e.g. *What does each person need to do in order to scatter?* in the second scenario) and global (external observers, e.g. *If you were up really high, and could watch your class scatter, what would you see from above when they're scattering?* in the second scenario).

Procedure

An iterative approach was followed to refine the questions and validate the instrument. A first version of the questionnaire was sent out to 11 participants of varying ages and educational backgrounds. The goal of this first validation was to evaluate the understandability of the scenarios and questions and to obtain a range of the possible answers from our target population in order to develop a coding scheme. Based on this first feedback, the questions were refined, and confusing statements were clarified. The first draft of the coding scheme was also developed. Our goal in the second iteration was to validate that the chosen questions assessed the set of complex systems concepts, further validate the understandability of the questions and refine the coding scheme. The second validation phase included two steps. First, we discussed and validated the questions and coding scheme with an expert in complex systems education to ensure that the five scenarios and accompanying questions were representative of all the complex systems concepts. Second, we followed a verbal cognitive methodology in which three novices (undergraduate students) and three experts (graduates/post graduates in swarm robotics) were asked to read the questions and describe verbally what they understood from the question and how they would answer the questions. Then they wrote the answers in the questionnaire. Based on this second validation, final refinements were done to the questions and coding scheme.

Subjects

The final version of the questionnaire was administered to two groups of participants:

- An ***expert*** group including eight subjects who responded to a personal request for participation sent by email. They were purposively sampled to include PhD students or holders in a related domain (mainly in swarm robotics, physics, and computer science). They self-rated their expertise in complex systems with an average of 5/7 and confidence in answers with an average of 5.625/7. The mean age of the group was 33.88 years (SD = 3.59), with six males and two females. Classified by ISCED Majors, 3 are in Engineering and 5 are in Science.
- A ***non-expert*** group including 29 subjects. They were recruited from requests diffused online and among students in university and high school. The mean age of the group was 24.21 years old (SD = 6.31) with 16 females (55%) and 13 males (45%). These included five students from high school, 25 in Bachelor, 7 in Masters, and 2 PhD students. Classified by ISCED Majors, 15 are in Science, 3 in Health, 4 in Engineering, 1 in Education, 2 in Social Science, and 4 in General Knowledge (high school students).

Scoring and Coding Scheme

The responses were scored based on the five key concepts mentioned previously. We consider 3 levels of understanding: a clockwork (corresponding to a centralized mindset) mental model, a complex systems mental model, and an intermediate or in-between level. Table 1 provides the concepts, focus, and the difference between

clockwork and complex responses (Jacobson et al. 2011, Yoon et al, 2019). Based on these concepts a detailed coding manual was developed for each of the questions (can be found here).

Table 1

General coding scheme: concepts, focus, and the difference between clockwork and complex responses.

Concept	Focus	Clockwork Mental Model	Complex Systems Mental Model
Control	The control is centralized or decentralized	Response indicates that the system is controlled by a leader (order is top-down)	Response indicates that the system is decentralized (order is bottom-up)
Causes	The number of causes that contribute to the outcome	Response attributes the outcome to one primary cause/factor	Response attributes the outcome to multiple causes/factors
Action Effect	Interaction between agents are linear/proportional or not	Small action→ small effect Large action→ large effect	Small action →large effects Effects of actions may not be repeatable
Agents Effect	Predictability of actions of agents	Actions of agents may be predictable	Actions are not predictable, random
Process	How the system works	System is an event defined by its global behavior	System is a dynamic process, self-organizes through agent interactions

The inter-rater reliability of the coding scheme was assessed with three raters coding 25% of the responses. The interrater agreement was measured using Cohen's Kappa and was found to be 0.66 which denotes a substantial agreement. The discrepancies were discussed and related details were added to the coding scheme to make it clearer. The remainder of the responses were subsequently split among the three raters to code.

Below we describe the traffic jam scenario and its coding scheme as an example. The instruction is:

On the road, each car followed only three rules: 1) If there is a car close ahead of you, slow down
2) If there aren't any cars close ahead of you, speed up (unless you are already moving at the speed limit)
3) Comply with driving regulations concerning all other elements on the road, such as: slow down if you detect a radar trap, traffic lights, accidents, entry ramps… (we attach a gif)
Question 1: What is causing this traffic jam? Select all applicable choices (radar trap, broken bridge, entry ramp with merging traffic, accident, nothing, other)
Question 2: Explain in your own words how your choice(s) is (are) causing the traffic jam.
Question 3: The radar trap is removed, and there are no accidents on the road, no broken bridge, no entry ramp or any other external events. Can a traffic jam still form? (Yes, No)
Question 4: If yes, why do you think a traffic jam can still form? If No, explain in your own words, how the cars will behave on the road.

We target three main complexity concepts with this scenario: causes, control, and action effects. Examples of responses and scores are given in Table 2.

Table 2

Scores of 3 participants for the first scenario: Traffic Jam

ID	Q.1	Q.2	Q.3	Q.4	Scores
P1	Radar trap, Broken Bridge, Entry Ramp with merging traffic, Accident, Nothing	Slow down compounds resulting in a complete halt. Netlogo has this model and explains it well too.	Yes	As one car's behavior is dependent on others, the speeds and behaviors become nondeterministic. Even a slight slowdown to avoid bumping into the car in front can compound as the reaction time may have a slight delay as well.	Control (1) Causes (1) Action (1)
P2	Radar trap	Cars are driving slower after they stopped suddenly	No	They will behave freely with no stops or jams	Control (0) Causes (0) Action (0)

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P3	Broken Bridge, Accident	They basically cause a blockage to traffic, so that vehicles 'pile up'	Yes	It also depends on the amount of cars on the street	Control (1) Causes (0.5) Action (0)

Results

For each participant, we summed up all the scores per concept, as well as per scenario. Each raw score was divided by the total possible score, to have standardized scores for the different concepts and scenarios. The total score was calculated as the average over all the concepts. A significant difference was found between the scores of experts and the non-expert over all concepts, except the concept "Causes" where the non-expert also scored high (see Figure 1). Considering scenarios, significant differences were found between the experts and non-expert participants in all scenarios except in the second (scatter) scenario (see Figure 2). In the robots and gold scenario, the difference was larger with a huge effect size (Cohen's d = 2.2).

Figure 1

*Comparison of experts and non-experts over the concepts. * (**) indicates a significant difference with p-value<0.05 (<0.005) with a Mann-Whitney Test.*

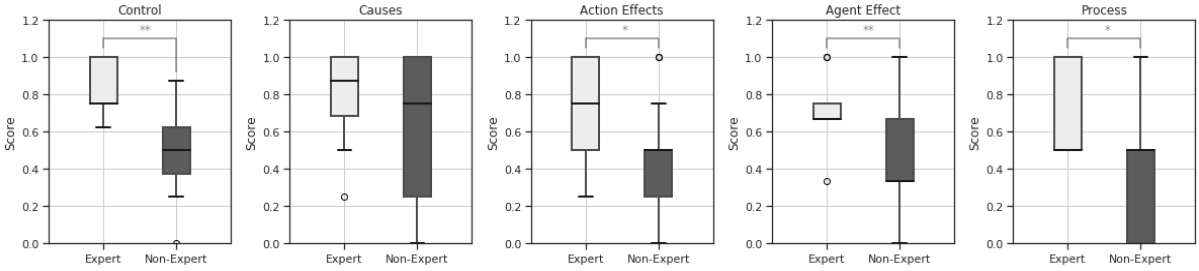
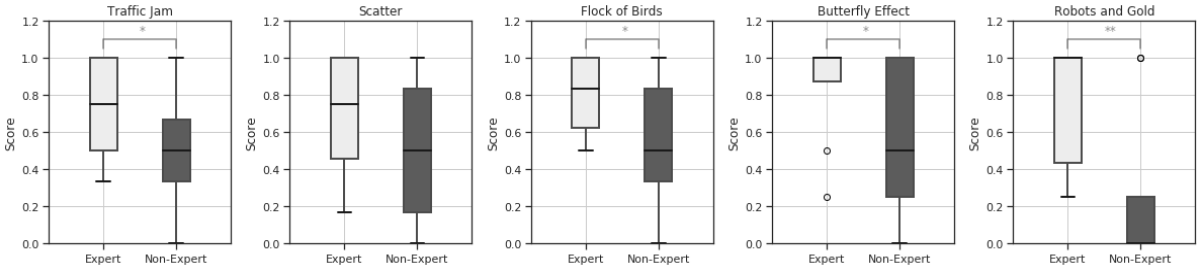


Figure 2

Differences per scenario among the experts versus the non-experts.

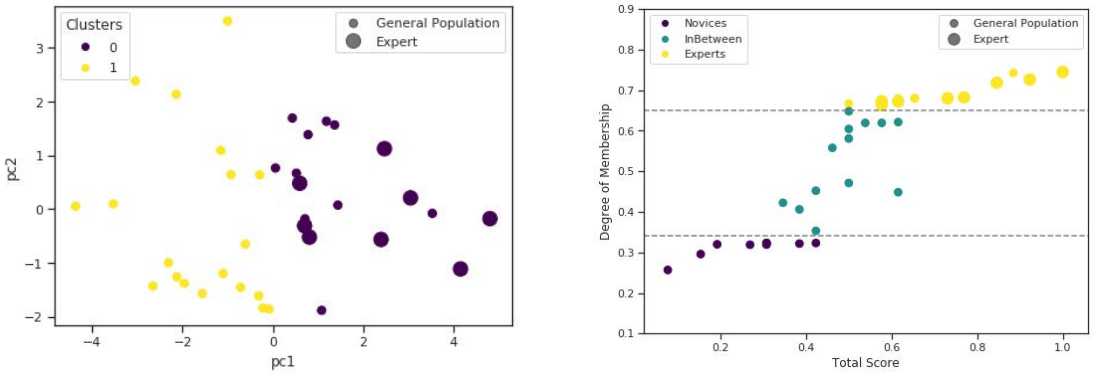


To verify that our mapping of concepts to questions was complete, we investigate the correlation between concepts. A strong significant correlation exists between total score and each of the respective concepts (spearman correlation with control = 0.75, action effects = 0.72, agent effects = 0.68, process = 0.66) and a moderate correlation with the causes concept (0.46). A moderate significant correlation also exists between the control concept and each of action effects (0.44) and agent effects (0.62) concepts and between action effects and process (0.48) concepts. A weak significant correlation (0.34) also exists between the concept action effects and agent effects. Furthermore, we investigate the correlation between scenarios. We only found weak significant correlation between scenarios 1 and 3 (0.35), as well as scenarios 2 and 4 (0.37).

While experts are expected to be knowledgeable on the concepts (and this assumption is supported by their high scores), participants belonging to the non-expert group can have varying degrees of understanding of complex systems, lying at different points on the continuum from novices to experts. Therefore, to verify whether the population can be divided into two groups, namely the novices and the experts, we conduct a clustering on the whole dataset involving the 37 participants on the basis of 10 features taken into account: the scores of each concept, as well as the scores of each scenario. A principal component analysis (PCA) is conducted to extract the 6 most significant principal components, explaining 95% of the variance. The purpose is to make groups which are hardly separable in the space by the original features, but better separable in the new space spanned by the Principal Components (PCs). To verify the separability of our population, we perform a C-means clustering for the association of each participant to a cluster. The number of clusters is fixed to 2 to verify whether the expert participants indeed cluster together when all features are considered together. The results, shown in Figure 3a, revealed that all the experts belong to the same cluster, as well as some of the participants from the non-experts. An extended discussion of this finding is reported in the Discussion section.

Figure 3

(a) Clustering results (b) fuzzy system output vs total score and division into 3 classes



(a) (b)

Figure 4

Differences per concept among the three groups.

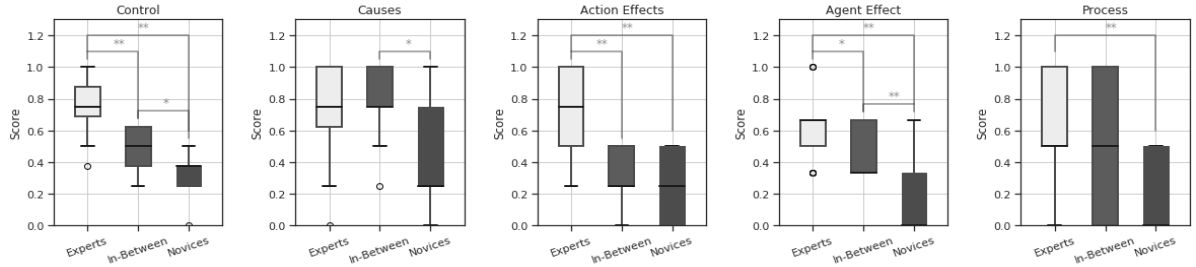
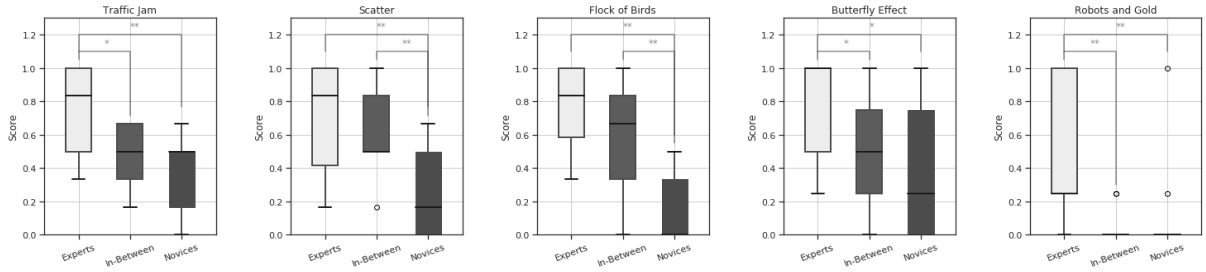


Figure 5

Differences per scenario among the three groups.



So far, we have analyzed our participants' responses either over single concepts/scenarios, or over the dimensions returned by PCA, which are a combination of these scores. What would be interesting is to have a global complex systems expertise score, which makes it immediate to evaluate a person's complex systems understanding. More concretely, our goal is to define a mapping between the concepts/scenarios and a global score of expertise. One approach is to sum and average over all the concepts; however, with this method, the distribution over all concepts is blended. We address the above challenges by using techniques from fuzzy logic systems. Fuzzy logic allows us to encode qualitative relations among multiple variables (fuzzy rules) in a unifying formalism (Driankov, 2001). In our case, the relation to describe is the one between a given vector of values for the complex systems' scores (concepts and scenarios), and the corresponding global level of expertise. The fuzzy rules are encoded as if-then rules underlying the qualitative fact that an expert level should have a high level in all the input variables; conversely, a novice level should have a low level in all the input variables. Each input membership function is modeled as a logistic sigmoidal function. The parameters of a sigmoid are fitted after applying a 1D clustering on each of the dimensions. The output membership function is modeled as a trapezoidal function with cut-off limits set between 0.35 and 0.65. Figure 3.b shows the relation between the total score and the output fuzzy logic score. We notice that the relation is sigmoidal rather than linear. Again, we verify that the group that we already know are experts actually score high on the degree of membership of the expert level. We also can identify a separation of three classes: experts scoring higher than 0.65, novices scoring lower than 0.35 and an average in-between group. We recomputed the differences per concepts and scenarios between the populations of three identified classes. Results are shown in Figures 4 and 5.

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Discussions and Implications

In this paper, we propose a tool that can be used to assess a person's expertise in complex systems which requires solving five different scenarios and relies on a coding scheme to extract their competence in five ontological concepts required for complex systems understanding. A study with 37 participants including experts and non-experts was conducted to validate our instrument. Significant differences were found in the scores of the two groups. Finally, an automatic approach based on fuzzy logic for getting a general score is proposed and analyzed.

In our first analysis, we found a significant difference between the scores of experts and the non-experts over different concepts and scenarios, which is in line with previous literature (Jacobson, 2001). One exception is the concept of "Causes" where the non-experts scored high too (see Figure 1). While it may be possible that this concept is easier to grasp than others, an alternative explanation is that in our instrument the questions measuring causes were mainly MCQs, which possibly led respondents to select more than one option. Conversely, in the last scenario (robots and gold), the difference in scores was much larger: a possible explanation is that in this scenario, participants were asked to enact/design rules in a novel scenario, rather than explaining an observed phenomenon. Given the ubiquitousness of centrally controlled systems in the world around us and novices' inclination towards the centralized mindset (Resnick, 1994), it is likely that novices believe in the superiority of centralized over decentralized systems and so chose to enact centralized rules.

Subsequently, we designed a Fuzzy System to compute a global score of expertise in complex systems understanding. The score computed by the Fuzzy Inference System (FIS) is not always equal to the average score, since the FIS takes into account the combination of scoring high on the different features, rather than having more skewed scores by one high value. For example, a participant with very high scores on the *causes* concept and scenario 4 (both 1) but very low scores on the *control* concept, and scenario 5 (0.25, and 0 respectively), had the final score pushed down with comparison to the average score (0.44 instead of 0.61). Similarly, a participant with very low scores on the *causes* concepts, and scenario 2 (0.25 and 0.33) but high scores on the *control* concept, and scenario 5 (0.75, and 1 respectively), had the final score pushed up with comparison to the average score (0.67 instead of 0.58). Moreover, in our total score analysis, the results indicate a separation between 3 groups of expertise. The subjects already known to be experts all belong to the expert cluster. Few participants from the non-experts also belonged to the same expert group. By looking at their major, they were a group of students doing their masters in biology, so they perhaps have a background knowledge in biological complex systems, which could explain their performance. The other two groups had populations of mixed educational backgrounds. Although not significant, looking at the mean age of the clusters, the novice group had the lowest mean (22.0), then the in-between group (26.5), then the experts group had the highest (28.7).

To better understand the differences between the three groups, we look again at the difference between the concepts. Significant differences were found for the concepts: control, causes, and agent effects between the novices and in-between groups; and for the concepts: control, action effects and agent effects between the expert and in-between groups. For the scenarios, it was scatter and flock of birds between the novices and the in-between groups, and traffic jam, butterfly effect and robots and gold between the expert and the in-between groups. Looking back to the theoretical background, we observe similar trends to link difficulties related complex ideas. Yoon et al (2019), reported that order and deterministic effects (which link to control and agent and action effects in our definitions) constitute the hardest concept to grasp. Similarly, Resnick (1994) suggested that the commitment to centralized mindset constitutes a strong misconception for learners. Lastly, Grotzer et al. (2015) focused on the difficulty of understanding non-linear effects in a system.

Finally, although through our questionnaire we only target the implicit knowledge of complex systems, the use of declarative knowledge (emphasis in italics) was observed in the experts' responses (Jacobson et al., 2011). An example is the explanation of the butterfly effect given by an expert:

> In a system with *nonlinear dynamics* such as with *positive feedback* loops, small changes in certain periods or locations can have large effects. Collective decision-making for a new nest in ant groups is one example, where the number of insects recruited to go to a specific new nest depends on how many are recruiting […]

On the other hand, an answer to the same question, given by a participant from the non-experts and which also display implicit but lacks declarative knowledge is:

> I think those effects are the norm rather than an exception. For example, teachers influence the future life of students in small ways every day, and therefore also influence the lives of those they interact with.

In conclusion, the assessment, coding scheme and scoring approach proposed in this paper advance our understanding of people's understanding of complex systems. Moreover, our instrument contributes to the design of learning activities to engage students about complex systems and helps investigate the effectiveness of such activities. The differences per concepts and scenarios between three different groups observed in our study suggest to follow a learning progression moving from less to more advanced concepts, as well as following a learning process based on the conceptual change approach to trap existing conceptions from a clockwork mental model to a complex systems mental model, which will be part of our future work (Khodr, et al, 2022).

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Investigating experts' and middle school learners' uncertainty management during collaborative engineering design tasks

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Abstract: Young learners are increasingly engaging in engineering design activities in their classrooms. However, limited research exists regarding uncertainty management practices in engineering design, what experts do, and how to scaffold the process for novice learners. To address this gap, we investigated uncertainty management practices in engineering design of experts and beginner designers at the middle school level. We interviewed five design experts and identified six prominent uncertainty management practices in engineering design. We also analyzed data from five groups of middle school learners working on ill-structured design problems to understand their uncertainty management processes and identified learner difficulties in productively engaging in uncertainty management practices.

Introduction and Background

Managing uncertainties is an integral part of solving engineering design problems. While there has been a growing emphasis on teaching young students about design thinking and productively engaging them in engineering design practices (Crismond & Adams, 2012), the focus lacks on how to help them tackle the inherent uncertainty. Engineering design problems require learners to tackle uncertainties at every stage of the design process, choose from multiple alternatives, and deal with incomplete information and unclear objectives while collaborating with multiple team members (Dym, Little, Orwin, & Spjut, 2009; Ullman, 2001). Prior research acknowledges that learning how to deal with uncertainties productively is crucial and young learners can and should engage in the process at the school level itself to further develop their reasoning and sense-making (Dasgupta, 2019; Dym et al., 2009; M. E. Jordan & McDaniel, 2014). However, prior work sheds limited light on how learners' subjective experiences of uncertainty affect their actions and design approach, how it is different or similar to expert designers, and how we can help learners manage uncertainties productively.

Amongst the limited literature available on this topic, seminal contributions by Jordan et al. (2014) highlight the important role of peer responses for collaboratively tackling uncertainty faced by middle school learners during a robotics engineering activity. The authors concluded that learners respond to uncertainties in both supportive and unsupportive ways, shaping the trajectory of their uncertainty management processes. Other researchers focusing on K-12 learners have highlighted how uncertainty affects learners' engagement in science practices (e.g., Metz, 2016; Radinsky, 2008), scientific argumentation (e.g., Chen, 2020), and how can we engage learners in "productive uncertainty" (Manz, 2018) in the context of science learning. We take these relevant and valuable research into consideration as we investigate the following research questions: (a) What are uncertainty management practices in the context of engineering design as defined and practiced by experts? (b) What challenges do middle school learners encounter while productively engaging in engineering design practices?

Cognitive and learning scientists have favored contrasting expert and novice processes for understanding disciplinary practices in a domain and identifying scaffolds required for supporting novices' processes (e.g., Crismond & Adams, 2012). We interviewed five design experts to identify and describe uncertainty management practices in engineering design. The experts in our study have eight to twelve years of experience in solving engineering design problems in different capacities like - participant in large projects, mentor, and project manager. These experts are at the "Informed Designer" level (Crismond & Adams, 2012). Expertise at this level maps well to "a generic model of design expertise that corresponds to ways of perceiving, interpreting, structuring, and solving complex problems" and is considered appropriate for contrasting and interpreting learners' behaviors at the "beginner designer" level (Crismond & Adams, 2012). We also referred to literature on design expertise to inform and validate our findings. Then, we analyzed middle school learners' behaviors and interactions during their attempts to resolve uncertainties to help us unpack learner processes and problem areas that hinder their productive engagement in uncertainty management practices.

Method

Participants and Setting

We interviewed five professionals (four males and one female) specializing in the fields of engineering, architecture and design to answer our first research question i.e. what are uncertainty management practices in the

context of solving engineering design problems? All the professionals have experience of eight to twelve years working on various engineering design projects. The projects range from devising solutions for bio-medical problems to developing tools for assessing environment friendly and sustainable designs. Two of the male experts (Expert ND and Expert KG) are currently working as design entrepreneur. Expert SA (female) is an assistant professor at a technical institute in India. Expert AK (male) is a Senior Project Manager at a Medical Device Development Unit at a technical institute in India and Expert AR (male) is a Senior Interaction Designer and Design Expert at a multinational company.

The interviews were semi-structured in nature and conducted by the first author of the paper, in online mode using the Google Meet platform. Each interview lasted for sixty to ninety minutes and the medium of communication was English. The experts were informed about the broad goals of the research and provided with the sample questions that would guide the interview. The questions probed them to talk about different situations and scenarios where they experienced uncertainty, reflect on how they dealt with them, the role of team members in the uncertainty management process, and how different uncertainty situations and management strategies relate to the engineering design process. All the experts also have teaching and mentoring experience, therefore we also asked them about their views on teaching and learning of uncertainty management and kind of support that learners might need in this regard.

To identify what difficulties and challenges learners face in productively engaging in uncertainty management, we analyzed data of five groups of sixth and seventh grade learners. Data came from two studies that were conducted with the broader aim of understanding middle school learners' uncertainty management processes in collaborative settings. The first study was a four-hour study conducted in a one-day workshop mode with five seventh grade learners from multiple schools in an Indian metropolitan city. Learners had to design a cleaning robot using the LEGO Mindstorms™ kit that could accomplish certain tasks efficiently while optimizing the design cost (Kaur & Dasgupta, 2019; Kaur, Patel, & Dasgupta, 2019). We grouped learners into two teams randomly for working on the design problem. First team (Group A) consisted of two students (one boy and one girl) and the other team (Group B) consisted of three students (two girls and one boy).

The second study was a four-day study (approximately one hour each day) conducted in a middle school classroom setting in a large public school in an Indian metropolitan city. A total of 44 students participated who were randomly divided into 12 teams (groups of 3 or 4) by the researchers. We analyzed data from three teams who were the most vocal (hence had clear audio). Group A consisted of four participants (three males and one female), Group B also consisted of four participants (two males and two females), and Group C consisted of three participants (two females and one male). We gave students a design task of building a balloon powered toy by maximizing the distance traveled in a straight line (Kaur & Dasgupta, 2021). We collected both audio and video recordings of the teams for the entire course of the activity in both the studies. The authors of the paper were present in the class as observers. Teaching assistants (T.A.s) from the same department (two T.A.'s for first study and three T.A.'s for the second study) were also present. They handled the audio and video data collection and also mentored groups from time to time.

Data analysis

We analyzed interview data from the five experts using thematic analysis (Braun & Clarke, 2012) to identify themes related to uncertainty management practices of experts. We also reviewed literature on design expertise to support this analysis process. Thematic analysis is an appropriate method for our goal since we wanted to explore the range of ways experts experience and deal with uncertainties. Following the methods of inductive thematic analysis, we first familiarized ourselves with the data by listening to the audio recordings of interviews and transcribing them. Then we generated initial codes from three interviews from our data set. Refer to Table 1 for an example of how initial codes emerged from transcript. The next step was to review the literature on design expertise to find if more codes emerge related to experts' uncertainty management. Then we collated the related codes into categories and themes (See Table 2 for an example), which was followed by reviewing the themes against the remaining two interviews to ensure consistency. Finally, we refined our themes by repeated discussions where we examined their descriptions.

Table 1

Initial codes emerging from the transcript of expert interviews during thematic analysis

Transcript	Initial Coding
[00:16:45.26] Interviewer: Can you tell me about the uncertainties that you experienced with respect to these projects (Projects mentioned by expert earlier to this question)?	

[00:17:10.15] *Expert ND:* Yeah, so uncertainties are part and parcel of this whole process. And earlier it used to be a little scary. This was I think 4-5 years ago but then after NIT and after working on these projects, it was clear that **uncertainty is going to be part of this process** and **they have to just be accepted so that we keep moving forward**. So uncertainty, yeah it is part of the process and it **has to be acknowledged** in the process.	- *Acknowledging uncertainty* - *Accept uncertainty to keep moving*

Table 2
Themes emerging by combining codes during thematic analysis of expert interviews

Combining Codes		Theme
- Collect more information - Talk to multiple experts for different perspectives - Clarify with industry, clinical partners, technology partners and relevant stakeholders in initial phase - Literature and existing patents - Weekly meetings	- Involve experts and team-members to understand the breadth and depth of the problem - Seek advice from experts and team-members for evaluating and revising ideas, and planning next steps - Analyze and evaluate gathered knowledge in the problem context (List is not exhaustive)	*Taking feedback from relevant sources*

Themes emerging from analysis of expert data were then used as a guiding framework to identify learner difficulties and challenges in productively engaging in uncertainty management practices during the collaborative engineering design task. For the learners' data, we first used a coding scheme by Jordan et al. (2014) to identify all the episodes where uncertainties were expressed by the team members. This coding scheme uses indicators like hedges (e.g., 'maybe,' 'sort of,' 'perhaps'), probabilistic statements (e.g., 'likely,' 'probably'), and non-verbal cues (e.g., use of gaps like 'mmm…') to identify expressions of uncertainty. These indicators marked the start of an uncertainty episode for the team. The episode ended when the conversation or the physical activity of the team members no longer focused on the specific uncertainty the group was dealing with. A total of ninety-four episodes were analyzed from the two learners' data sets combined. We analyzed these episodes following inductive and interpretive approach and using methods of interaction analysis (Jordan & Henderson, 1995). Our unit of analysis was "individual in a group" (Hogan & Fisherkeller, 2005) and we paid attention to both verbal and non-verbal learner behaviors during their interaction. By analyzing learner interactions against the uncertainty management practices identified from the experts' data, we identified difficulties and challenges that the learners encountered during the uncertainty management practices.

Findings

We identified six prevalent uncertainty management practices that experts engage in during the engineering design process. The following section will define these six practices (P1 to P6) and simultaneously discuss middle school learners' uncertainty management behaviors concerning these practices.

Acknowledge and proactively respond to uncertainty (P1)

The experts who participated in our study partially agreed that ignoring uncertainty is a common practice in their design practice. They reported that ignoring is not a 'good' way of dealing with certain types of uncertainty. According to the experts, some uncertainties cannot be dealt with immediately because of reasons like dependence on other tasks or situations that cannot be controlled in the present. Experts suggest that instead of completely ignoring uncertainty in such situations, one should proactively discuss them and plan immediate and future steps that would help in addressing them. For example, expert ND mentioned that his strategy of dealing with such uncertainties is a combination of *"proactive" and "ignorance."* He says, *"proactive is the first immediate future, first two stages or something and the rest, I am ignorant about it because it is too early to think about it."* Experts also mentioned that strategies like *"categorizing"* and *"prioritizing"* uncertainty helps in planning how to manage them. Experts prioritize uncertainties based on aspects like - their relevance to the current design phase, dependence on other uncertainties or tasks, and which uncertainties are critical for making progress.

In contrast, beginner learners usually ignore uncertainties expressed by their team-members at various instances. Learners from our study dismissed uncertainty expressed by others by either explicitly declaring it as irrelevant, delaying it without any discussion or by choosing not to respond. For example, consider the excerpt below from Team A's episode in Study 1. Aditi expressed the uncertainty regarding whether they should design

their robot to clean the eraser dust (one of the trash materials) as she considered it to be a difficult task. However, the other team member (Sneha) completely ignored this uncertainty by calling it *"unimportant."*

Sneha: Our robot will clean everything.
Aditi: Should we use Eraser dust? Won't it be difficult to clean it? It kind of…sticks to the floor.
Sneha: This is not important right now; we will be able to do it.

One of the factors contributing to learners ignoring uncertainty was the way they position themselves and other team members. For example, in study 2, group B (See Table 3), Anu and Anmol ignored Krish when he raised his concern about Anu's decision (line 9). Instead of responding to his concern, Anmol reminded him of the task he had asked him to do and instructed him to concentrate on that (lines 9, 10). Even Krish did not confront Anmol; instead, he updated him about his work and asked what he should do next (lines 11, 12). Both Anmol's and Krish's behavior indicates that they positioned each other in a supervisor and assistant kind of relationship. This kind of relationship between Anmol and Krish persistently existed in other uncertainty episodes also. Anmol's behavior of ignoring Krish's uncertainty and Krish's behavior of not confronting Anmol and following his instructions seemed to stem from their positioning dynamics.

Summary. Expert designers acknowledge and proactively plan mitigation steps to address uncertainties at appropriate design stages. However, learners may not acknowledge every uncertainty and usually respond by delaying them without a plan or completely ignoring them.

Maintaining uncertainty (P2)

It is the tendency to increase uncertainty by going into the depth of knowledge required to resolve it. The following excerpt from Expert KG's interview where he talks about expanding on ideas in the ideation phase of design interview speaks to this practice: *"So I had to think three-four ways of cleaning the membrane. For all of them, I had sketched down ways in which I could do it and these sketches, what I did was, I had taken to the expert from the 'X' institute….but I let that uncertainty be in the ideation phase so that it does not affect my ideation….So if I kill this stupid idea right now, I will not get those two brilliant ideas later and I would have never learned what all right or wrong cold happen with them."*

There are episodes where beginner learners engage in deep discussions for understanding and resolving uncertainty. These situations provide learners opportunity to share and discuss alternative perspectives, negotiate ideas, and collaboratively build knowledge to make progress in the design process. However, in most cases such productive discussions do not sustain. One of the reasons is the tendency to prematurely converge on ideas and make quick decisions instead of expanding uncertainty further. For example, consider the excerpt from an episode from group B (Study 2) in Table 3, Anmol asks his team-mates to remind him of the straw that they decided to use as nozzle (line 1 and line 3). Anu picks up a 10mm straw to answer him (line 4). When Anmol asked for Anu's reasoning for choosing the 10mm straw, she randomly pointed to the other team saying, *"they are also using the large straw, so we can use it too."* Anu tried to defend her decision without providing a logical explanation. The other team-member, Krish, also confronted her (line 9) but both Anu and Anmol ignored his concern. In this episode, Anu's actions of ignoring the disagreement expressed by her team-mates (lines 5 & 9) and providing superficial rationales for her decision indicated that she expected to manage uncertainty by making a quick decision, without engaging in any sense-making discussion. She was concerned about moving ahead and complete the task *"fast"* instead of making an informed decision (line 14). Even the other team members – Pooja and Krish did not persist on resolving their uncertainty and agreed to the decision made by Anu and Anmol who were primarily making all the other decisions in the design process.

Table 3

Excerpt from an episode of group B, Study 2

	Verbal Transcript	***Nonverbal Transcript***
1	*Anmol: Ae which nozzle had we thought of?*	*Anmol picks the 8mm nozzle straw, which is tied to the balloon.*
2	*Anu: On your mark, get set*	*Anu rolls the wheels on the desk.*
3	*Anmol: Hey which one we had to take from these?*	*Anmol places his hand over the chin and speaks louder than before.*
4	*Anu: This*	*Anu takes the 10mm nozzle straw in her hand and raises it high.*
5	*Pooja: No the smaller one*	*Pooja directs her gaze to the 8mm nozzle straw in Anmol's hand and lifts her eyebrow to point to it.*

6	*Anmol: why this one?*	*Anmol is looking at Anu. Anu is looking around in the room.*
7	*Anmol: Tell*	*Anmol raises his voice.*
8	*Anu: They are also using the large straw, so we can use it too*	*Anu points to the team sitting next to them.*
9	*Krish: But those people are using white ones*	*Krish points to another team in the class.*
10	*Anmol: You first complete this. Do it carefully.*	*Anmol turns towards Krish.*
11	*Krish: Yes, it's almost done. What should I do after this?*	*Krish starts collecting the cardboard pieces.*
12	*Anmol: Wait, I will tell you*	*Anmol uses hand gesture asking Krish to wait*
13	*Anmol: Then tell what should we do?*	*Anmol turns his face towards Anu.*
14	*Anu: Let's use red one. We have to do this fast and complete it. Otherwise, we will be left behind*	*Anu is looking at Anmol as she speaks.*

*Summary***.** Experts expand uncertainty for clarifying different aspects of uncertainty and logically converge to informed decisions. But learners prematurely converge to decisions with intentions to reduce uncertainty quickly.

Taking feedback from relevant sources (P3)

When uncertainty is experienced, one common practice is identifying and approaching the appropriate source of knowledge. This can help reduce the uncertainty by clarifying doubts and confusions and introducing more uncertainties that would further guide the knowledge seeking path, or act as an anchor for deciding next steps. Experts emphasized that this practice is particularly essential during the initial stage of design when they are defining problem as it helps in *"planning"* what to do next *"better"*. For instance, Expert AK said - *"You get it clarified with your industry, your clinical partners, your technology partners, whoever it is, the stakeholders who are there, that's where your prior art becomes really important in clearing the uncertainties. May be reading up literature on that, may be reading existing patents regarding the same. So all of this helps in clearing up these uncertainties, the unknowns which are there in the project. So once the ground up work is done, we plan accordingly, at least some part of the unknowns become known to us and then planning becomes better."*

A crucial aspect of clarifying uncertainty is assessing and evaluating the gathered information in the context of problem that is being solved. For example, Expert ND says, "*After doing certain experiments, we saw some observations. So if I were to interpret those observations, I would interpret it in a certain way but if I give the same experiment results to an academic person, they would see it in a very different way. I have to consider both perspectives and see how they serve the purpose of resolving my uncertainties."*

On the other hand, some learners usually ask for direct solutions and answers from authority figures to resolve uncertainty instead of asking relevant questions that could guide their uncertainty management processes. Some learners do attempt to engage in collaborative discussions and reasoning with fellow team-members, however in most cases, there is problem of unequal participation. Learners usually approach only specific team-members to discuss their uncertainties, as was the case with Anmol from group B, study 2 (see Table 3). Anmol only approached Anu for discussing which nozzle straw to use. This was clearly evident as Anmol was turning towards her and maintaining eye contact only with her during the discussion of the uncertainty (lines 6, 7, 13). These behaviors usually produce knowledge that lacks sound reasoning and is biased due to limited perspectives.

Learners also faced difficulty in framing their uncertainty into relevant questions that could trigger constructive discussion or feedback and usually do not persist on asking questions or expressing uncertainty to elicit responses. They even do not assess the information received from other sources, and usually accept it especially if it comes from a person considered as a higher source of knowledge authority.

Summary. Similar to experts, learners do engage in taking feedback. However, they struggle in articulating their uncertainty and lack critical assessment of gathered information.

Using engineering design specific tools and techniques (P4)

There is evidence that experts use conceptual and technical tools and techniques for resolving uncertainties. Experts from our interviews used tools such as *"usability goal setting"* (Joshi, 2009), *"sketches and drawings",* and *"standard project management tools"* which help resolve uncertainties at different design phases.

The beginner designers do not have awareness about the existing engineering design tools and techniques. Although, they do intuitively engage in tactics like brainstorming and making drawings and sketches for different purposes during uncertainty management. However, learners lack knowledge about how to use these tools

effectively. For example, sketches made by learners in our study lacked details like labeling of parts and mention of specifications like dimensions, size, and materials. Leaners miss out on important details when they use these sketches during design phases like creating prototypes, causing problems later.

Summary. Experts effectively use standardized design tools and techniques to manage uncertainties, while beginners lack apriori knowledge about these tools and their application.

Keep track of micro and macro progress (P5)

All the experts in the interviews had a view that continuous progress in the uncertainty management and the overall design process is an important indicator of productive uncertainty management. For example, Expert ND when asked about how they judge if their students are managing uncertainty productively during a design project, says, *"the biggest, the first marker is - Are they moving forward? If I am looking at them every half an hour or 2 hours, when I come back, if they are still solving the same problem, that means there is something wrong, they are not moving forward ..... so basically it is the progress of whatever they are doing. Are they stuck at the same point? if yes, why are they stuck? Why are they not able to resolve that uncertainty? That is the question."* Experts monitor the micro progress made on sub-tasks within a bigger problem and consider it essential for tackling uncertainty. They frequently reflect on the state of uncertainty and accordingly prioritize them to decide how and when to address them. They simultaneously keep track of the overall progress (or macro progress) of the design life cycle which helps them regulate tactics and strategies for resolving uncertainties. For example, in the excerpt below, Expert AK emphasize the need to *"track progress"* by ways like setting *"milestones"* for managing uncertainty and regularly checking if the team is progressing towards them. Similarly, Expert AR talks about tactic of using *"weekly reports"* to *"capture all the uncertainties, all the dependencies"* and use it an anchor for discussion with the teammates and for tracking progress.

In our learner data, we came across only a few instances where learners reflect on their state of uncertainty and regulate their uncertainty management strategies and this was not a regular practice for any of the groups. The teams reflected on the state of their progress only towards the end when they were left with limited time to complete the task and when they were unable to resolve a critical uncertainty. For example, consider the excerpt from Team B, study 1. After failing to figure out where and how to place the EV3 brick for a long time, Team B participants reflect back on ideas that did not work for them earlier. However, they finally decided to copy what the other team had done, realizing that they do not have enough time left to complete the task.

1	*Shilpa: What should we do? We have not attached it (EV3 brick) yet. We also have to try it then*
	[Kartika and Shilpa discuss about different ideas for keeping the EV3 and contrasting them with orientations that did not work for them before]
6	*Kartika: See, they have used the cage (structure to hold the EV3 brick).*
7	*B2: Yeah I think we should also just do it and start testing, we have no time left.*

Also, learners do not explicitly discuss and prioritize uncertainties. In episodes where teams struggle with multiple uncertainties at the same time, they find it challenging to break uncertainty into relevant questions and smaller tasks, and often do not reflect on the interdependencies among different uncertainties which is required for planning next steps in the uncertainty management process.

*Summary***.** Experts track their micro and macro level progress; reflecting on their uncertainty management process regularly. But learners do not engage in such processes regularly, likely leading to poor uncertainty management.

Maintaining positive attitude (P6)

Experts emphasize the importance of maintaining a positive attitude when dealing with uncertainties. For example, while reflecting on his earlier experiences of managing uncertainty, Expert ND says: *"You are working on a project, and you want it to succeed, so all the uncertainties have to be resolved. Now you can do it with a positive attitude or a negative attitude. Negative attitude will not lead you anywhere, so positive attitude is must to resolve all those uncertainties. And I think I learned this from the funding application process long back where a lot of experts are sitting in a room, and they are just throwing questions at you. Is it going to be safe? How is it going to work? What percentage? And all of that."* Similarly, while talking about her teaching experience with undergraduate students, Expert SA says that learners generally start panicking if they cannot resolve uncertainties. In such cases, her approach is to intently listen to their concerns and encourage them to look at the uncertainties as *"opportunity for learning"* instead of feeling "*demotivated."*

We observed that learners in our study also get demotivated when they felt stuck in a situation or experience multiple uncertainties simultaneously. For example, in one of the episodes from Study 2, Team C participants used phrases like "*let us go die*" (figuratively speaking) and "*we will be disqualified*" when all their efforts failed to figure out why their toy vehicle was not moving. Their tone was anxious and indicated disappointment. Also, after this episode of repeated failures, the team members changed their uncertainty management approach. Earlier, they were engaged in systematic experimentation and logical reasoning to troubleshoot the problem. However, afterward, they blindly took decisions with the focus to somehow complete the task instead of making sense of their actions.

Summary. Experts emphasize on keeping a positive attitude for effective uncertainty management. Learners often panic in difficult situations and hence needs support for staying positive to ensure progress.

Discussion

Findings from the analysis of experts' interviews advance our understanding of how uncertainties are managed in authentic scenarios of solving ill-structured engineering design problems. Comparative analysis of learners' uncertainty management behaviors with respect to experts' uncertainty management help identify potential learner difficulties and challenges while managing uncertainties. These challenges could throw light on the key problem areas where learners need support.

Our findings revealed that learners' response to the uncertainty of their team-member(s) is not very supportive (refer P1). This is aligned with the findings of Jordan et al. (2014) regarding the supportive and unsupportive role of peers during a robotics engineering activity. We found that in our study, the learners ridicule, ignore or delay uncertainties expressed by their team members. One of the reasons leading to these behaviors was found to be learners' positioning of themselves and their team members during the uncertainty management process (P1). Therefore, to ensure that learners acknowledge uncertainty expressed by their team members and learn from their experiences to resolve it, they should *consider themselves and other team members as equal collaborators* and *equally participate in discussions and decision-making*. These findings thus indicate towards the possible need to *help learners build team rapport and enable equal participation* so that they acknowledge each other's uncertainty and collectively engage in its management process.

Prior research suggests "ignoring uncertainty" as one of the uncertainty management strategies of designers (Lipshitz & Strauss, 1997). However, experts suggest that instead of completely dismissing or ignoring uncertainty, one must acknowledge it and proactively plan mitigation steps to address the uncertainty (P1). Furthermore, experts frequently expand uncertainty and then logically converge to a decision (P2). This aligns with prior research that suggests that instead of converging to decisions early, problem-solvers need to indulge in divergent thinking, especially during the initial phases of design, where they break down uncertainty further, ask more questions, explore various ideas and seek as much information. This helps in clarifying uncertainty, expanding knowledge repertoire, and ensuring that decisions are logical and sound (Dym et al., 2009). Thus, based on these findings, we suggest that learners need support to *build tolerance to uncertainty* so that they feel comfortable with its existence, acknowledge it, and also allow it to persist till they have adequate knowledge to make informed decisions.

Another finding was that learners often ask questions that demand direct answers or information when seeking feedback and usually accept the information without assessing or evaluating them (P3). In contrast, experts seek information from multiple reliable sources before taking a decision (Dym et al., 2009). Experts engage in practices like critical thinking, analytic discussions, argumentation and systematic experimentation for assessing information, evaluating it and applying it in the relevant context in order to make design decisions (Crismond & Adams, 2012). This suggest that learners will *likely require support for articulating uncertainty better and posing relevant questions* that guide their uncertainty management process. Learners may also benefit from *support for making judgments and decisions about the credibility, relevance, and application of information received from various knowledge authorities.* These supports could be in the form of *tools along with instructions regarding their applicability to various uncertain situations.* Tools serve as a medium for asking questions and finding answers as the design process unfolds (Dym et al., 2009) and are frequently used by experts (P4). Such scaffolds are part of an expert's repertoire and often help them keep track of micro and macro progress (P5).

Uncertainties can be overwhelming and lead to a state of *'paralysis'* (Ullman, 2001). To overcome these situations, maintaining a positive attitude and persevering in the face of adversity become imperative (P6). Hence learners may benefit from *environments that foster positive attitudes and behavior*s.

Limitations, Implications, and Conclusion

A limitation of this study is the relatively small sample size of experts and learner groups to make claims about the generalizability of the findings. Although the large number of episodes analyzed from the data of five

groups provides sufficient breadth for analysis, including more heterogeneous groups would ensure diversity amongst participants. Similarly, interviewing more experts and conducting an ethnographic study of experts resolving uncertainties in their workplace setting could help in validating and refining the findings.

This paper looks at engineering design practices from the lens of uncertainty management and highlights six practices that are essential for managing uncertainty effectively. These findings provide new insights for informing teaching and learning of engineering design at the K-12 level. Uncertainty is an inherent part of the engineering design process and findings from this study can inform the design of learning environments to support productive engagement in disciplinary practices of engineering design. For example, our study highlighted how experiencing certain uncertainties at specific design stages triggers negative emotions like feeling anxious and demotivated, and how it affects learners' uncertainty management processes. These findings can be leveraged by the Learning Sciences research community for creating robust scaffolds for supporting uncertainty management in classrooms. Future research could further elaborate on key problem issues that hinders learners' engagement in engineering design practices and identify relevant pedagogical and technological solutions to address them. Simultaneously, we need to keep advancing our knowledge regarding underlying processes that affect learners' uncertainty management.

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University Students' Conceptions of Reflective Learning in Education Courses

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Abstract: Reflective learning experience has been considered crucial in higher education. Accordingly, most programs have embedded reflective learning experiences into the curriculum. However, there is a dearth of research on students' conceptions of reflective learning and how they perceive the value of their experience. This study aimed to explore how university students taking education courses understand reflective learning. A qualitative analysis of data collected from 12 student interviews and 161 open-ended survey responses revealed four different ways of understanding reflective learning: engaging with content, evaluating learning, relating learning to other experiences, and reframing understandings and perspectives. The findings have implications for design of learning environments for reflective learning.

Introduction

Reflective learning experience has been considered crucial because of its importance both in formal and informal learning environments. In formal learning environments, reflective learning experiences provide students with opportunities to engage in high quality dialogue (Brockbank et al., 2002; Dukewich & Vossen, 2015), develop learner agency (Lin & Schwartz, 2003), and examine the effectiveness of their learning strategies (Ertmer & Newby, 1996). Reflection has also the potential to cultivate lifelong and transformative learning that go beyond the context of classrooms (Brockbank et al., 2002; Tan, 2021). In informal learning environments such as social media and the Internet, for instance, students are often presented with a great deal of misinformation and disinformation. Thus, developing reflective skills and mindset helps them question and challenge the source and validity of the information rather than readily consume it. In the context of workplace learning, reflection can serve as a tool for dealing with uncertain and complex issues (Chan & Lee, 2021) and coping with the demands of multiple expectations (Ryan & Barton, 2020). It is also argued that reflection is central in the concept of graduateness as it underpins the skills and attributes that are valued by employers (Wharton, 2017).

Because of the above-mentioned potential benefits, there has been widespread calls for integrating reflective learning into courses and experiences in higher education. As a result, reflection has become a requirement of many university courses (Ertmer & Newby, 1996; Quinton & Smallbone, 2010; Rivers et al., 2014). However, little is understood about how to develop reflective skills (Clara, 2015; Ertmer & Newby, 1996). Besides, reports indicate that students' engagement in reflective learning is minimal (Mair, 2012; Power, 2016). Mair (2012) argued that the value of reflective learning in higher education is seldom realized as students' engagement is very unsatisfactory.

Students' minimal engagement in reflective learning can be attributed to the various elements of learning environments. Among these elements is students' own conceptions of what reflective learning entails. Research on students' conceptions of learning has generally gained considerable attention because of its association with learning strategies, approaches to learning, and effective learning (Loyens et al., 2009). Conceptions are often adopted based on perceived learning contexts (Trigwell & Ashwin, 2006) and develop and change through educational experience (Entwistle & Peterson, 2004; Loyens et al., 2009). Thus, purposes and underlying values of reflective learning that are conveyed either implicitly or explicitly by instructors or their educational programs determine the forms and focuses of reflection (Ecclestone, 1996). Understanding students' conceptions provides insights about the nature of learning environments designed to foster reflective learning and student engagement.

Research on reflective learning employed an array of approaches to examine students' reflective learning experiences and/or develop frameworks for the purpose. Some researchers have relied on learning artifacts such as journals, portfolios, and reflective assignments to gauge levels of students' reflection (e.g., Fund et al., 2002; Kember et al., 2008). Others employed structured surveys and conducted quantitative analysis to determine students' reflective skills and to compare the levels across certain demographic variables (e.g., Kember et al., 2000). Both approaches provide insights into the nature and level of students' reflective skills and experiences. However, more evidence of and insights into the why and how of students' approaches to reflective tasks can be obtained by looking into their conceptions of what reflective learning entails. This paper therefore aimed to explore students' conceptions of reflective learning. The study was guided by the research question, "What are students' conceptions of reflective learning in the context of education courses?"

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Conceptions of Reflective learning

Conceptions refer to the different ways people understand a particular phenomenon (Marton & Pong, 2005) that mediate their reactions to situations involving the phenomenon (Pratt, 1992). In the literature, there exist a variety of conceptualizations of reflective learning ranging from a simple awareness of events and thoughts to critique and transformation of assumptions and hegemonic practices. Dewey's (1933) conceptualization of reflective learning relates to a rational and systematic process of problem solving. Building on Dewey's work, Clara (2015) emphasized the notion of transformation of an incoherent situation to a coherent one as central to the concept of reflection. In his transformative view of learning, Merizow (1991) understood reflection as critique of assumptions and taken-for-granted beliefs. Others considered self-examination and inquiry as central in the reflective learning process (Boyd & Fales,1983; Mortari, 2012).

These diverse interpretations of reflective learning allow educators to adopt or develop perspectives that align with the purposes they pursue in their courses. These perspectives have the potential to influence students' conceptions of reflective learning. This is because conceptions are situational and exposure to different learning contexts impacts how students adopt and develop them (Smith & Blake, 2009). For instance, research showed that constructivist conceptions of learning were reflected by students who experienced a learner-centered learning environment compared to students who were enrolled in a conventional curriculum (Loyens et al., 2009).

Students' conceptions, which are adopted based on perceived learning contexts, would influence their approaches to and engagement in the task (Trigwell & Ashwin, 2006). Cognizant of such relationships, we believe that efforts to foster reflective learning in higher education would benefit from an understanding of students' conceptions. This paper therefore aimed to explore the different ways students understand reflective learning in the context of education courses.

Method

This is part of a larger study on perspectives and practices of reflective learning in higher education. The purpose of this paper is to understand and describe students' conceptions of reflective learning using data from interviews and open-ended survey at a western Canadian university. To achieve our purpose, we adopted a phenomenographic research approach. At the heart of phenomenographic research is participants' conceptions of the phenomena of interest. The underlying theoretical assumption is that there are only a limited number of ways of understanding a given phenomenon (Entwistle, 1997; Richardson, 1999; Tight, 2016). In this study, the phenomenon of interest is students' conceptions of reflective learning.

Data were collected from students in the Faculty of Education in 2020. Although reflective learning is expected to be incorporated in different programs and disciplines, we focused on students taking education courses because they are expected to have a more nuanced view of reflective learning. Thus, education courses that were scheduled to be offered in the academic year were first identified. Then, the brief course descriptions that were posted online to assist student enrollment were examined pertaining to inclusion of reflective learning experiences. Accordingly, 22 courses that included reflection in the course descriptions, learning outcomes, and/or assessment strategies were selected as sources of data. Such preliminary assessment was important to ensure that participants who had the experiences of the phenomena of interest are included which is considered important in phenomenographic studies (González, 2011). Then, students were accessed via their professors and invited to complete a survey and to volunteer for interview.

A total of 274 students participated in the survey. Students were comprised from undergraduate, graduate and professional development programs. Graduate students are MA/MSc/MEd students who were enrolled in different programs such as mathematics education, curriculum studies, educational leadership, and equity studies in education. Undergraduate students are comprised from different faculties of the university, but they were all taking education courses. Students of the professional development program (PDP) are teacher education students who were admitted to the program after completing a bachelor's degree in different disciplinary areas and were preparing to become elementary or secondary school teachers.

Data were collected through interview and open-ended survey. Interviewing is considered in phenomenography a primary method to understand participants' conceptions of phenomena (Åkerlind, 2005; Marton, 1986) because of its capability for eliciting detailed and rich account of participants' lifeworld (Ashworth & Lucas, 2000). We employed a semi-structured approach to interviewing that involved improvising questions and probes when appropriate. The general purpose of the interview was to explore students' understanding of reflective learning, the kind of opportunities they were provided to engage in reflective learning and their perceptions of barriers to engage in the processes. However, the data used for this study focuses on their conceptions of reflective learning. Examples of interview questions that helped to elicit participants' understanding include: How do you describe reflective learning? In what ways do you think you have been engaged in reflective learning in this course? How did you go about reflection in the course? How is being

reflective important in higher education? Interviews were conducted both in-person and virtually. Since most of the data were collected during the COVID-19 pandemic, phone and zoom interviews were used depending on the participants' choice. Among the interviews we conducted for the larger study, the analysis for this paper is based on data from twelve participants. Interviews were audio-recorded and transcribed verbatim.

The survey included both close-ended and open-ended items that were intended to answer the research questions we formulated in the larger project. However, in this paper we used responses to one open-ended item, i.e., How do you define reflective learning? Among the 274 students who completed the general survey, 161 students responded to this question. Of these, 51.6% were taking professional development courses, 29.8% undergraduate courses, and 18.6% graduate courses.

In phenomenography, data analysis is a recursive process in which transcripts are read several times, pertinent data are identified and segmented, and then the underlying meanings of the sorted data are compared (Åkerlind, 2005; Forster, 2016; Tight, 2016). Accordingly, we sorted, segmented, organized, and examined data from the responses to the open-ended item in the survey and the interview transcripts. Then, we read the transcripts multiple times to explore similarities and differences in participants' conceptions. The process resulted in the development of categories of descriptions, which are the main outcomes of phenomenographic analysis (Åkerlind, 2005; Entwistle, 1997; Svensson, 1997).

Results

Analysis of data indicate four qualitatively different conceptions of reflective learning by students: engaging with content, evaluating learning process, making connections to experiences, and reframing understandings and experiences. Descriptions of each category are presented with examples of excerpts from the data.

Table 1

Categories of students' conceptions of reflective learning

Category	Description	Example Excerpts
Engaging with Content	Reflective learning is seen as engaging with course content and involves an in-depth examination and analysis rather than merely memorizing the information	"I think it's more about taking what you learn and not just memorizing facts and then spitting them out on a test, but learning it and then kind of processing it more deeply and showing it in a paper or some kind of project that you can really think about it and critically think about it" (UGs1)
Evaluating Learning process	Reflective learning looking back and reviewing learning goals, activities and strategies and determining their effectiveness	"It is about learning strategies, thinking about effective strategies, what works, what does not work, etc. . . . I think it's, at this point, the only way that I know to actually like how to do well in my classes. These are the methods that I use for every single class. And this course is no exception" (UGs6)
Relating learning to experiences	Reflective learning is about making connections among course concepts, prior knowledge, past personal experiences and anticipated practices and experiences	"I think [reflective learning] encourages the student to come out of their comfort zone and then they're sharing their stories as well, because each thing . . . can be tied to something in the real life and that's why we're studying it because you want to take to the job sector, real life sector or home life." (UGs7)
Reframing understandings and perspectives	Reflective learning is seen as developing new knowledge, modifying, or reconstructing beliefs, experiences, and practices	"It's that the reflective piece is the goal and is the learning and when you kind of spiral in your learning, so I find that I revisit certain themes that's to do with my inner landscape. And it's changing the perspective that I once had on something that was a truth" (GRs16)

Reflective learning as engaging with content

In this category, reflective learning is understood as a process of critically engaging with disciplinary concepts, principles, and ideas that students are presented with. Participants used an array of expressions that denote the thought processes and activities involved while engaging with the subject matter content which include thinking deeply, critically assessing, contemplating, taking a moment/time to think, looking back, mulling over, pondering, and understanding. Despite the variations in expression, they refer to mental activities applied to content that go beyond surface level. The following excerpts demonstrate the processes involved while engaging with content:

UGs25: Deep thinking about the course material that can be reflected in interesting engaging group discussions, written assignments, or any other opportunity for critical thinking. Not pure fact memorization.

PDs104: Going beyond just surface level to explore and develop new ideas.

UGs72: Reflective learning is learning that occurs when given a chance or moment to stop and think. It is the deeper understanding of thoughts and ideas, rather than the mere memorization of them.

PDs159 Taking time to think about and contemplate on ideas, readings and discussions related to education.

In the above excerpts, one can notice words and phrases such as 'deep thinking', 'stop and think' and 'contemplate' that illustrate the thought processes involved when engaging with contents and reading materials. These descriptions imply that reflective learning entails going beyond rote memorization and learning and rather focus on engaging in higher order thinking processes pertaining to the content being learned. When asked about how they understand reflective learning, one interviewee replied, "I think just generally it's not blindly following and consuming the material that we are given but taking time to almost like digest this, and have it make sense in for a personalized understanding of whatever it may be" (GDs22). So, the main facet of this category of conception is that reflection targets content with the aim of developing an in-depth understanding of what they are learning.

Reflective learning as evaluating learning process

In this category, reflective learning is understood as looking back to learning goals, strategies, activities, and outcomes. This category is different from the previous as reflection mainly targets the "how" than the "what" of learning. The following excerpts from four participants' responses to the question on what reflective learning is clearly demonstrates this conception.

UGs01: From a student perspective, looking deeply at study habits, strategies, and skills; and motivations for learning. Analyzing these areas and deciding whether they are effective and serving goals, and how improvements can be made in the future.

PDs134: Reflective learning is understanding both how you learn and the influences that allow you or disallow you to learn.

GRs56: I would think about how engaged I was, what my circumstances were at the time, what factors contributed to or detracted from my learning or non-learning, and the result of those factors on my learning.

UGs13: You complete the task and then you reflect on it - how you approached the task, what strategies, what went well etc.

Here, students reflect on learning activities and processes that they were engaged in. An important facet of this conception is that reflection targets not only the goals they set, the learning strategies they chose and employed, or the activities they performed, but also the factors that are associated with the way they approach the tasks. Such a reflection often aims to identify what worked well and what did not in the learning process and thereby inform future learning. UGs20's definition of reflective learning succinctly describes this aim. The participant defined it as "looking back on your own learning/studying to think about how it went, how it could have been better, and what you can do to make it better."

Reflective learning as relating learning to past and future experiences

In this category, reflective learning is seen as making connections between learning and personal life experiences and anticipated future practices. Key terms such as relating, connecting, and reconciling are emphasized in participants' responses that are coded in this category. The connections can be of different kinds with different purposes; however, participants viewed it as a key characteristic of reflective learning that makes it distinct from

non-reflective activities. One of the common types of connection evident from participants' responses is between course contents and personal experiences. That is, reflective learning is viewed as relating concepts and ideas encountered in the courses to personal life experiences. The following excerpts illustrate the point:

PDs146: The ability to make connections with what you are learning to your personal experiences and values.

UGs02: Taking a step back after readings or assignments to see how it would manifest in my own life in order to better understand concepts and create a deeper connection with the material

UGs58: Reflective learning involves students thinking about what they have read, done, or learned, relating the lesson at hand to their own lives and making meaning out of the material.

PDs179: A style of learning in which students are encouraged to think about concepts introduced in seminars/readings/assignments and how the ideas are related to their own values and experiences.

Reflective learning as relating entails connecting course concepts not only to personal lives but also to previously learned concepts and anticipated professional practice situations. The following excerpt from a participant illustrates the importance of making connections between contents over time:

> Reflective learning (or at least the process of reflective assignments in this course) combines summation of topics and encourage extension of presented ideas and philosophies into previously covered topics/information as well as whether the topics/information agree or disagree with personal, currently existing values. (PDs153)

Another facet of connection is expressed in terms of applying learning and/or personal experiences to other situations. Participants illustrated various forms and directions of transfer of learning and experience which include applying concepts or theories learned in courses to practice situations, or future practice; applying personal experiences to the understanding of the course experience; or use learning strategies that are found effective in future learning. Among these variety of applications, the most common one entails the use of course based knowledge and skill in personal and professional lives. UGs59's response to the question of what reflective learning is typifies this conception. The participant stated, "reflective learning is applying what you learn in class to your daily life. Applying it can take the form of thinking about the material, discussing it with someone else or creating beneficial activities for your family's development." The notion of application is not only from contents to personal and professional life but also from personal and professional experience to course experiences. UGs40's response indicates the bidirectional nature of application between content and personal experiences. The participant stated, "applying own experiences on what is being taught and what things I learn apply to my own life." Another participant also described reflective learning as "using past experience to contemplate current issues and guide future actions."

In general, this category is different from the previous categories in its focus on examining current learning experiences in relation to past and anticipated future experiences. The purpose could be simply to facilitate understanding of what they are learning or consider the relevance of what they are learning by examining its applicability.

Reflective learning as reframing understandings and experiences

In this category, reflective learning is considered as changes in ideas, understandings, practices, or personal perspectives. Although experiences based on the previous three categories would ultimately lead to such kinds of changes, what differentiates this category of conception is its prime focus on the outcomes of the reflective learning process. As such, it entails acquiring new ideas pertaining to subject matter content; reframing prior assumptions and perspectives; and adopting new ways of doing things like learning or teaching.

One of the outcomes is questioning personal perspectives and biases. That is, participants understood the outcomes of reflective learning in terms of reframing preconceived ideas and beliefs. One participant, for example, described reflective learning as: "critically thinking of your internalized attitudes, assumptions, beliefs, and experiences and how we can shift our views to better consider the experiences and contexts of others" (PDs188). In a similar way, the following response emphasizes the notion of reflective learning as reconstructing perspectives and experiences:

> [Reflective learning] is kind of see where you yourself as an individual have come from. So, for example, when I left the country [Canada], and I began teaching in Korea, and where I was, as a teacher, and, as a beginning, like a new educator in a new environment is a very different person from where I am now. So, it's like you have to self-reflect not only on new pedagogies that you've learned and how you can implement them, but also how you as person has to have changed over time. (GTs17)

When asked about the importance of reflective learning, another interviewee illustrated how change and growth is key by saying, "I wanted to say, I don't think you can grow without reflection.… I think change is inevitable, but to kind of create authority in your growth, yeah, I don't know that's possible without being able to reflect" (PDs23). A related aspect of reframing focuses on modifying, adding to, or correcting previously acquired knowledge or just acquiring new knowledge. The following excerpts indicate changes related to knowledge:

UGs47:	Learn things you didn't know before or things knew already but others may hold different ideas.
UGs57:	Acquiring new knowledge with self-reflection during or after that new learning.
GRs76:	Being able to revisit concepts in order to further improve and cement them.
PDs191:	The idea of coming back to previously owned knowledge to challenge, complete, correct it.

In general, this conception emphasizes the changes achieved as a result of reflective learning experiences. Participants' responses may include both the processes and objects of reflection; however, seeing things anew and/or reframing existing understandings, beliefs and assumptions are seen as central to the concept of reflective learning.

Discussion

Our findings indicate that students understood reflective learning in four qualitatively different ways: engaging with content, evaluating learning, relating learning to other experiences, and reframing one's own understandings and beliefs. Scholars contend that students' conceptions are situational and are influenced by the nature of learning environments they experience (Loyens et al., 2009; Smith & Blake, 2009). Thus, the four categories we identified in this study provide insights into the kind of reflective learning experiences and tasks that students have been engaged with. These experiences vary in their focus ranging from disciplinary concepts to personal beliefs and life experiences.

The goals of engaging with content at greater depth; evaluating one's own learning strategies; and exploring concepts and theories in relation to one's prior experiences and assumptions are all relevant. However, considering the uncertainties and complexities of the contemporary world as well as the abundance and pervasive influence of digital information on students' formal and informal learning, the focus of reflective tasks on content, learning strategies and personal experiences may not suffice. Gorski and Dalton (2020) question the adequacy of achieving personal transformation through reflection on one's experiences and biases, albeit an important goal by itself. We concur with their call for the need to provide students with opportunities of examining hegemonic practices and taken-for-granted assumptions and thereby transforming structures and systems to pursue justice in the wider society. In addition, explicit instruction of conceptualizations of reflective learning that go beyond content and personal reflection would provide students opportunities to explore alternative possibilities and aim towards the larger goal of social justice.

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Teachers' and principals' views of interdisciplinary learning

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Abstract: Little is known about how teachers and principals view interdisciplinarity at the K-12 level. In recent years, we have been working with Israel's Ministry of Education and ten secondary schools to develop and enact interdisciplinary curricula in the humanities. During this partnership, we conducted a series of twenty-four interviews with teachers and principals, to glean their views of interdisciplinarity. We found that they understood interdisciplinarity as a broad reform with the potential to impact school life in myriad ways. Moreover, their views on the definitions, potential benefits, and ways to enact interdisciplinarity at the K-12 level extended beyond a cognitive lens, to include sociocultural and critical interpretations as well. Ultimately, we believe that teachers and principals are uniquely situated, and that their points of view could contribute to a grounded theory of interdisciplinarity at the K-12 level, which is currently lacking.

Over the past century, interdisciplinary learning at the K-12 level has often been seen as a promising innovation. Yet, notwithstanding many efforts at interdisciplinary reform, there is scant unbiased theoretical and empirical research explicating what it is, why it may be worthwhile, or how best to implement it (for a brief historical review see Grossman et al., 2000). Indeed, not much has changed since Applebee et al. (2007, p. 1004) noted that "scholarship in the field is remarkably underconceptualized".

With an eye towards understanding the meaning of interdisciplinary learning at the K-12 level, its potential value, and how it is best enacted, this paper presents teachers' and principals' views on these questions. The data we analyzed was drawn from an ongoing research-practice partnership (RPP) between our group from the University of [blinded] and Israel's Ministry of Education, which may pave the path towards a large-scale shift to interdisciplinarity in the humanities across Israeli middle schools.

During the first phase of our study, we conducted twenty-four interviews with twenty teachers and principals representing ten schools, to glean their views on what interdisciplinarity means in a school context. Most of the existing research on interdisciplinarity at the K-12 level is rooted in three approaches – cognitive, sociocultural and critical – which we describe briefly in the Background section. In the subsequent sections, we show how our interviewees simultaneously adopted all three approaches, leading us to conclude that they ought to be viewed as coalescing; and setting the stage for future efforts to generate a grounded theory of interdisciplinarity at school that takes all three approaches into account.

Background

Underlying any definition of interdisciplinarity is a particular view of what constitutes a discipline. Three central ways of conceptualizing disciplines can be found in the literature and each bear on interdisciplinarity differently. The cognitive approach, which is focused primarily on knowledge, understanding, and ways of thinking (e.g., Hirst, 2010), views disciplinarity in terms of content and expertise. Bruner, for instance, argued that at the core of each discipline are some fundamental concepts, such as *tragedy* in literature or *number*, *measure*, and *probability* in science (Bruner, 1960/1999; cf. Schwab, 1964). In another notable example, Wineburg (2001) identified and articulated professional historians' disciplinary heuristics and unique disposition towards far-removed objects of knowing (cf. Herrenkohl & Polman, 2018). From a cognitive perspective, an interdisciplinary curriculum could entail investigating complex phenomena that are better understood when viewed simultaneously through multiple disciplinary lenses (e.g. Boix Mansilla et al., 2000).

While the sociocultural approach recognizes that disciplines are marked by identifiable bodies of knowledge and ways of thinking, it views them as part of a complex system: "mind, culture, history, and the social world [are] interrelated processes that constitute each other." (Lave, 1991, p. 63) This view considers disciplinary knowledge in light of the identities of the people who create and use it and the human contexts within which it is applied. Viewed in this way, interdisciplinarity would manifest itself first and foremost in the creation of a new community whose members hail from diverse disciplinary ones, which in a K-12 context could comprise teachers of different subjects. Forming the community would require new routines, a shared history and a collective sense of purpose, in addition to intellectual innovation (Grossman et al., 2001).

Finally, the critical approach views the disciplines primarily as hierarchical structures that regulate discourse by determining how people are allowed to use language. Most notably, it was Foucault who argued that

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to partake in a disciplinary discourse, one must "fulfil certain conditions, in a sense stricter and more complex than pure and simple truth… in order to part of a discipline, a proposition has to be able to be inscribed on a certain type of theoretical horizon" (Foucault, 1981, p. 60; cf. Apple, 2004). By extension, disciplinarity can also determine how financial resources are allocated and which activities are valued by the institutions that allocate them (Weingart, 2010). Thus, interdisciplinarity would mark an opportunity to unveil and undermine institutional power structures and empower individuals to engage in activities previously considered illegitimate (Fish, 1989) (1).

Several empirical studies have fleshed out these theoretical approaches. Applebee et al. (2007) adopted a cognitive lens, distinguishing between different levels of conceptual integration that form an "interdisciplinary continuum." They found a correlation between the degree of integration and the likelihood that teachers incorporate discussions and "envisionment-building" into their instruction; but they also warned that there are additional factors at play (p. 1035). Grossman et al. (2001) established an interdisciplinary community of English and History teachers and studied it through a sociocultural lens, to show how the evolution of the community's integrative epistemic discourse was intertwined with interpersonal dynamics and additional cultural dimensions. Brandes and Seixas (2000) used a critical lens to explore how a group of teachers navigated the institutional tensions and inconsistencies between school and university contexts, when studying at an interdisciplinary program in the humanities. Yet lacking from the existing scholarship is an in-depth view of teachers' and principals' own perspectives on interdisciplinarity at school – what they understand it to mean, why they are drawn to it, or how they think it is best to implement it. To address this gap in the literature, we asked:

1. How do teachers and principals understand interdisciplinarity?
2. What motivates them to implement interdisciplinary curricula?
3. How do they believe interdisciplinarity should be enacted in school contexts?

Method

Context

In 2019, we partnered with Israel's Ministry of Education for a four-year Research-Practice Partnership (Coburn & Penuel, 2016) with two goals in mind. First, we set out to develop, implement and test new interdisciplinary curricula in the humanities at Israeli middle schools. Second, we were interested in further conceptualizing interdisciplinary learning, understanding its unique features, and perhaps most importantly, articulating its affordances and constraints in educational contexts. Because we hope to make contributions to practice and theory in an iterative process, a Design-Based Implementation Research (DBIR) approach was selected (Fishman et al., 2013). We commenced by recruiting ten middle schools, which had already begun implementing interdisciplinary programs or were intent on doing so soon. For the first iteration of our study, each school sent several representatives to a professional development (PD) course in which we discussed some theoretical background; provided scaffolds for each team to develop a concrete plan of action to implement in 2021/2; and encouraged each team to experiment with a small-scale pilot implementation (2).

Participants

In this paper, we present findings from twenty-four interviews conducted in two rounds, with representatives of each of the ten schools in our project. The schools represented a variety of sizes, socioeconomic levels, and academic achievement levels. The practitioners we interviewed ranged from second-year teachers to seasoned principals.

Data collection and analysis

Our data sources included recordings and fieldnotes from all PD sessions; artifacts produced by participants, including a set of lesson plans and a summative poster by each school team; and interviews, which provided the bulk of the data for this paper. For each of the ten schools, we interviewed either the principal or vice-principal, and one teacher. The first interview focused on interdisciplinarity in K-12 in general, whereas the second round, which only included the teachers, focused on their experiences at the PD course, and how their views and plans had developed throughout the year (3). Interviews were semi-structured and were conducted via ZOOM, recorded, and transcribed. We used a thematic approach (Braun & Clarke, 2006) to analyze the transcripts, generating a detailed portrait of their views of interdisciplinarity, their motivations for implementing it, and the changes to school life that they think it might entail. Where possible, the interview data was triangulated with other data sources to increase validity and broaden our interpretive horizons.

Findings

For our interviewees, interdisciplinarity extends beyond the walls of the classroom and can impact life at school in myriad ways. Our analysis culminated in a distinction between three spaces that serve as metaphors for the kinds of dynamics that were described: the classroom, the teachers' room, and the principal's office.

Inside the classroom

How do teachers and practitioners perceive what goes on in class during an interdisciplinary lesson? In a traditional disciplinary setting, the content of a curriculum is often organized around the big ideas that shape a specific discipline's discourse. But in lieu of the typical disciplinary structure, how are interdisciplinary curricula organized? Our interviewees described three interdisciplinary foci: historical, topical, and identity-centered. Describing the historical focus, one teacher explained that "for every grade we choose three disciplines, and the central discipline is always history… [the others] could be literature and civics, [or] geography and literature" (Esti) (4). The topical focus invites learners to investigate a single topic from multiple disciplinary perspectives; for instance: "We discussed nature, the connection between humankind and nature. Really nice. We learned a poem […] and the Jewish attitude towards nature and the environment. We also learned about social activism in Jerusalem" (Adelle). Another teacher described a unit that was organized around an investigation of students' identities: "each day we ask a specific question about identity, and then all of the disciplines are learned through the prism of that identity-focused question" (Neta).

Integrating the disciplines in these three ways – which are not mutually exclusive – is intended to highlight the connections across knowledge that would otherwise remain fragmented, rendering it more meaningful. One interviewee explained: "[interdisciplinarity is] when the students get the coherence of the whole story, [when] they understand that now we're talking about racism and they find it in the story we're reading, [*and*] in human history, *and* understand what Judaism's attitude towards it is." (Adelle) For another interviewee – an experienced principal – the difference between fragmented bits of information and interconnected knowledge is equivalent to the difference between rote learning and learning for understanding: "shifting from a student who knows s/he needs to memorize the material to one who understands, who really understands the topic and sees it from multiple perspectives. That, from my point of view, is the [interdisciplinary] approach." (Sivan)

In addition to content, the practitioners we interviewed also described other ways in which a shift to interdisciplinarity could impact classroom dynamics. By default, abandoning disciplinarity in Israel means departing from the mandatory curricula, which are overseen by the Ministry of Education's Pedagogical Secretariat. This comes with a renewed sense of freedom, which Ari, an experienced principal, called "complete autonomy", allowing teachers to do "whatever they want." While this principal wasn't happy with all his teachers' choices, he still called this aspect of interdisciplinary learning "a huge success." Another principal explained how this sense of freedom that derives from the lack of oversight inherent to interdisciplinarity affords a practice that he called "to flow," allowing the lesson to develop in unpredictable ways that aren't constrained by disciplinary boundaries: "all of my pedagogical sensors light up when a discussion in class flows and flows… looking back, […] these [interdisciplinary] lessons were much more interesting and instructive." (Amir) Another teacher reiterated this:

> We start talking about refugees in Israel [but] according to the curriculum we designed, next lesson is meant to be about the French Revolution… dammit, there is no matriculation, we just had an amazing discussion about immigrants' children, which is important from an ethical perspective, I go with it, happily! So, it will take some time, OK… fourteen-year-old's finally express their opinion about something… you want me to interrupt that? It's anti-democratic (Alex).

Some interviewees also tied interdisciplinarity to other pedagogical reforms that they hoped to implement. For example, one teacher explained how the interdisciplinary curriculum they designed was primarily intended to grant students more agency: "For us, interdisciplinarity came after we decided to focus on student proactivity as a pedagogical goal." (Neta) Another principal explained that "interdisciplinary learning at its best is something that is very, very independent for students. They know how to do it on their own and in groups. The teacher is a mediator not a lecturer…" (Sivan). One teacher explained that while inquiry learning was not necessarily contingent upon interdisciplinarity, the latter is "much more inviting, because it opens things up." (Jen) Some examples of project-based alternatives to traditional forms of teaching and learning that interviewees associated with interdisciplinarity included field trips, creative art projects, recording a podcast, and producing books.

A final feature of the classroom dynamics that our interviewees tied to interdisciplinary curricula is that it affords more meaningful learning for students. This can manifest itself in (a) a focus on skills rather than content;

(b) teaching content that is relevant to students' everyday lives; (c) improved emotional wellbeing; and (d) a deeper relationship between the teacher and the class. Several interviewees perceived interdisciplinary learning as an opportunity to focus on age-appropriate transferable skills, at the expense of discipline-specific content. One principal explained that there is not enough correspondence between the official disciplinary curricula overseen by the Ministry and students' stage of cognitive development; whereas "when we're talking about interdisciplinary pedagogy it means we aren't looking at each subject, we are looking at what skills the learner needs in the middle school." (Dvir) Ron explained that while interdisciplinary settings afford an opportunity to focus on skills, the nature of these skills is similar to those taught in traditional disciplinary lessons: "it's the same skills: reading, writing, comparing texts." In contrast, Neta described a unique skill that is inherently interdisciplinary:

> Once you connect the [multiple] disciplines, you understand complexity. If you bring a literary work that illuminates the aspects of dealing with a particular issue, then history will gain depth […] the connectedness allows us to deepen students' perspectives. A lot of times at the year's end [students] themselves tell us that they acquired diverse perspectives on events or phenomena, they tell us that they learned to look at the world in a more complex way.

For some educators, the main reason for adopting an interdisciplinary approach is because students are bored with disciplinary content or unable to relate to it: "I [also] teach history, and the student can't connect with that." (Esti) Along the same lines, one principal explained that the primary motivator for an interdisciplinary curriculum is to make learning more relevant to students' lives: "for it to annoy them, make them happy, do something to them… they may not remember the details, but they will remember the values that derive from it, the things that are relevant to their lives." (Sivan) Another principal explained that interdisciplinary learning is more relevant *and* more interesting, because "reality is interdisciplinary. You look at the Supreme Court [for example]; understanding what happens there at any given moment requires an understanding of civics, history, and sociology." (Amir)

Some teachers and principals identified interdisciplinarity as a setting that can also contribute to students' emotional wellbeing. According to one principal, "the main benefit is that it will be good for kids to come to school. It's considered almost taboo or rude to talk about the enjoyment of learning, the pleasure that Socrates talks about." From his perspective, "connecting learning to kids' lives will make it more interesting and by extension more pleasurable." (Amir) This idea related to another theme that emerged from our analysis. Some of the interviewees explained that interdisciplinarity enables teachers to forge deeper, more meaningful, relationships with their students, due to the greater number of teaching hours dedicated to interdisciplinary curricula, which essentially pools resources from multiple subjects: "…I get to see these students for all their difficulties, complexities, successes… these connections forged over time transform me into a meaningful figure for them." (Esti)

Teachers' room

Being a teacher extends beyond the classroom. The practitioners that we interviewed described various ways in which enacting a new interdisciplinary curriculum might relate more broadly to a teacher's professional identity and daily routines. For instance, one interviewee discussed how teacher training programs cultivate a disciplinary identity among trainees, which can be difficult to apply in an interdisciplinary setting. Others also identified a similar tension – when they assume a disciplinary identity, teachers have a sense of confidence grounded in their expertise; but at the same time, this limits opportunities to learn new content:

> This year I began teaching literature, which is something I've never done [because I am a history teacher], and I really enjoyed it. On the other hand, this raises the question of professionalism… I am the only person at school with an MA in history and I think I'm a good history teacher [so why should others teach history?]. There is a tension here. (Jason)

What characterizes the professional identity of interdisciplinary teachers? Given the requirement to teach content outside their realm of expertise, a teacher must be "open to learn, an autodidact, creative, think outside the box… there needs to be openness and desire, it won't work with everyone. For a teacher who's been in the system for thirty years it could cause an identity crisis." (Esti) Others mentioned a sense of professional loneliness that accompanies interdisciplinarity, which isn't backed by any formal body in the Ministry of Education: "I am doing something so lonely… When I talk about it with the head of History or Literature [at the Ministry] they are

shocked, so who's backing me?" (Adelle) Another teacher explained that the interdisciplinary approach requires a different disposition towards students:

> For my professional identity the success of the interdisciplinary program is a dream… if there are teachers that think that children, teens […] don't have a deep inner world or well-formed or interesting views, a teacher who believes that is unsuited for interdisciplinary teaching. Really. Interdisciplinary teaching is for teachers who believe that each student has depth, curiosity, an opinion […] whoever believes that is suited for interdisciplinarity. (Alex)

Almost all the practitioners we interviewed discussed the process of *developing* the interdisciplinary curriculum at length, identifying it as a unique experience that had an impact on their day-to-day lives at school. One teacher with three years' experience teaching interdisciplinary curricula described the norm at her school:

> We sit and build the curriculum; each teacher in the community comes from a different discipline, and then according to the topic we choose, everyone brings content from their own world… no year is like the previous one, because the curriculum is always being updated, and if there are new teachers I believe everyone needs to leave their mark, because otherwise it's like "let's find a lesson plan online and teach it", which is worthless… (Esti)

Designing the new curricula requires effort on behalf of the teachers, who don't always feel they've received adequate training: "no one taught me how to design an integrated curriculum." (Adelle) Indeed, one principal identified curriculum design as a major hurdle for enacting a new interdisciplinary curriculum: "[it] requires intense collaboration between teachers… how do you indicate that they're doing something amazing that not everyone can do?" (Amir) Given that the content in the humanities can be controversial, designing the curricula also generates an ethical discourse among teachers, who need to decide what's worth teaching and what is off-limits: "[the conflict with the] Palestinians is an explosive topic… we're not going to agree, as colleagues, we're not going to agree; we won't form a clear message on this issue […], which is fine, I love it!" (Alex) With regards to this tension, another interviewee suggested that teachers be allowed to choose their own path: "not everything will be dictated [to teachers]; there will be suggestions, but they won't be dictated." (Ron)

Designing the curriculum is typically done collaboratively, meaning that enacting an interdisciplinary curriculum requires intense teamwork, which tends to revolve around a weekly meeting that is seen as essential: "there is no such thing as cancelling the [interdisciplinary] staff meeting, it's our 'holy of holies.'" (Noam) Sometimes, collaboration can lead to power struggles between teachers of different subjects, which one principal called "the discipline wars." (Ari) Some of the teachers also drew a parallel between the collaboration among the teachers on the team and the ways in which students interact in class: "I do the same with the teachers as I demand from students. Meaning I form a group, make sure there is all kinds of enrichment and camaraderie, and that it is experiential… meetings are significant, not just coming together to chat." (Noam)

What purpose do interdisciplinary staff meetings serve? One of the teachers discussed emotional support, explaining that at a certain point "it really feels like family, you can share, everything said there stays there, I feel safe to vent… it's totally open." (Alex) Other teachers pointed out that they sometimes need their colleagues' professional guidance: "if I am a language arts teacher I will teach history if need be, but I will first sit with someone who is more professional." (Sarah) Others pointed out that collaboration affords an equal distribution of the workload: "in the end it pays off, because I wrote a [lesson] plan, and six others each wrote one, so we already have seven lesson plans." (Esti) Finally, one principal described how collaboration offers "a new group to belong to. I no longer belong to the literature staff, or bible, or history, I am part of a development staff… everyone contributes something that the others don't have" (Dvir).

Principal's office

A third realm of influence that interviewees tied to interdisciplinarity touched on the school's institutional structure and organizational culture. This category included strategies for implementation and potential organizational hurdles and benefits, timetables and schedules, and external partnerships. Several interviewees described who they think is best suited to lead the implementation of an interdisciplinary approach. One teacher said that to successfully enact an interdisciplinary curriculum, "you mainly need a brave principal," explaining how parents tend to challenge new initiatives. In her view, only the principal can stand up to parents, "and say 'listen, there is a cutting-edge program here, it's different, it's fresh, but it really connects learners to the content.'" (Esti) Another principal noted: "Parents today say, 'you need to give so and so [teaching] hours in a certain subject and suddenly you're making it interdisciplinary, are you giving less hours [in total]?'" (Natalie) What does

enactment look like? In some cases, our interviewees described an extended process led by a small group of "gung ho" teachers, for instance:

> We began with a curriculum that we built […] about topics we thought would interest the students… we always feel like we need to edit it, change it, add to it, move things around. In the first years, the curriculum was criticized a lot at school, the students were also baffled, and a lot of the teachers didn't know their role, it created a lot of confusion and we, a group of gung-ho teachers, kept developing it… by the second or third year we had a curriculum that was more organized and precise in terms of its goals, which was less confusing for students. (Sivan)

Most experienced interviewees described the first years of enactment as challenging; one principal went as far as declaring that "the chances of failure [in the first year] are almost 100%". (Dvir) Some schools enacted their interdisciplinary curricula gradually, while others did so only partially. One principal explained: "I am opposed to doing the whole school and prefer taking one grade, which will be a success. The kids will enjoy. We'll see some results. That's what I am after." (Sarah)

Organizationally, Israeli schools face several acute challenges that can be tied to interdisciplinarity. The interviewees identified three specific organizational problems that might be overcome by enacting an interdisciplinary curriculum: a surplus of subjects, a lack of teachers, and a lack of facetime for each teacher per class. One principal in a school with a well-established interdisciplinary curriculum explained: "if I teach disciplinarily, I am talking about twelve subjects for each Israeli student… so I ask myself, how is meaningful learning possible [with so many subjects]?" (Ari) Another teacher suggested that her principal chose interdisciplinarity because he thought: "I don't have enough literature teachers, so I can do humanities [instead] and the history teacher can teach literature too." (Adelle) Another principal also noted that "initially our goal was organizational, to give humanities teachers six hours [in each class] instead of the normal two." (Sivan) She explained: "Two hours a week isn't enough; a cancellation here, a field trip there, another event, and there is no connection [between the teacher and the class] … That was the need at the beginning."

Leveraging the interdisciplinary curriculum to overcome these challenges can require changes to the schedule, such as shifting from single-period to double-period lessons, yet along with the excitement about the organizational affordances of implementing a new interdisciplinary curriculum, interviewees noted challenges to planning a new schedule: I, right now, have no idea how I'm going to do it, really… I have teachers who supposedly have blank hours in their timetables, or I give some classes too many hours. This is where I am stuck." (Natalie)

Another problem that one teacher identified was that interdisciplinarity might serve as an instrument to accelerate the decline of the humanities in Israel's education system: "the school has to be very honest not to take teaching hours intended for Literature and History and allocate them to Math and English." (Adelle) Yet another challenge was the increase in workload that worried some of the interviewees. In response, most of them suggested freeing interdisciplinary teachers from some of their normal responsibilities and compensating them for developing the new curricula. In two cases, we were told about teachers who are paid the equivalent of a weekly teaching hour, which they dedicate to staff meetings and curriculum design. One teacher had another idea: "in my opinion… [they should] give us two days off [every year] so we can write lesson plans and develop new ideas, because there is no textbook, and usually it's on our own time. You need to fund [the work we do]." (Alex)

One principal with a well-established interdisciplinary curriculum discussed how "these are the places we can enjoy some freedom" from the rigorous oversight on the part of the Ministry of Education. However, he also bemoaned the lack of support and backing that are the result of being alienated from a system that is inherently disciplinary: "as far as I'm concerned, any cooperation with elements at the Ministry or the Municipality are a blessing… [I need] people to back us up." (Ari) (See Table 1 for a summary of the findings).

Table 1
Summary of findings: The potential impact of interdisciplinarity throughout school

	Classroom	**Teachers' room**	**Principal's office**
How is inter-disciplinarity enacted?	Content from multiple subjects is organized historically, topically, or by identity.	Teachers act as content developers, teamwork is essential.	Enactment can be partial or take years to implement; principal and teachers play leadership roles.

Potential benefits of inter-disciplinarity	*Students*: increased understanding, meaningful learning; emotional wellbeing. *Teachers*: sense of freedom. *Both*: better connections with each other.	Teachers develop a sense of belonging to a new group that provides emotional support; workload is distributed.	Better timetable organization; freedom from institutional oversight.
Hurdles to implementation		Teachers' training is less relevant; disconnect from broad professional community; teams may experience "discipline wars."	Difficulty organizing teachers' timetables; lack of institutional backing.

Discussion and conclusion

The teachers and principals we interviewed understood interdisciplinarity broadly, as an innovation that could have a major impact on life at school. And while we distinguished between the classroom, the teachers' room, and the principal's office for analytic purposes, our interviewees described intricate ways in which they overlap with one another. For instance, the lack of institutional supervision was viewed from the principal's office as an advantage (less restrictions) and a drawback (less backing). In the classroom, it crucially allows teachers to "flow"; whereas in the teachers' room, it was tied to feelings of loneliness and disempowerment. Based on this example and others like it, one key takeaway was that teachers and principals view interdisciplinarity as a broad and complex reform that cannot be contained within a single part of school life.

We also found that teachers and principals view interdisciplinarity simultaneously through all three theoretical lenses introduced in the background section. For instance, consider how teachers pool their hours when teaching interdisciplinarily. This shift in teachers' timetables has profound implications that extend across all three approaches. Cognitively, interdisciplinarity in this context affords drawing connections between subjects typically learned separately (Stevens et al., 2005), which interviewees saw as an opportunity to cultivate students' understanding. Socioculturally, it lays the foundation for new types of interactions between teachers and students that afford deeper, more meaningful relationships. Finally, viewed through a critical lens, changing teachers' timetables in this way is nearly impossible, due to pressure from parents, teachers' unions or government supervision. This example, and several others that emerged in our analysis, indicated that the three theoretical lenses of interdisciplinarity actually overlapped and interacted in educators' views. In future, this could form the basis of a grounded theory of interdisciplinarity at school, which is currently lacking.

Almost three decades ago, Lytle and Cochran-Smith (1994, p. 24) argued that "Missing from the field of research on teaching, then, are the voices of teachers themselves, the questions teachers ask, and the interpretive frames that teachers use to understand and improve their own classroom practices." This paper shows that teachers and principals understand interdisciplinarity in multiple ways, which overlap, complement, and contradict one another. It follows that the benefits they associate with interdisciplinarity extend across school, touching on content, students' wellbeing, teachers' professional identity, and even their terms of employment. Finally, enactment requires meticulous planning, and must overcome many hurdles.

Endnotes

(1) Another potential theoretical framing derives from Isaiah Berlin's distinction between "Enlightenment" and "Counter-Enlightenment" and its applications to curricular philosophy. The Enlightenment view corresponds with the cognitive lens, whereas Counter-Enlightenment corresponds with the sociocultural and critical lenses (cf. Mali et al., 2003).
(2) One of the scaffolds distinguished between multidisciplinary, cross-disciplinary, interdisciplinary, and transdisciplinary (cf. Julie Thompson Klein, 2010), and operationalized each term for curricular design.
(3) Interview protocols are available upon request. Please contact the corresponding author for more details.
(4) We used pseudonyms to protect the privacy of interviewees.

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On-line designs for supporting teacher epistemic communities: A comparative analysis

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Abstract: Over the past four decades, various types of epistemic resources required for teaching, and alternative infrastructures for creating and disseminating them, have been proposed. Today's proliferation of online tools for teachers means that there are infinitely more possibilities, setting the stage for a reinvigorated discussion surrounding what teachers are expected to do, and how best to support them in their work. In this essay, we offer a comparative analysis of three online platforms for teachers, to identify contemporary conceptions of teaching and to highlight some of the considerations and tradeoffs that should be taken into account when designing such a platform.

Introduction

Over half a century ago, Derrida (1967/1997) foresaw "The end of the book and the beginning of writing" in the history of ideas. Contrary to the traditional philosophical view that sees language as a means to express an eternal truth – an undertaking he thought was epitomized by the book – Derrida argued that the meaning of a text is transient and contingent upon its readers. "The end of the book" thus acknowledges the limitations of language and ushers in a new era of philosophical inquiry, which Derrida called "the beginning of writing".

In a similar vein, we are currently witnessing a major shift in the history of teaching, driven in part by the emergence of online platforms for teachers that offer viable alternatives to textbooks. Like Derrida's notion of "the book", textbooks symbolize a definitive, finalized version of the curriculum, content, and means of its transmission to students. But contemporary information and communication technologies (ICTs) offer infinitely more design choices than traditional textbooks. As a result, questions pertaining to what teachers are expected to do, and how best to support their work, can be reevaluated in a new light. Like "the end of the book" – which is a precursor to "the beginning of writing" – the "end" of the textbook might bring about a "beginning" of teaching; a revitalized conversation about what teaching is, and what resources and infrastructures can best support it.

In this essay, we offer a comparative analysis of three online platforms for teachers. Our intention is to highlight possibilities afforded by emerging ICTs and discuss the ways in which they can position teachers vis-à-vis their students, the curriculum, and the teaching profession. For instance, should social networking technologies support teachers in sharing their work with one another? How much agency should teachers have in determining what, and how, to teach? What communities should teachers engage with in their work, and to what ends?

Resources for teaching

Epistemic infrastructure

With the goal of elevating teaching from "mere craft" (Shulman, 1986, p. 13) to full-fledged profession, Shulman identified and articulated several types of knowledge that master teachers display in their work, including content knowledge, general pedagogic knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of educational ends. Shulman maintained that the study of best practice could enable researchers to articulate this knowledge, so that it might be disseminated to teachers as part of their training, through professional development, and by other means, thereby contributing to the improvement of teaching across the board.

In the years since, efforts to develop epistemic resources for teachers, and the means for their creation and dissemination, have advanced in several directions. Ball and Cohen (1996) suggested redesigning curricular materials so that they might also be used to disseminate epistemic resources pertaining to content, pedagogy, the curriculum itself, and more, to teachers. Davis and Krajcik (2005) envisioned "educative curricular materials" that help teachers anticipate and interpret learners' responses; enhance teachers' own knowledge of the subject matter; draw connections between different curricular units; understand the pedagogical considerations that drive curriculum designers; and promote teachers' ability to adapt existing curricula to their own particular needs. Hiebert et al. (2002) advocated a "knowledge base for the teaching profession". Notably, they detailed some characteristics required to ensure that resources for teachers would be useful and reliable. According to Hiebert et al., ensuring that resources are detailed, concrete, and specific, helps link them to practice. Organizing these

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resources according to problems of practice (not according to the theoretical distinctions favored by researchers) interconnects different types of knowledge. Making resources publicly accessible means they can be openly examined and widely consumed by colleagues. And finally, sound mechanisms for quality control ensure that the resources are accurate, verifiable, and continually improving. What might such a repository look like? Hiebert et al. call on readers to "imagine large digital libraries linking video examples of teaching, images of students' work, and commentary by teachers and researchers, all integrated around shared topics, and even shared lessons" (p. 8).

Epistemic Communities (ECs) offer another approach to creating and disseminating epistemic resources for teachers. ECs "consist of individuals with identical or similar 'frames of reference' and cognitive 'orientation systems'" (Hakanson, 2010, p. 1807). Underlying an EC is a triad of theory, codes, and tools shared by community members. A *theory* is any frame of reference shared by community members that provides the context required for sensemaking, be it an evidence-based scientific theory, a normative view of what is good or right, or a ubiquitous rule of thumb. *Codes* are the "symbolic means" (p. 1810) by which community members communicate with one another, including both ordinary and specialized language such as formulae, diagrams, etc. Finally, *tools* are tangible artifacts such as hardware and software that community members use to accomplish their work, to communicate with one another, and to store their communal memory. According to Hakanson (2010), the epistemic infrastructure provided by ECs streamlines knowledge transactions – namely articulation of new knowledge and replication of existing knowledge in new contexts – within the community (cf. Nonaka, 1991).

Glazer and Peurach (2015) offered two concrete examples of well-developed ECs that functioned as an infrastructure for creating and sharing knowledge within a professional community of teachers and other educational practitioners. In their own words, "shared tools, theories, and codes served as the thread connecting classrooms and schools" (p. 192) and led to the success of *Success for America* and *America's Choice*. Their analysis showed how the community's epistemic and social infrastructures enabled *Success for America* to draw on the shared experiences of teachers to inform the design of the curriculum. Similarly, they observed numerous cases in their study of *America's Choice*, where individual teachers' insights were integrated into the design of formal tools that were then disseminated, shaping activity throughout the community.

Communal infrastructure

In recent decades, sociocultural theories demonstrating how knowledge and other aspects of belonging to a particular community are interdependent have gained traction (e.g., Lave, 1991). Therefore, the expectation that teachers will simply draw on a public repository of epistemic resources may be unrealistic. While access to epistemic resources is crucial for supporting teachers in their work, a communal infrastructure is also likely vital.

Indeed, Shulman was ultimately dissatisfied with his earlier work because it focused on individual teachers and overlooked the communal infrastructure mediating their growth and activity. The alternative model that Shulman & Shulman (2004) proposed integrated two levels of analysis – individual *and* communal – and argued that the two co-constitute each other. Specifically, they posited that the individual teacher's vision, skills, understandings, and motivations were supported by the communal ideology, community of practice, knowledge base, and mutual support within which they were situated (and vice-versa: the communal is also shaped by the individual). In a similar vein, Lampert, Boerst, and Graziani (2011) showed how access to a shared knowledge base supported ambitious forms of teaching at scale when it was coupled with a robust social infrastructure. Their study showed how (a) teachers with students in common regularly shared their experiences and insights with their colleagues; (b) lesson plans were neatly organized and easily accessible to everyone; and (c) the entire staff was well-versed in a shared theory that served as a basis for the shared enterprise of planning and evaluating learning.

ECs similarly highlight the social infrastructure that can support effective knowledge work among teachers. In addition to the cognitive work they afford, shared theories, codes, and tools also lay the groundwork for *communication* and *collaboration* among colleagues. Moreover, belonging to an EC provides members with a sense of *identity*, which is mediated by their participation in the community. Finally, the "irreducible tension" (Wertsch, 1997, p. 6) between individuals and communities' cultural tools determines members' sense of *agency*. The measure of agency can increase or decrease, depending on the design of the tool: "in some cases the cultural tool dominates the picture… in other cases the cultural tool presents a wide range of possibilities for improvisation and the mediated action that emerges is more heavily shaped by the agent" (ibid.).

Mediating tools

Cognition can be viewed as a process that is distributed across agents' minds and their surroundings, including the tools that they employ (Brown et al., 1989). To ensure that tools are useful, their designers imagine how they will be used, and build into them a consequent set of affordances and constraints. A tool's *affordances* are the ways in which it can be used, which are "jointly determined by the qualities of the object and the abilities of the agent that is interacting" with it (Norman, 2013, p. 11); whereas *constraints* limit the ways in which one can

interact with a tool. For example, glass *affords* vision and *constrains* passage (Norman, 2013). Therefore, glass can be useful for designing a barrier that people are meant to see through, but not pass through. Importantly, affordances and constraints are not contradictory, but complementary. Together, they shape how a tool is used. To communicate a tool's intended use and affordances or constraints, designers use *signifiers*: "any mark or sound, any perceivable indicator that communicates appropriate behavior to a person" (Norman, 2013, p. 14).

The proliferation of ICTs in recent decades has led to an influx of educational technologies and online tools for teachers. These tools can be imbued with new types of affordances, constraints, and signifiers unavailable in traditional textbooks. They can include large amounts content; can be interactive and customizable; and can function as social networks for disseminating user-generated content and supporting teacher collaboration and mutual learning. Thus, ICTs can support novel forms of teaching, and can reflect evolving conceptions of what teaching is or what it ought to become. These emerging possibilities and views are reflected in the affordances and constraints embedded into the specific design of each tool.

Some concrete examples

To advance our understanding of how online platforms can support different forms of teaching, we offer a comparative analysis of three platforms: *The Lesson Planner*, recently launched by Israel's Ministry of Education; *Reading Like a Historian* (RLH), of Stanford's History Education Group; and *Sefaria*, a virtual Jewish library. These online platforms were chosen based on a purposive sampling that highlights maximum variation in terms of their epistemic and communal infrastructures (Patton, 1990). Specifically, we asked three questions. First, what epistemic and communal infrastructures does each platform provide? Second, how are the epistemic and communal infrastructures mediated by the online platforms, in terms of each platform's affordances, constraints, and signifiers? And finally, what vision of teaching and teachers does each platform reflect and support?

For the sake of clarity and coherence, we adopted ECs as an analytic lens, focusing on the epistemic and social infrastructures provided by each platform, as well as their intended uses. Specifically, we analyzed each of the websites (i.e., *tools*), asking what *theories* of teaching underlie them; what *codes* they use to talk about teaching; how they afford and constrain *creative knowledge work* by teachers; how they afford and constrain *communication and collaboration* among teachers; what sense of *belonging* and *identity* they seek to inspire and support; and how each site affords and constrains teacher *agency*.

The Lesson Planner

Design

The Lesson Planner offers Israeli teachers access to thematic units and lesson plans in math, science, language arts, humanities, and more, organized according to the official curricula for grades 1-10. For instance, a unit intended to support eighth grade history teachers includes three lessons on the Enlightenment. The first lesson focuses on Enlightenment epistemology, exemplified by Kant's dictum *Sapere aude!* ("have courage to use your own reason!"). The second lesson shifts to a discussion of society and governance, introducing the terms *social contract*, *separation of powers*, and *enlightened absolutism*. The final lesson surveys Diderot and d'Alembert's Encyclopedia, and its significance to the history of ideas. The unit's landing page includes a paragraph with some background information, followed by three buttons labelled "knowledge and big ideas", "skills", and "values". Underneath, there are three more buttons linking to the individual lesson plans. Links to the lesson plans also appear in a sidebar as well as a drop-down menu at the top of the page.

"Knowledge and big ideas" leads to a 1200-word essay on the Enlightenment that includes references to academic works. It articulates three big ideas that are the crux of the unit: "anything can be achieved through the power of mind", "the growth of knowledge advances human progress", and "ideas breed political change". "Skills" leads to a list of nine generic skills, such as "digital literacy" and "critical thinking," that the unit mediates. Each skill is briefly defined, and a table details the various components in the unit that are connected to each skill. Finally, "values" leads to a list of three virtues: "passion for learning", "respect for humankind and family members," and "commitment to Israel as a Jewish and democratic state," which are all supposedly strengthened by studying the Enlightenment unit. Here too there is a table with links, but there are no definitions or explanations.

Each individual lesson has its own landing page, with four tabs: "Knowledge in the lesson", "Skills in the lesson", "Values in the lesson", and "Proposals for building a lesson". Again, the knowledge tab offers a comprehensive essay, whereas skills and values are more telegraphic, offering titles (in the case of skills also brief definitions) and a table linking to relevant components of the lesson. The fourth tab leads to an interactive interface that assists users in constructing lesson plans based the unit's themes and resources. On the left is an empty lesson plan template, titled "my lesson", which is divided into three sections labeled *introduction*, *body*, and *conclusion*. The right side of the screen is similarly divided into the same three sections, including several proposals for

activities and assignments in each section. For instance, for the first lesson on the Enlightenment, there are three proposed introductions. The first suggests asking students to share what comes to mind in association with the word "light"; the second suggests writing "2+2=5" on the board and discussing with students what they know and how they know it; and finally, the third suggests contrasting epochs and events in the study of history.

Some of the assignments that appear on the right are interactive, allowing students to contribute by answering open-ended questions, commenting on a forum, highlighting text, etc. Some are collaborative, so that students can see each other's contributions, whereas others collect individual student answers and present them to the teacher in an LMS interface. As they scroll through, teachers can either drag and drop individual suggestions from the right to populate the empty sections of the lesson plan on the left, or they can create new assignments of various types (open question, highlight the correct answer, add comments to a thread, etc.). Once the lesson plan is complete, it is automatically saved to the teacher's profile pages, and s/he can share it with students via a link for distance learning, project it to a screen for face-to-face sessions, or print it.

Epistemic infrastructure: Theories and codes

The theories about teaching that are embedded into *The Lesson Planner* touch on content and structure. In terms of content, the site calls for a triple focus on knowledge, skills, and values. In the Israeli context, this is part of a broader effort to realign pedagogic practice with a view that assigns the education system responsibility to promote social values and cultivate learners' 21st century skills. Along these lines, Israel's principal education law was redrafted in 2000 to highlight educational goals that include love and respect for others; cultivating learners' personalities, creativity, and talent; and a set of skills and dispositions including intellectual curiosity, critical thinking, and ingenuity. In 2020, Israel's Ministry of Education drafted a strategic document entitled "Skills of the [ideal] graduate," calling for a greater focus on preparing graduates for the innovation age. Yet notwithstanding these frameworks, which are reflected in the general design of *The Lesson Planner*, the areas dedicated to knowledge, and the tools offered therein, are far more developed than those dedicated to skills and values.

As for structure, the platform assumes that individual lessons are insufficient for exploring big ideas, but that entire curricula are too broad. The middle ground – thematic series' of up to five lessons – is considered best. The platform requires any lesson, regardless of subject and age-level, to be structured similarly, with intro, body, and conclusion sections. Thus, the designers of *The Lesson Planner* view teachers of various subjects such as mathematics, science, and history, similarly. The codes throughout the site's interface reflect these two foci as well. The landing page for each unit and each lesson features multiple buttons and tabs labelled "knowledge and big ideas", "skills", and "values"; lesson plans are divided into "intro", "body", and "conclusion".

Communal infrastructure: Communication/collaboration, identity, and agency

The Lesson Planner allows teachers to easily share links to lesson plans with students. However, it does not afford collaboration among teachers: they cannot co-create new lessons, nor can they share their lessons with one another. By being open to *all* teachers, and to teachers *only*, the platform demarcates a professional identity that is determined by one's status as teacher and is uninfluenced by specialization or focus (e.g., subject matter). Teachers are encouraged to be agentive, abandon textbooks, and innovate by creating original lesson plans. Yet, the role of teachers is also heavily constrained. Though in theory teachers could rely on the platform to plan their own lessons, the platform's organization according to the existing curricula, the ease of drawing from available predetermined activities rather than creating new ones, and the requirement that all lessons be structured according to a general template, imply that teachers are encouraged to mostly stay within the vetted lesson plans.

Reading like a historian

Design

Stanford's *Reading Like a Historian* (RLH) platform offers teachers free access to over 150 lesson plans. According to the site, "each lesson revolves around a central historical question and features a set of primary documents designed for groups of students with a range of reading skills." For each individual lesson plan, there is a landing page with a brief introduction, an image, and links to downloadable materials at the bottom of the page. For instance, in *The battle of Lexington* lesson "students practice sourcing, corroboration, and contextualization as they weigh competing accounts of who fired the first shots of the Revolutionary War" (sheg.stanford.edu/history-lessons/battle-lexington). The landing page features downloadable teacher materials, student materials in English and Spanish, original documents (all three in PDF), and a PowerPoint file. Teacher materials detail specific instructions, scripted questions, and points to highlight for each PowerPoint slide.

Once teachers establish some basic facts about the battle, they are instructed to pose two questions: "What happened at the battle of Lexington? And who fired the first shot?". These questions are first addressed by

comparing two images depicting the battle, one by Canadian artist Henry Sendham in 1886 and the second by Thomas Doolittle, a silversmith who spoke with veterans of the battle, in 1775. Teachers are instructed to "make sure to highlight how each painting might be considered both trustworthy and untrustworthy" before moving on to a comparison of two additional accounts of the battle: a diary entry by a British soldier, and the testimony of 34 colonists. Ultimately, "students should note that evidence about who fired the first shot is contradictory" as they summarize what they have learned about the Battle of Lexington and about historical inquiry more broadly.

Epistemic infrastructure: Theories and codes

The theory underlying RLH touches on the purpose of history education, and on the role of teachers in realizing it. In his research, Wineburg (2001) has shown that professional historians ask a unique set of foundational questions when engaging with historical documents as they attempt to reconstruct and understand the past. However, the ultimate aim of history education in Wineburg's (2016) view is not historical at all, but rather to cultivate historical thinking among learners, with an eye on transferring and applying it to contemporary contexts.

This goal is achieved by means of four key heuristics, which are also codes that describe the authentic work done by historians as well as by students in the RLH class: *sourcing*, i.e., considering the document's source and purpose; *contextualization*, i.e., placing the document in a temporal and cultural context; *corroboration*, i.e., comparing the accounts of multiple sources against each other; and *close reading*, i.e., carefully considering an author's use of language and word choice (Riesman, 2012).

Communal infrastructure: Communication, collaboration, identity, and agency

The files that are available on the RLH platform are ready for use, and do not require any preparation. The site uses the PDF file format, which affords ease of use and consistent appearance in multiple interfaces, but is difficult to edit, thereby constraining modification. The implicit message to teachers is that designing the lessons does not fall under their auspices. The site does not afford any communication or collaboration between teachers, who are viewed as end users, not contributors. In terms of identity, history teachers are positioned as a bridge between expert historians and history students. They understand the purpose of history education and the codes that historians use; and they can make them accessible to learners by simulating historical inquiry. However, they are not expected to sift through archives seeking out primary documents that can shed light on the past. Teachers do not select which primary sources to teach, what questions to ask, or how to structure lessons in ways that are conducive to advancing learners' historical thinking skills.

Sefaria

Design

According to its *About* page, "*Sefaria* is a non-profit organization dedicated to building the future of Jewish learning in an open and participatory way". The site has two primary interfaces for interacting with hundreds of Jewish texts originating from across the globe and spanning thousands of years of authorship. The library interface allows users to search the entire corpus in various ways, such as a search bar, navigating to a particular passage (e.g., Genesis, 11, 4), or by topic (e.g., Yom Kippur). Selecting any passage in any work reveals a sidebar with links to all other passages throughout the entire corpus that cite it (or are cited by it), so that users can open multiple sources that are in conversation with one another, side-by-side. The sidebar includes additional functions, such as "chavruta" (=dyad), which provides a link to a video-chat room that users can share to learn a text together.

In addition to the interactive library, *Sefaria* also includes a *source sheet* function. Source sheets are blank documents that users can populate with texts, images, and videos that they upload or link to. In addition, users can search or navigate the library from within the source sheet interface and add select passages to their sheet. Alternatively, when a passage is selected from the library interface, it can be added to a user's source sheet through a dedicated "add to sheet" button on the sidebar. Source sheets are an invitation to users to articulate new meanings by placing existing passages from various sources side-by-side. Like other contemporary cloud-based word-processing software, *Sefaria*'s source sheets are collaborative, and can be edited simultaneously by multiple users. Source sheets have unique URLs, are attributed to their creators and saved to their profile pages, and are also published on a curated "community" page that is regularly updated. In addition to the platform's native functionality, *Sefaria* also actively maintains Facebook and WhatsApp groups for teachers. For instance, a *Sefaria* employee recently posted the following to a private Facebook group called "The *Sefaria* Classroom: Where Educators Share, Ask, and Think Together":

> Pop culture is definitely not my strong suit these days, but […] I find it's a nice way to engage students. I've put together a sheet of clips from *Ha-Yehudim Ba'im* ("The Jews are Coming"), a

> satirical (and irreverent) Israeli [TV] show, with some of the texts they reference or comment on. The sheet is collaborative, so you are all invited to add your own texts and clips you know of to this sheet. No need to restrict to The Jews are Coming, though! Any and all shows/movie clips are welcome!
>
> (https://www.facebook.com/groups/*Sefaria*.classroom/permalink/3927401540676757)

Attached to this post was a link to a source sheet on *Sefaria*, extending 25 pages long, which started off with the following explanation: "This sheet is a work in progress and collaborative, which means that anyone with a *Sefaria* account can add their own links and sources to this very sheet. Please contribute ...!"

Epistemic infrastructure: Theories and codes

According to one Jewish tradition, the Jewish canon contains infinite meanings that come to light as individuals engage with it over time (Hartman, 2002). Indeed, a hallmark of Jewish culture is that the same canonical texts have served as the foundation for contemporary discourses throughout the ages, resulting in a vast and interconnected web of texts that are in dialogue with one another, in which the same words and expressions have taken on many meanings when interpreted from within different socio-historical contexts (cf. Bakhtin, 1981). Along these lines, *Sefaria* embodies a theory of teaching that fuses together four key ideas: (a) intertextual (b) meaning making, that is (c) mediated through discourse and (d) pluralistic in nature.

The codes that *Sefaria* employs reflect how it combines two distinct worlds: Torah study and contemporary ICTs. For example, the source sheet interface is reminiscent of modern word processors, with "file", "format", and "insert" menus and a "share" button at the top. But the library's sidebar includes buttons such as "manuscripts", "Torah readings", and "Chavruta" – words drawn from the discourse of the Yeshiva world.

Communal infrastructure: Communication, collaboration, identity, and agency

Sefaria's design affords many forms of communication and collaboration among users. *Source sheets* can be collaboratively co-created; they are available through users' profile pages; and they have unique URLs that can be shared. *Sefaria*'s homepage also includes a "community" button linking to a curated collection of recently published source sheets. Finally, source sheets are indexed by the site, and are searchable according to lexical content, tags, and topic, which essentially makes them part of the Jewish canon. The *virtual library* interface also affords communication, by means of the "Chavruta" video chat function.

While *Sefaria* maintains separate Facebook and WhatsApp groups for teachers to share ideas and lesson plans, the platform does not distinguish between teachers and other users. In terms of identity, *Sefaria* positions teachers as members of an intellectual community that extends beyond formal education and seeks to blur the boundaries between school and the outside world. Because this intellectual community values novel contributions to an ongoing open-ended conversation, teachers are encouraged to be agentive in their engagement with sources. The site does not preselect what to teach or how to teach it, but rather affords opportunities to easily navigate a large corpus of data and to offer novel contributions by selecting specific passages to focus on.

Designing ICTs for teachers in a post-textbook age

Resources and infrastructure

In the previous section, we identified several key differences between the epistemic resources available on each of the platforms we surveyed. This comparison highlights the degree to which the theories, codes, and tools provided by each site cohere with one another. RLH's platform is markedly coherent. The site's codes all derive directly from the corresponding theory of history education, and the tools (e.g., PDFs and PowerPoints that serve as handouts, presentations, and lesson plans) are appropriate resources for mediating the types of interactions this theory calls for: a learning environment in which students can read "like historians".

Because it is trying to create a new type of learning experience that situates traditional Jewish texts within a contemporary digital context, *Sefaria*'s interface must bridge two distinct cultural worlds. The theory underlying it and the codes and tools featured on the site are complex and may not always cohere with one another. For instance, seasoned Torah scholars might easily navigate the traditional texts, yet still not comprehend the purpose of digitizing the library. Likewise, digitally literate individuals will quickly grasp the site's hyper-textual, collaborative, interface; but they may not identify with the goal of intertextual discourse-based meaning-making.

Finally, *The Lesson Planner*'s interface features a different type of tension. The platform's infrastructure outwardly embodies the view that teaching ought to focus simultaneously on knowledge, skills, and values. Yet, in practice, the resources it provides are almost exclusively focused on knowledge. This incongruence reflects the different forces at play within the Ministry of Education, whose influence is apparent in the design of the site. The

Ministry's leadership – responsible for outlining the *infrastructure* – is primarily political, and thus focused on the changing role of the education system in Israeli society, which is expressed in the emerging focus on skills and values. Yet the *resources* provided on the site were drafted by teachers and curriculum designers, whose perspective is shaped by their real-world classroom experiences, which tend to be knowledge focused.

Identity and agency

So, who *are* teachers and what are they expected *to do*? One crucial insight that emerged from our analysis touches on the communities that teachers are expected to belong to, which shape their professional identity. According to *The Lesson Planner*, all teachers – regardless of the subjects they teach or the age of their students – belong to a single professional community.

In contrast, RLH is geared specifically towards history teachers and designed to cater to the unique aims of history education. RLH recognizes the value of the unique thinking skills that professional historians apply when investigating the past and sees history teachers as central to translating and importing them into K-12 settings. Yet notwithstanding the overlap between the two communities, professional historians and history teachers do essentially different things. For historians, sourcing, contextualizing, corroborating, and close reading are a means to interpreting and understanding the past. Yet for teachers, the equation is reversed. Historical inquiry is a means that serves the purpose of developing learners' thinking skills, which they require to successfully navigate current affairs. Finally, *Sefaria* also recognizes a distinction between two communities of learners: everyday people, and teachers. But contrary to RLH, *Sefaria*'s aim is to blur the lines between the two communities, to the point where what goes on inside the classroom and what goes on outside of it are in direct conversation with one another and essentially part of the same project.

Different views of what teaching is, what teachers do, and what they need, also entail different measures of agency. History teachers are not historians and cannot be expected to curate the primary sources for their lessons, because they do not have the expertise or means required to do so. Therefore, the resources that RLH provides are intended for use as-is; they are packaged in a format that is not intended to be edited (e.g., PDFs). In contrast, *The Lesson Planner* sees lessons as flexible, and so long as teachers adhere to the basic guidelines for content and structure, they are encouraged to design individualized lessons. However, while it provides a proprietary drag-and-drop technology to support the design of new lesson plans, *The Lesson Planner* does not allow teachers to share their original work with colleagues. This may be due to quality control concerns, or because the government is unwilling to relinquish control over content, especially in light of the politically-charged public scrutiny of curricular materials that address controversial issues ([blinded], 2017). Finally, *Sefaria* affords creation *and* dissemination of resources created by teachers, because its purpose is to democratize meaning making and undermine existing power structures so that more people will partake in an ongoing conversation they may previously have been marginalized from.

Design tradeoffs

When resources are packaged in a ready-to-use format, as on RLH, they do not require much time or expertise to deploy; teachers can print PDFs and download PowerPoints in a matter of minutes. In contrast, navigating *The Lesson Planner* requires more time and expertise. Beyond the expectation that they will master its new drag-and-drop interface, teachers are also expected to choose from multiple suggested activities and resources, which is also time-consuming and expertise-dependent. Finally, using *Sefaria* to plan and teach a lesson requires even greater time, effort, and expertise, due to the requirement to curate different resources within a coherent theme.

Another important tradeoff concerns the interplay between quality assurance and teacher agency. The more agency teachers have in creating and disseminating content, the less oversight and control moderators have. This means that while a view of teacher-generated resources might seem appealing at first, there can be no guarantee that the resources they produce will be in line with the worldview the site is intended to advance. For instance, *Sefaria*'s moderators have no way of ensuring that teachers do not use the platform to create spurious connections or advance anti-democratic interpretations. *The Lesson Planner* can similarly be abused, but because lesson plans cannot be shared among teachers, the potential damage is relatively limited by the sites design constraints. And finally, RLH's approach means that quality of the materials on the site is assured.

Conclusion

How might the emergence of new ICTs reshape teaching? Replacing textbooks with online platforms does not in and of itself ensure qualitative shifts in expectations from teachers or in the types of resources they are provided. Indeed, educational innovation can result "in even more old-fashioned, traditional forms of teaching and learning – instructionism on steroids" (Sawyer, 2014, p. 729).

However, the mere presence of online platforms alongside textbooks brings the inevitability of the content-delivery approach into question and requires curriculum designers to justify their choices. For instance, social networking technologies potentially afford a bottom-up approach to curriculum design, whereby teachers are actively engaged in creating and sharing – not just delivering – educational content. But as we have seen, there are tradeoffs inherent to such a model. More teacher agency means less quality control and might require teachers to engage in a new line of work they may not be prepared for. In light of emerging ICTs, these are tensions that should be addressed either way.

Like other professions that have undergone fundamental changes in the information age, teaching may eventually adapt to new technologies. The multitude of platforms that already exist online offer diverse possibilities, requiring practitioners, policymakers, researchers, and others to stake their ground, and clearly articulate what types of infrastructures and resources they believe contemporary teachers need, and why.

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International Society of the Learning Sciences

"Learning Experiences, Technology, and No Grades" – What Students Expect from a Non-Formal Learning Setting Outside of School

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Abstract: The present study investigates the expectations of 88 students towards their visit of an out-of-school lab (OSL) for social sciences and humanities and how these expectations relate to both their actual experiences of the visit and their situational interest in the project contents. OSLs are non-formal learning settings which are usually visited by whole classes and aim at authentically communicating scientific ways of thinking and working. In contrast to this goal, our findings suggest that the least students expect from an OSL visit is to get authentic insights into scientific research. They rather expect to have a nice time with their classmates and without pressure to perform. Our findings also point to the need to change these expectations, as especially the expectation to get authentic insights into scientific research positively correlated with students' reported experience of having acquired knowledge during their visit and their situational interest in the project contents.

Introduction

"Well, we'll see whether I'll do better or worse on the next exam [pause/interruption] but the teacher couldn't care less about what we're doing here anyway.[1] These thoughts were stated by a secondary school student at the beginning of a collaborative problem-solving activity that took place in an out-of-school lab (OSL) for social sciences and humanities during one of our previous studies (Nachtigall et al., 2020). The student visited the lab together with his whole educational science course and attended a one-day project which focused on principles of experimental design in educational science research. Similar to other non-formal learning settings outside of school (such as museums, science centers, science outreach programs, etc.), OSLs pursue the goal of fostering students' interest in and knowledge about scientific ways of thinking and working by providing them authentic insights into scientific endeavors (e.g., Scharfenberg & Bogner, 2014). These goals are partly in line with the expectations that students hold when visiting OSLs for *natural sciences*. As the findings by Garner and Eilks (2015) and Schwarzer and Parchmann (2015) demonstrate, students who visit those labs for natural sciences especially hope to conduct experiments (which is a typical scientific practice of natural scientists) and to have access to authentic scientific tools (Schwarzer & Parchmann, 2015) or at least to better laboratory equipment than in school (Garner & Eilks, 2015). In OSLs for *social sciences and humanities*, students usually cannot conduct hands-on experiments by applying, for instance, high-tech laboratory equipment. Instead, these labs implement problem- or inquiry-based learning activities in order to emulate core features of scientific inquiry and to provide students with authentic experiences of scientific ways of thinking and working (Pauly, 2012).

The effectiveness of OSLs for students' knowledge about and interest in scientific ways of thinking and working could be affected by students' expectations towards visiting an OSL. Findings from research on museum learning indeed demonstrate that the visitors' expectations (especially the expectation to learn something) affect the impacts of a museum visit on student learning (e.g., Falk, 2006). According to the contextual model of learning developed by Falk and Dierking (2004), the visitors' motivations and expectations represent one factor that affects the quality of a museum experience, and as Falk and Dierking (2004) state "When expectations are fulfilled, learning is facilitated. When expectations are unmet learning suffers." (p. 141).

In contrast to research on museum learning, research on OSLs has not yet focused on investigating students' expectations and the role that these expectations may play for the effectiveness of OSLs. But knowledge about students' expectations could be helpful in order to enhance the intended effectiveness of OSLs. One outcome variable that has been particularly focused on by previous research on the effectiveness of OSLs relates to students' situational interest. Situational interest is defined as "the psychological state of engaging or the predisposition to reengage with particular […] content" (Hidi & Renninger, 2006, p. 112), and is assumed to be first triggered and then maintained by (usually but not exclusively) external features, such as learning materials and activities, of the learning setting (Hidi & Renninger, 2006). However, so far, empirical evidence barely supports the intended effects of OSLs on students' development of (situational) interest or their acquisition of knowledge. For instance, large-scale studies conducted by Itzek-Greulich and colleagues (e.g., 2017)

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demonstrated no (partly even negative) effects of OSLs on both students' situational interest and achievement in chemistry. Thus, uncovering the expectations of students visiting an OSL may be helpful or even necessary in order to get a better understanding of the potentials and boundaries of OSLs for fostering students' knowledge about and interest in scientific ways of thinking and working.

Investigating the expectations of students who visit an OSL *for social sciences and humanities* may be particularly interesting and necessary as students tend to associate the work of scientists within the social sciences and humanities – in contrast to the work of natural scientists – with activities, such as teaching and helping others, but not with scientific research (e.g., Nachtigall & Rummel, 2020). Thus, one could assume that students' expectations with regard to their visit of an OSL for social sciences and humanities are not in line with the goal of OSLs, namely to provide students with authentic insights into *scientific* ways of thinking and working. This assumption is further supported by the student's statement above suggesting that students may hope to improve their achievement in school by visiting an OSL for social sciences and humanities or, at the same time, to just have a day off from school on which they do not have to meet any expectations from their teachers.

Against this background, the present study first explores the expectations of students who visit an OSL for social sciences and humanities (Research Question 1). For this purpose, we developed and tested a respective questionnaire. We then examine how students' expectations at the beginning of their visit relate to their actual experiences of the OSL (Research Question 2). Thereby, we aim to investigate whether or not students' initial expectations have been met during their OSL visit. Finally, we examine the relation of students' initial expectations to their (triggered and maintained) situational interest in the contents of the project (Research Question 3), whereby we investigate whether students' initial expectations are associated with an outcome variable that has been focused on in previous OSL research, and that is assumed to be linked to student learning.

Method

We developed a one-day project for an OSL for social sciences and humanities at a large German university. The project, entitled "*Media and its impacts – critical interpretation of study results and reflection on one's own media use*", primarily aimed at communicating social science research methods to students and consisted of two parts. While the first part of the project focused on the differences between correlative and causal evidence exemplified by studies investigating different impacts of media usage, the second part of the project tried to sensitize students for some actual risks while using media, or more specifically, while sharing personal data in social media. It should be noted that we designed our OSL project primarily as a project for educational science courses. However, after our first data collection with an educational science course and after the first COVID-19 regulations, we opened our OSL project for all interested courses in order to increase our sample size.

Participants

Participants were 88 high school students (Age: $M = 16.49$, $SD = 0.78$; 60% female) who visited the OSL as whole classes and with their teachers. In total, four classes from three schools attended the OSL. See Table 1 for an overview of the sample characteristics per class.

Table 1
Descriptive statistics of the sample separated by class

Course	School	Month of data collection	Number of students			Age
			Total	Female	Male	*M* (*SD*)
Educational sciences / 11th grade	A	March 2020	30	18	12	16.63 (0.81)
Mixed course / 10th grade	B	September 2020	23	10	13	16.35 (0.49)
Mixed course / 10th grade	B	September 2020	17	10	7	16.24 (0.44)
Psychology / 11th grade	C	November 2020	18	15	3	16.73 (1.22)

Measures

To investigate our research questions, we administered two online questionnaires that the students completed on laptops during their visit in the OSL: (1) A pre-questionnaire at the beginning of students' OSL visit and (2) a post-questionnaire at the end of the OSL project. The pre-questionnaire assessed students' expectations related to the OSL visit. The post-questionnaire measured students' experiences of their OSL visit and their situational interest in the contents of the OSL project.

The pre-questionnaire assessed students' *expectations* related to the OSL project by using two open-ended questions and eight scales with, in total, 24 items. We adapted the following *two open-ended questions* from Garner and Eilks (2015): (1) What do you expect from today's out-of-school lab visit? (2) Does the work in the out-of-school lab differ from regular lessons in school? – What do you think, what are the differences? Through a bottom-up process and, thus, grounded in the actual data, we developed six categories that classify the student answers to the first open-ended question (see Table 2), and ten categories for the student answers to the second open-ended question (see Table 3). Two raters coded 100% of the dataset and reached mostly satisfying agreements (see Tables 2 and 3). Prior to analysis, disagreements were resolved by discussion.

Table 2
Codebook for the student answers to the open-ended question #1

Category/ code name	**Description** Students expect …	**Example**	**κ**
INFORMATION ABOUT THE TOPIC	… to receive information about the topic of the project (i.e., media, its impacts, risks, and/or usage).	"Information about the correct usage of media"; "To learn a lot about the impacts of media"	.93
NEW (LEARNING) EXPERIENCES	… to gain (new) experiences more generally and/or to learn something (new).	"to gain experiences"; "to learn something new"; "new knowledge"; "to gain more knowledge"	.62
RESEARCH & UNIVERSITY	… to get insights into scientific ways of working and/or the university context.	"To get impressions of scientific work at the university"; "to gain more knowledge about the university and the things one can learn at the university";	.94
PERSONAL SURPLUS VALUE	… to make personally meaningful experiences.	"To learn more about me"; "To learn something for my future or for my life in general"	.61
INTERESTING CONTENTS	… interesting topics or an interesting project more generally.	"I hope it will be interesting"; "Interesting new insights"	.82
OTHERS	… nothing specific or exceptional things.	"I will let myself be surprised"; "to have fun and good collaboration"	.44

Table 3
Codebook for the student answers to the open-ended question #2

Category/ code name	**Description** Students think/describe …	**Example**	**κ**
MORE TECHNOLOGY	… that an OSL provides access to more/better technology and/or more innovative (modern) materials.	"maybe more work on computers and with technology more generally"; "regular instruction is not as modern as instruction in an OSL"	.86
NO PRESSURE AND GRADES	… learning in an OSL as being more relaxed than in school as they get no grades and have no pressure to perform.	"no grades → nor pressure to perform"; "the OSL is freer than regular instruction, there are no grades, less pressure, no compulsion"	.85
MORE COLLABO-RATION AND AUTONOMY	… that learning in an OSL offers more opportunities for self-directed and/or collaborative learning.	"More collaboration and personal decision-making"; "more collaboration"; "I think that one can perform more independently"	.97
MORE PRACTICE-ORIENTATION	… learning and the learning contents in an OSL as being more practice-oriented.	"the work in an OSL is possibly more practical than in regular instruction in school"; "more illustrative things"	.89
DIFFERENT CONTENTS AND TASKS	… that the contents and tasks in an OSL are different.	"I think that one works on more meaningful and modern topics than in regular instruction"	.75
SCIENTIFIC PRACTICES	… that OSLs employ certain research methods and/or that the	"the administration and analysis of surveys"; "maybe there are more	1.00

	learning activities are featured by elements of scientific practices.	experiments"; "one engages more with analysis and interpretation"	
DIFFERENT LEARNING ACTIVITIES	… that various features of the learning activities in an OSL differ from school.	"one works with more different methods and media"; "longer duration"; "the way how information is provided is different"	.51
MORE PROFESSIONAL	… features of OSLs that point to more professionalism.	"they know how one learns"; "the instructor will be more open to our criticism"; "It is more reputable here"	.88
MORE KNOWLEDGE AND INTEREST	… that learning leads to more knowledge than in school and/or is featured by higher motivation, fun, or interest.	"participating in the activities of the OSL is more driven by fun and interest"; "one becomes smarter"	.79
NO DIFFERENCES	… that there are no differences.	"Similar structure, almost no differences"; "no differences at all"	.65

We developed and partly adapted eight scales with *24 items* from previous OSL research (i.e., Garner & Eilks, 2015; Schwarzer & Parchmann, 2015) as well as from previous museum research (i.e., Phelan et al., 2017). The scales referred to the following expectations each measured through three items (all items started as follows: "During today's out-of-school lab visit it is important for me …"):

(1) Knowledge acquisition (e.g., "to extend my knowledge of educational science theories/concepts/topics.");
(2) Interest development (e.g., "to deepen my interest in educational science themes.");
(3) Reference to everyday life (e.g., "that the topics of the OSL project are related to my everyday life.");
(4) Social experience (e.g., "to spend time with my classmates.");
(5) Career orientation (e.g., "to get an impression of what it means to study at a university.");
(6) Scientific authenticity (e.g., "to work with contents, materials, or methods that are also used by real scientists.");
(7) Autonomy (e.g., "that the activities allow me to implement my own ideas.");
(8) Insights into research methods (e.g., "to learn something about research methods.").

Students responded to all items on a Likert scale ranging from 1 (*not true at all*) to 5 (*absolutely true*). As our OSL project was initially developed for educational science courses only, some of the items referred to the school subject/the discipline of educational sciences. However, as we opened our OSL project for all interested courses after the first COVID-19 regulations and our first data collection, we excluded four items that referred to expectations with regard to students' educational science classes in school (e.g., "to understand the relevance of topics from my educational science classes for my everyday life").

We included the remaining 20 items in a principal component analysis with varimax rotation in order to examine whether the eight theoretically assumed factors for assessing students' expectations could be found in our data. Using an eigenvalue of 1 or greater led to the extraction of five factors that explained 66% of variance. The first factor unified eight items from four different (initially assumed) dimensions (i.e., interest development: 3 items; knowledge acquisition: 1 item; career orientation: 2 items; insights into research methods: 2 items) that all somehow referred to the educational science discipline. Hence, we named this factor as KNOWLEDGE ABOUT & INTEREST IN EDUCATIONAL SCIENCES (*Cronbachs's* $\alpha = .88$). The second factor combined all three items of the dimension *scientific authenticity* and one item of the dimension *insights into research methods*, which did not refer to educational science research methods in particular but to research methods in general. We named this factor as AUTHENTIC INSIGHTS INTO SCIENTIFIC RESEARCH (*Cronbachs's* $\alpha = .78$). The third factor unified all three items of the autonomy scale, one item from the "reference to everyday life" dimension (see example item above), and the following item of the *social experience* dimension: "to have a nice time". We named this factor as NICE AND FREE TIME (*Cronbachs's* $\alpha = .74$). The two remaining items of the social experience scale, which both referred to the expectation to spend (a nice) time with one's classmates, loaded on the fourth factor, which is why we stuck with the original name SOCIAL EXPERIENCE (*Cronbachs's* $\alpha = .77$). One last item of the CAREER ORIENTATION scale (see example item above) loaded on the fifth factor. We will use these five dimensions for our present analysis of students' OLS expectations.

The post-questionnaire measured students' *experiences* of the OSL project by using the same, but slightly rephrased, items as in the pre-questionnaire for assessing students' expectations (e.g., "During today's out-of-school lab visit, I learned something about research methods"). We again excluded the four items that referred to educational science classes in school, and conducted an exploratory factor analysis. The results revealed a factor solution that differed from the solution for the dataset of the pre-questionnaire. Moreover, the extracted factors could not be comprehensibly interpreted. As we, moreover, aimed to compare students' initial expectations with their actual experiences, we decided to form the same five scales as for the dataset of the pre-questionnaire, namely: KNOWLEDGE ABOUT & INTEREST IN EDUCATIONAL SCIENCES (8 items: *Cronbachs's* α = .89), AUTHENTIC INSIGHTS INTO SCIENTIFIC RESEARCH (4 items: *Cronbachs's* α = .67), NICE AND FREE TIME (5 items: *Cronbachs's* α = .84), SOCIAL EXPERIENCE (2 items: *Cronbachs's* α = .81), and CAREER ORIENTATION (1 item).

For assessing students' *situational interest*, we used the scale from Lewalter and Willems (2009). Building on the assumption that situational interest is first triggered and then maintained (e.g., Hidi & Renninger, 2006), the scale consists of six items (e.g., "To what extent was the engagement with the contents of this project exciting for you?") that assess *triggered* situational interest (catch dimension) and of further six items (e.g., "To what extend would you like to learn more about certain topics of the project?") that measure *maintained* situational interest (hold dimension). Students replied to all items on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*). The internal consistencies of the catch (*Cronbachs's* α = .95) and hold items (*Cronbachs's* α = .86) are satisfying.

Procedure

Table 4 shows the procedure. It should be mentioned that we conducted the OSL project in collaboration with social psychologists from another university who were responsible for the second part of the project and who administered a questionnaire assessing students' usage of media which is not the focus of the present paper.

Table 4
Procedure of the present study

Pre-questionnaire (duration: 15. Min.)	
Part 1: Critical Interpretation of study results (2.5 hours)	Collaborative problem solving & presentation of results in whole class
	Short break
	Instruction + collaborative problem solving
Lunch break (1 hour)	
Part 2: Reflection on own media usage (2 hours)	Questionnaire assessing students' usage of media (not focused on in this paper)
	Interactive workshop with small-group activities and whole-class discussions
Post-questionnaire (duration: 15. Min.)	

During the first part of the project day (after filling in the pre-questionnaire), students were asked to collaboratively analyze the design of one out of three published studies on the relation between the use of different media (i.e., social media or media with violent content) on the one hand and different personal characteristics (i.e., mental and physical well-being, empathy, or aggressive behavior) on the other hand. Specifically, students were asked to think about the possible results that could be revealed by the study at hand and whether the study could test a causal hypothesis. The student groups created posters summarizing their thoughts and presented them to the whole class. Afterwards, they received an instruction on why correlation studies cannot yield causal evidence, which is a typical misconception of students and usually part of their solution generated during the initial collaborative problem-solving activity. Finally, students were asked to collaboratively develop a study design which would allow for testing a causal hypothesis. Afterwards, their ideas were discussed in the whole class and the instructor presented an ideal solution, namely the conduction of a controlled experiment.

During the second part of the project (after a lunch break), students first reflected on their own use and perception of different internet applications by filling in a questionnaire. Afterwards, they discussed (in small groups and the whole class) potential benefits and risks of sharing personal information on social media and the opportunities to improve one's internet privacy. They also received brief instructions on these topics. After the second part of the project and, thus, at the end of their OSL visit, students completed the post-questionnaire.

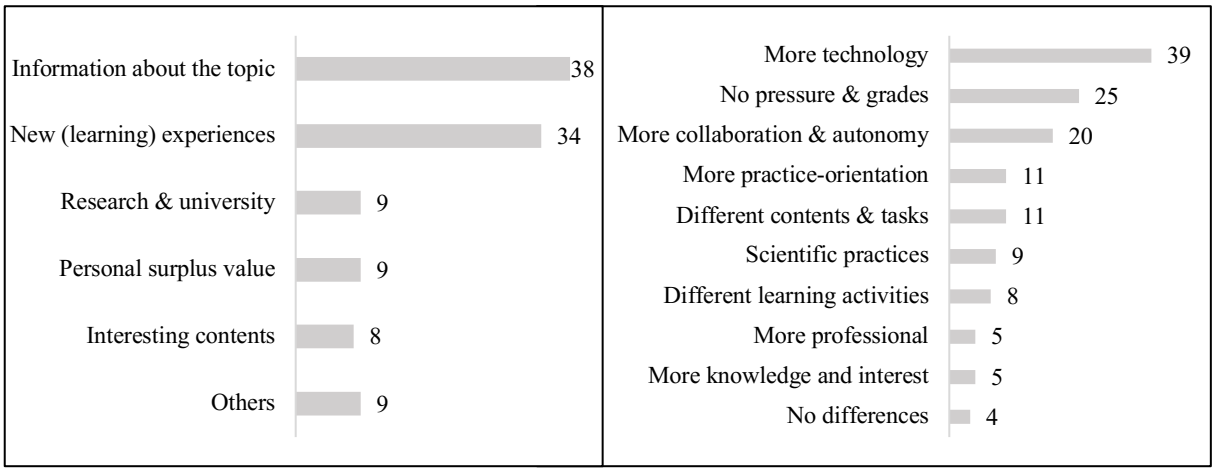
Results

Research question 1: Expectations

With respect to our first research question (i.e., what do students expect from their visit of an OSL for social sciences and humanities?), the analysis of the student answers to the two open-ended questions reveals that

students especially expect to get INFORMATION ABOUT THE TOPIC of the project (here: media) and/or to gain NEW (LEARNING) EXPERIENCES more generally. This may be exemplified by the following two student answers to the first open-ended question: "I expect that we will learn something new, e.g., how to better deal with media." or "Getting to know new things, maybe about the negative impacts of media.". Students, moreover, think that their work in the OSL differs from their regular instruction in school in particular with regard to their access to materials and tools that are featured by MORE TECHNOLOGY. Students further think that learning in an OSL, in contrast to learning in school, is featured by NO PRESSURE AND GRADES and/or MORE COLLABORATION AND AUTONOMY. One student, for instance, gave the following answer to the second open-ended question: "more relaxed atmosphere, no pressure to perform, better technology". Other students stated: "The work with technical devices and more work in groups could be a difference to school." or "more digital, more independent work". Figure 1 shows the descriptive statistics of the coded student answers to the two open-ended questions.

Figure 1
Absolute frequencies of the coded answers to the open-ended question #1 (left diagram) and #2 (right diagram)



Students' responses to the close-ended items further show that they especially expect to have a NICE AND FREE TIME (M = 3.79; SD = 0.71) in which they are enabled to work in a self-directed way on contents that are related to their everyday life. What they expect the least is to get AUTHENTIC INSIGHTS INTO SCIENTIFIC RESEARCH (M = 3.22; SD = 0.96). Students' expectations with regard to SOCIAL EXPERIENCES (M = 3.51; SD = 1.13), CAREER ORIENTATION (M = 3.48; SD = 1.41), and KNOWLEDGE ABOUT AND INTEREST IN EDUCATIONAL SCIENCES (M = 3.47; SD = 0.85) are almost equally high and range between the two former described expectations.

Research question 2: Experiences

The descriptive statistics show that students had high SOCIAL EXPERIENCES (M = 3.99; SD = 1.05) during their OSL visit. They, moreover, experienced their visit as a NICE AND FREE TIME (M = 3.84; SD = 0.89). Compared to these rather social and emotional experiences, students experienced their OSL visit as less beneficial for both their KNOWLEDGE ABOUT AND INTEREST IN EDUCATIONAL SCIENCES (M = 3.13; SD = 0.86) as well as their CAREER ORIENTATION (M = 2.74; SD = 1.18). Their experiences with regard to gaining AUTHENTIC INSIGHTS INTO SCIENTIFIC RESEARCH (M = 3.46; SD = 0.88) ranges in the upper middle of the previous four types of experiences.

To investigate our second research question (i.e., how are students' expectations regarding their OSL visit related to their experiences of their OSL visit?), we first conducted a Wilcoxon signed-rank test (as most of the data deviated from normality) in order to examine the differences between students' initial expectations at the beginning of their OSL visit and their actual experiences at the end of their visit. We then calculated the correlations between the two sets of variables. For CAREER ORIENTATION (z = -3.63, p < .001) and KNOWLEDGE ABOUT AND INTEREST IN EDUCATIONAL SCIENCES (z = -3.96, p < .001), the results of the Wilcoxon test demonstrate that students' expectations were significantly higher at the beginning of their OSL visit than their respective experiences at the end of their visit. For SOCIAL EXPERIENCES (z = -3.41, p = .001) and AUTHENTIC INSIGHTS INTO SCIENTIFIC RESEARCH (z = -2.09, p = .037), the results show that students expectations were significantly lower at the beginning of the OSL project than their experiences of the project at the end of their visit. We found no significant difference with regard to the variable NICE AND FREE TIME (z = -1.23, p = .22). For the correlational analyses, we calculated spearman rho and used an alpha level of .05. The results are depicted in Table 5.

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Table 5
*Correlations between initial expectations and actual experiences (Note. **p < .01 and *p < .05)*

	Initial expectations				
Actual experiences	Knowledge & interest	Authentic insights	Nice and free time	Social experiences	Career orientation
Knowledge & interest	r_s = .51**	r_s = .31**	r_s = .15	r_s = .13	r_s = .35**
Authentic insights	r_s = .17	r_s = .24*	r_s = .07	r_s = .11	r_s = .11
Nice and free time	r_s = .29**	r_s = .30**	r_s = .35**	r_s = .25*	r_s = .19
Social experiences	r_s = .21	r_s = .08	r_s = .18	r_s = .36**	r_s = .15
Career orientation	r_s = .28**	r_s = .32**	r_s = .14	r_s = .17	r_s = .13

As these results demonstrate, except for career orientation, all variables of the same dimension significantly and positively correlate with each other. For instance, if the expectation to increase one's knowledge about and interest in educational sciences is high at the beginning of the OSL visit, the respective experience of having increased one's knowledge and interest is also high at the end of the OSL visit. The correlational analyses further suggest differentiated experiences of the OSL visit depending on the initial expectations. For instance, the higher students expected to get authentic insights into scientific research at the beginning of their visit, the higher did they experience the OSL project as one that (1) promoted their knowledge about and interest in educational sciences, (2) provided them authentic insights into scientific research, (3) enabled them to have a nice and free time, and (4) offered career orientation. On the contrary, the initial expectation to have a nice and free time during the OSL visit is only positively associated with the experience of the OSL visit as nice and free time.

Research question 3: Situational interest

To investigate our third research question (i.e., are students' expectations towards their OSL visit associated with their situational interest in the contents of the OSL project?), we again conducted correlational analyses and calculated spearman rho. The results reveal that both students' triggered and maintained situational interest at the end of the OSL visit positively and significantly correlate with their initial expectations to (1) increase one's knowledge about and interest in educational sciences (catch: r_s = .38, p < .001; hold: r_s = .31, p = .003), (2) get authentic insights into scientific research (catch: r_s = .29, p = .007; hold: r_s = .22, p = .04), and (3) get impressions helpful for one's career orientation (catch: r_s = .27, p = .01; hold: r_s = .22, p = .04). The expectations to have a nice and free time as well as to make social experiences during the OSL visit do neither correlate with students' triggered situational interest (nice and free time: r_s = .20, p = .06; social experiences: r_s = .12, p = .27) nor with their maintained situational interest (nice and free time: r_s = .14, p = .19; social experiences: r_s = .07, p = .52).

Discussion

The findings of the present study on students' expectations towards their visit of an OSL (out-of-school lab) for social sciences and humanities (Research question 1) demonstrate that secondary school students have rather unspecific and broad expectations (e.g., "making new learning experiences" or "more technology") and especially hope to have a nice and relaxed time without pressure to perform and in which they can work independently and collaborate with their classmates. Students expect the least to get authentic insights into scientific research, which is, however, generally a goal of OSLs and was indeed the primary goal of the OSL project in which the present study took place. A possible explanation for this result may relate to the fact that the social sciences and humanities as well as scientists within these disciplines are barely associated with science and research (Nachtigall & Rummel, 2020). Thus, our findings point to the need to foster students' beliefs and conceptions about social sciences and humanities, and (maybe even thereby) their expectations towards visiting an OSL for social sciences and humanities. However, our findings also suggest that OSLs may have the potential to change these beliefs, as students experienced the OSL project at the end of their visit (Research Question 2) as one that provided them with insights into scientific research (i.e., this experience was significantly higher as the respective initial expectation). Consequently, to enhance the effectiveness of OSLs, one could assume that students have to visit an OSL multiple times: first to adjust their expectations, and then to increase their knowledge about and interest in scientific research. Our findings further support the assumption developed and tested in the context of museum research that the visitors' expectations affect the quality and experiences of their actual visit of a museum (Falk

& Dierking, 2004). Specifically, our correlational analyses suggest that the more students expected to increase their knowledge about and interest in educational sciences or to get authentic insights into scientific research at the beginning of their OSL visit, the more did they experience the OSL project as one that (1) promoted their knowledge about and interest in educational sciences, (2) provided them authentic insights into scientific research (correlated only with the respective initial expectation), (3) enabled them to have a nice and free time, and (4) offered career orientation. On the contrary, the initial expectation of having a nice and free time – what the students in the present study expected the most – correlated only with the experience of the OSL project as one that enabled them to have a nice and free time. The same is true for students' situational interest (Research Question 3). That is, while the expectations to increase one's knowledge and interest related to educational science, to get authentic insights into scientific research, and to receive information helpful for one's career orientation positively correlated with students' situational interest in the contents of the OSL project, the initial expectations of making social experiences and having a nice and free time did not correlate with students' situational interest. To conclude, although more research is required to further investigate students' expectations towards visiting non-formal learning settings, such as OSLs, and the role that these expectations play for different learning outcomes, the present study indicates that students' expectations relate to both their actual experiences of the OSL visit and their situational interest in the contents of the OSL project. With a better and deeper understanding of students' expectations towards visiting an OSL (for social sciences and humanities), future research could investigate ways for adjusting students' expectations and, in turn, for improving their actual experiences and learning outcomes.

Endnotes

(1) Translated from German; Original statement: „Hm, werden wir dann ja sehen, ob ich die nächste Arbeit besser schreibe oder schlechter [Pause/Unterbrechung] Außerdem is´ das dem Lehrer doch eh scheißegal, wat wir hier machen."

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Developing the Systems Thinking and Computational Thinking Identification Tool

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Abstract: We developed the Systems Thinking (ST) and Computational Thinking (CT) Identification Tool (ID Tool) to identify student involvement in ST and CT as they construct and revise computational models. Our ID Tool builds off the ST and CT Through Modeling Framework, emphasizing the synergistic relationship between ST and CT and demonstrating how both can be supported through computational modeling. This paper describes the process of designing and validating the ID Tool with special emphasis on the observable indicators of testing and debugging computational models. We collected 75 hours of students' interactions with a computational modeling tool and analyzed them using the ID Tool to characterize students' use of ST and CT when involved in modeling. The results suggest that the ID Tool has the potential to allow researchers and practitioners to identify student involvement in various aspects of ST and CT as they construct and revise computational models.

Introduction

Many of our current societal and ecological challenges involve complex systems composed of interconnected elements. From global pandemics to climate change, these challenges require systems thinking (ST) to identify how various elements contribute to emergent effects in large-scale systems. ST enables individuals to investigate how a single part of a system can have broader impacts on the whole system (Meadows, 2008). Given the complexity of most systems, computational thinking (CT) is often required to approach these problems. CT is a sensemaking process where one decomposes a problem in a systematic way, translates it into an algorithm that can be interpreted by an information processing agent, and iteratively refines it based on new observations and new data inputs (Grover & Pea, 2018; Wing, 2006). Because both ST and CT are important for addressing problems involving complex systems, it is fruitful to consider their synergies for investigating phenomena (Shin et al., in press; Weintrop, 2016). ST and CT are also increasingly being emphasized as important elements of science education on a global scale, being incorporated into official policy documents in many countries including the U.S., the U.K., and Taiwan (Csizmadia et al., 2015; NGSS Lead States, 2013; So et al., 2020).

These efforts to include ST and CT as key aspects of science education create a need for developing new research tools for characterizing and monitoring student use of these types of thinking (Grover & Pea, 2018). One framework that recognizes the interconnected relationship between ST and CT is the "ST and CT Through Modeling Framework," which describes how student use of ST and CT can be supported through the construction of computational models (Bowers et al., 2022; Shin et al., in press). This framework seeks to clarify and expand the conceptualizations of ST and CT as proposed by the NGSS as well as demonstrate the synergy between ST, CT, and modeling (NGSS Lead States, 2013; Shin et al., in press). Given its focus on the interconnectedness of ST and CT, this framework provides a foundation for developing an instrument for observing student use of ST and CT as they construct and revise computational models. Such a tool may facilitate researchers in recognizing instances of and patterns in students' use of specific ST and CT aspects as they construct and revise models. In this paper, we first summarize our conceptualization of the three main components of our framework (ST, CT, and modeling) and how these components combine to form five computational modeling practices. We then describe how we developed a research tool based on this framework to explore student use of ST and CT as they constructed and revised computational models using a semi-quantitative computational modeling tool. Finally, we provide examples of how this tool can be used to identify and categorize student use of ST and CT.

Theoretical Approach

Systems thinking is an approach to exploring a phenomenon as a network of elements that work together to create a system with emergent behavior that is more than the sum of its constituent parts (Arnold & Wade, 2015; Forrester, 1971; Meadows, 2008). We define an "element" as a key part of a system that can be independently described yet interacts with other aspects of the system to impact the overall behavior of that system. Many

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complex phenomena can be described as a series of interacting elements with feedback relationships and informational delays that often generate counterintuitive behaviors (Booth-Sweeney & Sterman, 2007; Cronin et al., 2009). To fully engage in ST, students need to move beyond simple linear causal reasoning to a system behavior perspective so that they can identify common structural patterns found within and across systems. Our framework identifies five major aspects of ST: (1) defining a system's structure and boundaries, (2) engaging in causal reasoning, (3) recognizing interconnections and identifying feedback, (4) framing problems or phenomena in terms of behavior over time, and (5) predicting system behavior based on system structure (Shin et al., in press).

Computational thinking has many definitions ranging from being grounded in mathematics and data analysis (NRC, 2012) to being an aspect of sensemaking centered on formulating questions through testing models and simulations (Schwarz et al., 2017; Weintrop et al., 2016) to thinking like a computer scientist (Grover & Pea, 2018; Wing, 2006). Synthesizing these approaches, we define CT as a form of sensemaking that uses an iterative and quantitative approach to decompose a phenomenon or problem to explore, explain, and predict the behavior of that phenomenon or to find a solution to a problem through the creation and iterative revision of algorithms (Shin et al., in press). Our framework identifies five major aspects of CT: (1) decomposing problems such that they are computationally solvable, (2) creating computational artifacts using algorithmic thinking, (3) generating, organizing, and interpreting data, (4) testing and debugging, and (5) making iterative refinements.

In addition to ST and CT, modeling forms the third component of our framework. Modeling is the process of creating a representation of a phenomenon such that the representation can be used to explain or predict the behavior of that phenomenon (Harrison & Treagust, 2000; Schwarz et al., 2009). From this perspective, models are viewed not just as the product of scientific inquiry but as essential tools for supporting scientific reasoning and sensemaking (Schwarz et al., 2009). Additionally, analyzing existing models can help one gain insight into different aspects of a phenomenon and predict its future behavior (zu Belzen & Krüger, 2010). Scientists and students often use models to represent their conceptualization of a phenomenon so that they can synthesize and communicate their ideas to others (Gilbert & Justi, 2016). Within our framework, students utilize both ST and CT approaches as they engage in the process of modeling.

While researchers (Berland & Wilensky, 2015; Wing, 2017) claim that CT and ST are intertwined and support each other, we view CT and ST as co-equal, yet distinct in the context of modeling because of their unique ways of approaching problems. CT focuses on designing solutions through computation while ST analyzes the various relationships among elements in a system (Shute et al., 2017). Our framework thus defines CT and ST as separate entities and identifies five computational modeling practices that combine aspects of ST and CT: (M1) characterize problem or phenomenon to model, (M2) define the boundaries of the system, (M3) design and construct model structure, (M4) test, evaluate, and debug model behavior, and (M5) use model to explain and predict behavior of phenomenon or design solution to a problem (Bowers et al., 2022). Students engage in these modeling practices as they construct, test, revise, and use their computational models. Students characterize the phenomenon (M1) as they discuss and unpack key elements of the phenomenon under study and as they learn about new elements of the phenomenon. Students define the boundaries of the system (M2) and design/construct model structure (M3) as they discuss which variables to add to their models and set relationships between these variables respectively. Once students have built their initial models, they can analyze the model output and should compare this output to real-world data or their emerging understanding of the phenomenon to identify and modify flaws in their model, thus testing and debugging of model behavior (M4). Finally, students use their models to construct explanations of the phenomenon or predict how the system will behave under different circumstances (M5). Each of these practices are supported by a combination of aspects of ST and CT (Table 1).

Table 1
The computational modeling practices and associated ST and CT aspects

Computational Modeling Practice	Associated ST and CT Aspects
M1. Characterize Problem or Phenomenon	ST: Define a System CT: Decompose Problems
M2. Define System Boundaries	ST: Define a System, Frame Phenomena in Terms of Behavior over Time CT: Decompose Problems, Create Algorithmic Artifacts
M3. Design and Construct Model Structure	ST: Engage in Causal Reasoning, Recognize Interconnections and Feedback, Frame Phenomena in Terms of Behavior over Time

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	CT: Create Algorithmic Artifacts
M4. Test, Evaluate, and Debug Model Behavior	ST: Define a System, Predicting System Behavior Based on System Structure CT: Generate and Interpret Data, Test and Debug, Make Iterative Refinements
M5. Use Model to Explain and Predict Behavior of Phenomenon	ST: Predict System Behavior Based on System Structure, Engage in Causal Reasoning CT: Generate and Interpret Data, Test and Debug, Make Iterative Refinements

Although the science education community has established ST, CT, and modeling as key learning goals, we know relatively little about how to support students in these practices. We used the ST and CT Through Modeling Framework to develop a research tool that could help researchers investigate student use of ST and CT as they build, test, and revise models. We hypothesize that such a tool could help researchers identify which aspects of ST and CT students use more frequently or find challenging. Therefore, we investigate these research questions: How can one characterize patterns of student use of specific aspects of ST and CT as they construct and revise models? Which aspects seem to be more challenging for learners? To address these questions, we developed the ST and CT Identification Tool (ID Tool) to classify instances of students using aspects of ST and CT as they build, test, and revise models.

Methods

Study context and data sources

The data used to develop and evaluate our ID Tool came from a high school chemistry unit on evaporative cooling designed to meet NGSS learning goals and enacted at a Midwestern U.S. STEM school. We designed this unit around Project-Based Learning (PBL) principles (Krajcik & Shin, 2022) in which students explore the phenomenon of evaporative cooling, use a driving question and a driving question board and conduct investigations to address the driving question. This unit also centered on students building and revising models of phenomena using an open-source semi-quantitative computational modeling tool called SageModeler (Figure 1). SageModeler is a modeling tool that allows students to construct semi-quantitative models without using formal programming language (https://sagemodeler.concord.org). Students can test these models using a simulation function to generate model output and using graphs constructed from the output or imported from real-world data. To collect data on students building and revising their models, we used 15 hours of screencasts from five pairs of students for a total of 75 hours. Screencasts record the students' actions on their laptop screens and record student audio while they are building and manipulating their computational models.

Instrument development

Content validity refers to the extent all aspects of our framework align with the literature. For content validity, we conducted an extensive literature review of CT, ST, and modeling, and deconstructed each practice into smaller aspects and sub-aspects (Shin et al., in press). We examined specific aspects of ST and CT to define how students should be able to use their knowledge through five modeling practices. During the development processes, our research team – including experts in science, learning sciences, learning technology, and science education – defined, reviewed, and revised the modeling process and specified aspects of ST and CT in the context of modeling through discussing disagreements and ambiguities, continuing (or updating) our literature review, and teachers' and students' data collected from implementation. Our research team expanded on this work, developing a theoretical framework describing how specific aspects of ST and CT are applied through five distinct modeling practices. These processes confirmed the theory-based modeling process outlined in the framework, ensuring that the ST and CT aspects were operationalized to monitor student involvement in these aspects while modeling.

Construct validity is the extent to which the indicators of our ID Tool measure our intended constructs. To accomplish construct validity, our approach focuses on defining indicators (evidence) clearly and comprehensively and describing measurable (observable) behaviors that are present when learners are utilizing the desired ST and CT aspects through modeling. We first decomposed the various aspects of ST and CT associated with each modeling practice into smaller sub-aspects. For example, the computational modeling practice of "test, evaluate, and debug model behavior" (M4) is supported by the ST aspects of "defining a system" and "predicting system behavior based on system structure" along with the CT aspects of "generating, organizing, and interpreting data," "testing and debugging," and "making iterative refinements" (Table 1). These ST and CT aspects can in turn be broken down into more specialized sub-aspects. Within the CT aspect of "testing and

debugging" we identified three key sub-aspects associated with the modeling practice of "test, evaluate, and debug model behavior": "detecting issues in an inappropriate solution," "fixing issues based on the behavior of the artifact," and "confirming the solution using multiple starting conditions."

We then identified specific learner-generated behaviors or knowledge products that can be associated with one or more of these sub-aspects of ST and CT. These behaviors were operationalized as indicators. In this study, we are specifically focusing on indicators associated with "testing and debugging" as the literature strongly suggests that students often have difficulty fully participating in its associated ST and CT aspects (Grover & Pea, 2018). The six indicators associated with the (M4) modeling practice behavior are listed below, along with their respective ST and CT aspects and sub-aspects.

- **4A**. *Analyzing and Sensemaking through Discourse*. ST: defining a system (redefining model structure) and predicting system behavior. CT: testing and debugging (detecting faults and fixing faults)
- **4B**. *Analyzing Model Output: Simulations*. ST: Not applicable (NA). CT: interpreting data (generating data, analyzing data), testing and debugging (detecting faults, confirming solutions), and iterative refinement (verifying solutions)
- **4C**. *Analyzing Model Output: Graphs*. ST: NA. CT: interpreting data (generating data, analyzing data), testing and debugging (detecting faults, confirming solutions), and iterative refinement (verifying solutions)
- **4D**. *Analyzing and Using External Data*. ST: NA. CT: interpreting data (generating data, analyzing data) and iterative refinement (verifying solutions)
- **4E**. *Using Feedback*. ST: defining a system (redefining model structure). CT: testing and debugging (fixing issues) and iterative refinement (making modifications and verifying solutions)
- **4F**. *Reflecting upon Iterative Refinement*. ST: defining a system (redefining model structure). CT: testing and debugging (fixing issues) and iterative refinement (making modifications and verifying solutions).

The modeling research team also reviewed the indicators to determine if they plausibly indicated student use of individual aspects of ST and CT. Once these indicators were reviewed, we further refined and developed them into a four-part classification system (ranging in ascending order from Level 1 to Level 4) to explore the sophistication of student use of these aspects. We then conducted an interrater reliability test for these indicators, which demonstrated a 91.7% agreement (Cohen's Kappa, .87) between two independent coders.

Data analysis and findings

To code students' collaborative interactions as they built a computational model with SageModeler, we analyzed screencast data using Atlas.ti to organize the data according to the four levels of the ID Tool and to determine the relative frequency of each of these six indicators. The patterns of each group as well as among groups were analyzed to characterize how students used ST and CT aspects during modeling and which aspects seemed challenging for learners. Below we summarize how student behaviors served as evidence for ST and CT by matching indicators from the ID tool with observations from our study.

The computational modeling practice of "test, evaluate, and debug model behavior" occurs as students evaluate their models and consider changes they need to make so that their models more accurately reflect their understanding of the phenomenon. Given the various approaches students can take to evaluating and revising their models, we have identified six observable indicators as evidence that students are involved in different aspects of this modeling practice as listed above as 4A-4F. As students worked on refining their models with their partners, they often discussed specific model relationships and/or broader model behavior. For example, when evaluating their early model, two students had this conversation regarding relationships between variables:

> "Student 1: As the molecular energy increases, that makes the molecular spacing of the substance increase. That's good. And then the spacing of the air molecules increases, this [molecular spacing] stays the same until it [spacing of the air molecules] gets small as there's not a lot of space. Student 2: Makes sense. Student 1: We can change this [the relationship between spacing of air molecules and molecular spacing]. Student 2: Yeah, I don't think that makes sense. Student 1: Is it the other way then? Student 2: Maybe?"

This conversation is an example of indicator 4A, students participating in analyzing and sensemaking of model structure through discourse. At Level 1, students verbalize the changes they made to their model or describe the area of their model they believe needed further revisions, but do not provide reasoning for making these changes or why an area of their model needs improvement. If a student verbalizes reasoning but does not participate in a mutual dialogue with their partner, they are considered performing at Level 2. To progress to Level 3 requires that students engage in a back-and-forth dialogue by providing reasoning for making key changes to

their model. Evidence for Level 4 would be a student exchange in which they consider how changes to their model would impact the behavior of the model. Because the students in this example provide a brief amount of reasoning as they are trying to justify the relationship between the spacing of air molecules and molecular spacing and both students contribute to the discourse (although Student 2 does so in a minimalist manner), we consider this to be evidence of students participating at Level 3 for Indicator 4A.

In addition to listening to student discourse, we observe students using model output features to test their model's behavior. SageModeler offers two ways of generating and analyzing model output: manipulating variables using the simulation tool and generating graphs. Both actions produce observable indicators (4B and 4C, respectively). The simulation tool allows students to manipulate the relative amount of each input to test its impact on model behavior (Figure 1A). If students adjust the relative amount of one or more input variables, but do not verbalize their interpretation of this process, we consider this evidence of some attempt to interpret data, even if only at Level 1. Once students begin verbalizing their interpretation of the testing process (either by identifying specific flaws in their model or by stating that their model is functioning in accordance with their expectations), we can map their progress to Level 2. Identifying Levels 3 and 4 requires that students participate in a meaningful back and forth dialogue with either their partner, one or more peers, or a teacher. If the conversation focuses on the smaller aspects of model behavior (centering on a single causal chain), we consider this evidence of Level 3 for interpreting data using the simulation tool, while evidence of Level 4 would require a more holistic discussion of the model (e.g., focusing on how multiple causal chains impact each other).

Students can also use SageModeler to generate graphs that analyze the relationships between two variables from their model (Figure 1B). If students unsuccessfully attempt to make a graph of two variables from the model output, we consider this evidence of Level 1 for indicator 4C. If students successfully make a graph of two variables, but do not discuss their interpretation of this graph, their behavior can be categorized as Level 2. Evidence for Level 3 requires students to participate in a dialogue where they discuss their interpretation of the graph and its implications for those two variables in isolation from the broader context of the model. If students consider the implications this graph has for both these two variables and broader model behavior, this is considered evidence for Level 4 for generating and analyzing data, detecting faults, and confirming and verifying a solution. In Figure 1A, these students used the simulate feature to look at their model output, but neither student verbalized this process in a meaningful way, so we inferred that the students were performing at Level 1 for indicator 4B. The students who made the graph in Figure 1B verbalized their interpretation of the graph, stating, "This graph shows that as IMF increases the potential energy increases but then plateaus. That makes sense to me." This is evidence of Level 3 performance for indicator 4C.

Figure 1A
Student use of "Simulate" feature in SageModeler.

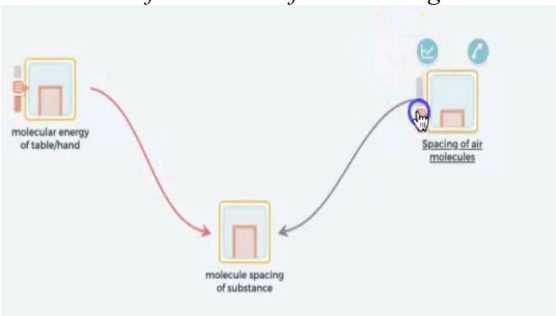
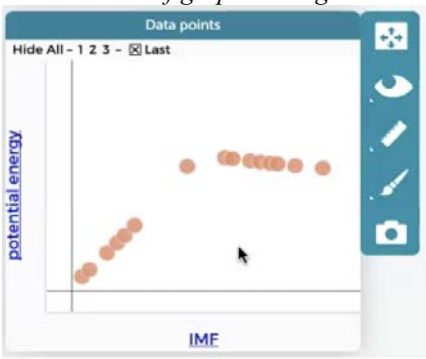


Figure 1B
Student use of graphs in SageModeler.



Just as students can analyze their model output to see if their model behaves according to their understanding of the phenomenon, students can also examine external data sources to verify if their models accurately describe the phenomenon as evidenced by indicator 4D. When students superficially refer to the existence of data or loosely reference dubious data sources, they are at Level 1. At Level 2, students reference external data (from real-world observation or specific information provided by instruction or readings) to inform or justify changes made to their models, but do not actively compare these data to their model output. Once students progress to comparing specific pieces of real-world data to their model output, they can be said to be engaging at Level 3. This is particularly evident if they input quantitative external data into the modeling program and directly compare it to their model output (Figure 2). Finally, if students compare and contrast their external data to model output and discuss the validity of the external data, this is evidence of Level 4 performance. In

Figure 2, the students input real-world data from an experiment into SageModeler but did not actively compare these data to their model output, indicating a Level 2 performance.

Figure 2
Students inputting external data

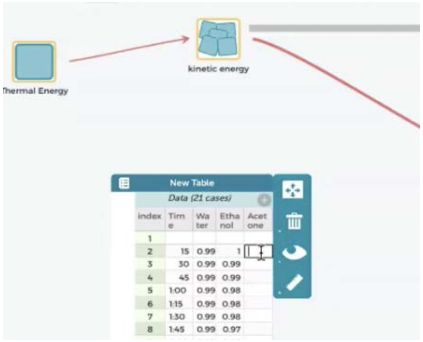
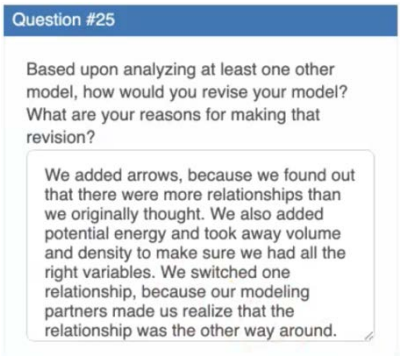


Figure 3
Student's written reflections on iterative refinement



Another important way students can receive feedback on their models is through discussions with peers or a teacher, which can inform further revisions, allowing students to engage in using feedback to inform model revisions (Indicator 4E). If the feedback students receive does not inform any changes to their model or prompt further analytical discourse, they are at Level 1. Note that if the feedback they receive is inappropriate and students do not discuss why this feedback was inappropriate their behavior would still be indicative of a Level 1 performance. Students who use this feedback to make changes to their models but have neither a discussion with their partner before making these changes nor test their models after making these changes are at Level 2. Once students use this feedback to either spark an analytical discussion or analyze their model's behavior after making recommended changes, they are operating at Level 3. If students then address the originator of the feedback or have a conversation with another student group about why they made these changes or what new insights have emerged from their testing and debugging of these changes, their behavior can be categorized as being at Level 4. For instance, one of their peers asked another pair to remove "density" as a variable from their model, arguing that it was not necessary to explain the phenomenon. This pair of students then removed the density variable but did not discuss why they were removing this variable. We classify this performing at Level 2.

Finally, students should be given opportunities to reflect on the changes they have made to their models. Students can participate in the process of reflecting upon iterative refinement (4F) through discussion or through writing as seen in Figure 3. Student level of expertise is suggested by the depth and richness of the insights they exhibit into their own revision process. When students give surface-level feedback on the quality of their models at a given point in time, without considering the changes they have made or the reasons for making these changes, they are performing at Level 1. To infer Level 2 performance, students list specific changes that they have made to their models, but do not provide any detailed reasons for making these changes. Evidence for Level 3 performance requires that students reflect upon specific changes to their models and explain their reasoning behind these changes. Finally, students performing at Level 4 emphasize broader changes that have occurred to their models over a longer period (often across multiple revisions) and provide an explanation as to how their model has evolved. In Figure 3, a pair of students list the changes they have recently made to their models and give specific reasons for making these changes (peer feedback and changes in conceptual understanding). As this reflection focuses on more immediate changes and not broader patterns, it is evidence of Level 3 performance. Overall, these results support Research Question 1 (How can one characterize patterns of student use of specific aspects of ST and CT as they construct and revise models?) as they demonstrate how our ID Tool can be used to identify and classify specific instances of students using ST and CT as they are testing and debugging their models.

Using our ID Tool, we examined the screencasts of five student groups during an evaporative cooling unit. We then compared the relative amount of time (as determined by the number of 10-minute intervals where students were involved in at least once in a respective indicator) these students spent participating in each of the six sets of behaviors we viewed as indicators of involvement with the modeling practice of testing and debugging (Table 2). Incidents were recorded for each 10-minute block and data from all five groups were aggregated to compare the relative amount of time coded for the presence of each indicator. Time points where students were not exhibiting any indicators were excluded from this data set and students could exhibit multiple indicators within one 10-minute block. The results suggest that students spent a large portion of their time using discourse-based strategies to analyze their models (as seen by their high use of Analyzing and Sensemaking of Models through

Discourse [4A], 59.5%) and often utilized the simulation features present within the modeling program. However, these students seem less likely to use external data sources to drive their revision process ([Indicator 4D], 15.1%) and even more hesitant to use graphs to analyze their model output ([Indicator 4C], 3.2%). This suggests that additional scaffolds are likely needed to support student participation in these activities. It is important to note that although students were more likely to participate in Analyzing and Sensemaking of Models through Discourse (Indicator 4A), many exhibited performance only at Level 1 and Level 2 behaviors, which might indicate that performing at higher levels for these indicators were more challenging for them. For instance, we observed several instances where the student in charge of the cursor dominated the sensemaking discussion, while their partner provided minimal feedback or verbal sensemaking support. Overall, these results address Research Question 2 (Which aspects seem to be more challenging for learners?) by suggesting that aspects associated with Indicator 4C are more challenging for students or are less supported by either the curriculum or their teachers compared to aspects associated with Indicators 4A or 4B.

Table 2
Relative time spent participating in each indicator for all five groups

Indicator	Total time Spent*	Relative Percentage
4A. Analyzing models: Discourse	75 (G1:13, G2: 24, G3: 16, G4: 9, G5: 13)	59.5
4B. Analyzing Model Output: Simulations	48 (G1: 4, G2: 15, G3: 12, G4: 5, G5: 12)	38.1
4C. Analyzing Model Output: Graphs	4 (G1: 0, G2: 0, G3: 4, G4: 0, G5: 0)	3.2
4D. Analyzing External Data	19 (G1: 6, G2: 6, G3: 3, G4: 2, G5: 2)	15.1
4E. Using Feedback	36 (G1: 11, G2: 5, G3: 3, G4: 11, G5: 6)	28.6
4F. Reflecting upon Iterative Refinement	41 (G1: 3, G2: 12, G3: 11, G4: 5, G5: 10)	32.5
Total	223 (G1:37, G2:62, G3: 49; G4:32 G5:43)	

Note: * Total number of 10-minute coding blocks where indicator is present at least once. G: group. GX: total coding blocks where indicator is present. Due to students often participating in multiple indicators in a single 10-minute block and the "relative percentage" referring to the percentage of coding blocks where this indicator is present, the sum of the relative percentages does not add up to 100%.

Conclusions and implications

These results demonstrate how the ID Tool can be used to characterize patterns and challenges of student use of specific aspects of ST and CT as they construct and revise models. While the instrument described in this paper focuses on aspects of ST and CT used during model revision, we have also developed other indicators for ST and CT that need to be validated. A draft of these additional indicators can be found at https://tinyurl.com/2ft6rkza**.** Building off the ST and CT Through Modeling Framework, our ID Tool seeks to connect abstract ideas of student cognition with concrete indicators that can be observed through screencasts, classroom videos, or direct observation of students in classrooms. As each indicator is grounded in specific aspects and sub-aspects of ST and CT, it can be used to track how students are using ST and CT in various learning activities across disciplines. Therefore, this tool can be used to develop future research instruments such as teacher and student interview protocols and classroom observation instruments as well as assist with creating ST and CT integrated learning activities. While the ID tool is primarily designed for research use, it can be modified to be used by teachers to help them identify moments where students are using ST and CT. Overall, our ID Tool represents an important step in developing a meaningful instrument for monitoring student use of ST and CT while constructing and revising models in realistic classroom settings. Further validity studies based on students' data in various learning contexts are needed to iteratively revise this ID Tool as an evidence-based principled tool to observe student use of ST and CT as they construct and revise computational models. We are also in the process of utilizing this tool to further investigate how students utilize ST and CT aspects within a computational modeling context. Given the increased need and benefits to incorporate ST, CT, and modeling into science education, there is a growing demand for tools that can support researchers, curriculum developers, and teachers in classifying instances of

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students use of these practices. Our research efforts on the ID Tool seek to further research in ST, CT, and computational modeling and promote the integration of these three research fields to support student learning.

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Exploring Students' and Mathematics Teachers' Conceptions About the Work of Mathematical Scientists and Possible Relations to Mathematics Teaching

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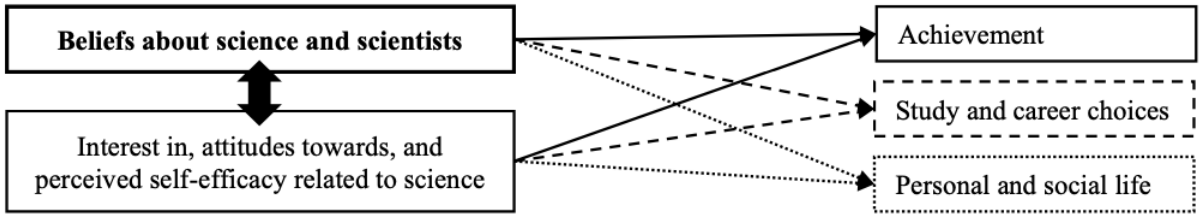
Abstract: The aim of this paper is to investigate students' and teachers' conceptions about the work of mathematical scientists, and to explore possible relations to mathematics teaching. Therefore, we conducted an exploratory interview study with 14 9th graders and 5 mathematics teachers. The results show that students have inadequate and limited conceptions about the work of mathematical scientists. The belief that mathematical scientists do the same kind of mathematics as students do in the classroom – namely calculating – but on a higher level supports the assumption that students' conceptions of the work of mathematical scientists are also based on their experiences in the classroom. We discuss the findings in light of previous research on images of mathematics, naïve epistemological beliefs about mathematics and conceptions about mathematicians. We further derive ideas for fostering more accurate conceptions in students.

Introduction

Several researchers (e.g., Christidou, 2011; Finson, 2002; Nachtigall & Rummel, 2020) have assumed that students' conceptions about science and scientists – especially in the field of STEM – are interrelated with their interest in and their attitudes towards science, and, therefore, affect their achievement as well as their study and career choices (see also Figure 1).

Figure 1
Model on the effects of students' beliefs about science and scientists (Nachtigall & Rummel, 2020, p.641)



Students' who have incomplete or negative conceptions of science and scientists are, for example, less likely to pursue science courses and enter a science-related career (Stamer, Kubsch et al., 2019). Consequently, it is necessary to explore and understand students' conceptions. Only if educators have some understanding of students' conceptions, they will be able to effectively and positively impact these conceptions through instruction (Finson, 2002).

Previous studies have shown that students often have limited, inaccurate, and stereotypical conceptions about science and scientists. For example, the results of the study by Newton and Newton (1992) show that the majority of students conceptualize science as the processing of substances for making new materials (a kind of applied chemistry) or as the study of living things, especially of animals. Research on students' images of scientists further demonstrates that many students picture scientists as older or middle-aged Caucasian men who wear lab coats, glasses and/or beards, and work in laboratories surrounded by symbols of research, knowledge, and technology, such as test tubes, Bunsen burners, flasks, and bottles (see Christidou, 2011; Finson, 2002). Especially with regard to mathematics Barbeau (1990, p. 42, as quoted in Picker & Berry, 2000) concludes that there is "probably no area of human activity […] as afflicted as mathematics with a gap between the public perception of its nature and what its practitioners believe it to be." Furthermore, Furinghetti (1993, p. 34) argues that mathematics "is a discipline that enjoys a peculiar property: it may be loved or hated, understood or misunderstood, but everybody has some mental image of it." Inaccurate or stereotypical conceptions about mathematics and mathematical scientists may hinder students' study of mathematics (Picker & Berry, 2000). The results of a study by Köller et al. (2000), for instance, show that students' beliefs about the nature of knowledge

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and the process of knowledge acquisition in mathematics influence their interest, their learning, and, consequently, their achievement in mathematics. It is likely to assume that students' conceptions about typical activities of mathematical scientists may also influence their interest, their learning, and, thus, their achievement as well as their study and career choices in mathematics (see Figure 1). However, in contrast to students' beliefs about the nature of knowledge and the process of knowledge acquisition, little research has been focused on students' perceptions about mathematical scientists until now. Especially, so far, students' conceptions about the work of mathematical scientists have not been explicitly investigated in detail.

Against this background, it appears essential to investigate students' conceptions about the work of mathematical scientists. Therefore, the aim of this paper is to investigate students' perceptions about typical activities of mathematical scientists. Subsequently, students' conceptions can be changed and, as a result, their thinking about their roles as future mathematicians can be facilitated and extended (Rock & Shaw, 2000). However, if inadequate and stereotypic conceptions can be found, it is important to explore where these perceptions arise from to then be able to derive specific interventions to foster more adequate conceptions. Obviously, students' perceptions about the work of mathematical scientists are likely mainly based on their classroom experiences. Thus, additionally, teachers' perceptions about typical activities of mathematical scientists are also investigated, in order to explore possible relations to mathematics teaching.

Students' conceptions about mathematics and the work of mathematicians

Students often have a negative image of mathematics (e.g., Furinghetti, 1993; Howson & Kahane, 1990; National Research Council, 1989) and naïve epistemological beliefs about mathematics (e.g., Köller et al., 2000; Schoenfeld, 1988) as well as limited conceptions about mathematicians and their work (Malkevitch, 1997; Picker & Berry, 2000; Rock & Shaw, 2000).

With respect to *images of mathematics*, several researchers (e.g., Furinghetti, 1993; Howson & Kahane, 1990; National Research Council, 1989) have shown that many people have a negative image of mathematics. The National Research Council (1989, p. 43) portrayed the following picture of mathematics:

> Unfortunately, as children become socialised by school and society, they begin to view mathematics as a rigid system of externally dictated rules governed by standards of accuracy, speed and memory. Their view of mathematics shifts gradually from enthusiasm to apprehension, from confidence to fear. Eventually, most students leave mathematics under duress, convinced that only geniuses can learn it.

Consequently, Howson and Kahane (1990) talk about the "mathematics' image problem".

A comparable picture was found in previous studies with regard to *epistemological beliefs about mathematics* (e.g., Köller et al., 2000; Schoenfeld, 1988). Epistemological beliefs are individuals' representations about the nature of knowledge and the process of knowledge acquisition (Hofer & Pintrich, 1997). Focusing on mathematics, Schoenfeld (1988) first investigated epistemological beliefs of students in a qualitative study. The results show that students believed that finding the right answer and expressing it in the right form is what matters. Moreover, students viewed themselves as passive consumers of others' mathematics. Schoenfeld assumes that these perceptions are largely affected by the experiences that students make in mathematics classes. In the mathematics classroom – according to Schoenfeld – the subject matter is presented, explained, and rehearsed; there is little sense of exploration or of the importance of understanding. He concludes that through such mathematics teaching, students learn only to master algorithmic procedures, but not to think mathematically. The results of the study by Köller et al. (2000) also show that students primarily emphasize the schematic-algorithmic orientation of mathematics and of mathematics teaching. The majority of the students agreed with the following statements: "Mathematics is the retention and application of definitions, formulas, mathematical facts, and procedures.", and "Doing mathematics means: applying general rules and procedures to specific tasks." Moreover, students seem unfamiliar with a relativistic scientific-theoretical position that emphasizes the constructive and processual character of mathematics. Furthermore, the results by Köller et al. (2000) show that students' epistemological beliefs about mathematics influence their interest, their learning, and, thus, their achievement: Students with the belief that mathematics is simply the application of solution algorithms to given tasks are less interested and obtain lower achievement, whereas students with a relativistic conception of mathematics demonstrate higher interest in mathematics and, as a likely consequence, gain higher achievement.

But not only the images of mathematics and students' epistemological beliefs about mathematics are inadequate. Many people also lack knowledge *about what it is that mathematicians actually do* (e.g., Malkevitch, 1997; Picker & Berry, 2000). From mathematicians' point of view, important mathematical activities of mathematicians mainly relate to participating in original research, conjecturing, generalizing, and exploring as

well as communicating, proving, and making connections (Brandt et al., 2016). Malkevitch (1997, p. 93) pointed out that students "can not connect the value of the study of mathematics with what mathematicians really do. […] students have learned when to 'call' or hire a doctor, electrician, geologist, or plumber, but not when to 'call' or hire a mathematician." Students' beliefs about the work of mathematicians probably constitute a part of their epistemological beliefs about mathematics. However, these beliefs about the work of mathematicians or scientists more generally are of particular interest with respect to students' study and career choices "because many young people base their occupational choices on these simplified conceptions" (Stamer, Kubsch et al., 2019, p. 85; see also Figure 1). However, so far, research has not focused on explicitly investigating students' conceptions about typical activities of mathematicians in detail. To our knowledge, there are only two studies conducted by Rock and Shaw (2000) and Picker and Berry (2000) that focused primarily on students' conceptions about mathematicians. These studies offer first insights into students' conceptions about the work of mathematicians: Students believe that mathematicians do applications similar to those they have seen in their own mathematics classes (e.g., arithmetic computation, area and perimeter, and measurement). Both Rock and Shaw (2000) and Picker and Berry (2000) attribute the inadequate and limited conceptions about mathematicians (and their work) to the experiences that students made in mathematics classes. Mathematics classes, in turn, are influenced by teachers' beliefs related to mathematics. For example, the results of a study by Stipek et al. (2001) show that teachers with more traditional beliefs about the nature of mathematics, the teaching, and learning of mathematics, i.e., who believe that mathematics is a static body of knowledge involving a set of rules and procedures that they have to transmit to the students, are less likely to implement inquiry-based mathematics instruction. Presumably, teachers' conceptions about typical activities of mathematical scientists may also influence their classroom teaching.

Research questions

As introduced before, the results of the study by Köller et al. (2000) show that students' *epistemological beliefs about mathematics* influence their interest, their learning, and, thus, their achievement. Similar impacts may be assumed for students' *conceptions about the work of scientists* in general (see Figure 1) or of mathematicians in particular. Students' conceptions about typical activities of mathematicians may particularly influence their study and career choices (Stamer, Kubsch et al., 2019). Against this background, the present study aims to explicitly investigate students' conceptions about typical activities of mathematical scientists (research question 1). Given that these conceptions are likely rooted in students' experiences in mathematics classrooms – which in turn are influenced by teachers' beliefs related to mathematics (Stipek et al., 2001) – the present study also aims to investigate teachers' conceptions about the work of mathematical scientists (research question 2). The purpose of the present study is then to uncover possible relations between students' conceptions about the work of mathematical scientists and the experiences they are given in mathematics classes (research question 3).

Method

To investigate our research questions, we conducted an exploratory interview study with 14 9th graders (age: $M = 14.86$, $SD = 0.66$; 78.6% male; interest in mathematics between 1 = no interest and 6 = high interest: $M = 4.14$, $SD = 1.23$; school grade in mathematics between 1 = very good and 6 = unsatisfactory: $M = 2.14$, $SD = 0.86$) and 5 mathematics teachers (one male; teaching experience in mathematics: 2 to 13 years) who taught in grades 9 or 10 from urban schools in Germany. Both students and teachers volunteered to participate in our interview study by responding to a written inquiry that we had sent to local schools. We interviewed the students as well as the mathematics teachers in June and July 2021 using semi-structured interviews. The interviews with the students lasted between 9 and 17 minutes and with the teachers between 16 and 34 minutes. The interview protocol contained the following three parts: (1) View on mathematics and doing mathematics, (2) Typical mathematical activities of mathematical scientists, (3) Typical mathematical activities during mathematical experimentation. The interview protocol for the mathematics teachers included additional questions about their teaching of mathematics in all three aforementioned parts of the protocol. We used the questions of the first part as an introduction to the interview and the topic. The third part was used to finally illustrate typical mathematical activities by using a specific classroom example and to enable the students and teachers to relate these activities to the work of mathematical scientists. To investigate the research questions of the present study, we look at the students' and teachers' responses to the questions of the second part of the interview.

In the second part of the interview, we asked the students and teachers the following question: "What do you think are typical activities of mathematical scientists who work, for example, at universities?" We also asked for similarities and differences between what mathematical scientists do and what students do. In addition, we asked the teachers: "To what extent do you teach typical mathematical activities of mathematical scientists in your 9th or 10th grade mathematics classes?" We systematically analyzed the students' and teachers' responses through

different coding procedures that were guided by the analysis process of constructivist grounded theory methodology (e.g., Charmaz, 2006). Charmaz's constructivist grounded theory methodology is particular suitable for exploratory investigations of little-known phenomena due to the largely exclusion of prior knowledge. It focuses on analytically capturing and interpretively understanding the characteristics and contexts of the phenomenon. For this purpose, we first analyzed fragments of data (i.e., words, lines, and segments) to assess their relevance for answering the research questions (initial coding; e.g., Charmaz, 2006). This process allowed us to remain open for exploring any conceptions about typical activities of mathematical scientists that can be detected in the data. In doing so, terms used by students and teachers were adopted as in vivo codes. For example, the following segment from a statement of T4 "that they [mathematical scientists] […] make assertions which they then perhaps try to prove somehow with the help of given theorems or somehow deduce things themselves, so that they can then somehow prove their assertions or relations which they want to show […]" was first coded with the in vivo codes *proving* and *deducing*. This first step of coding led us to a collection of various individual activities of mathematical scientists from the students' and teachers' point of view. In a second step (focused coding; e.g., Charmaz, 2006), we selected what we thought were the most useful in vivo codes and tested them against extensive data. Specifically, we compared data with data and then data with codes. Thus, we obtained core conceptual categories. These categories no longer included only individual activities, but rather represented more general and abstract conceptions. For instance, the statement of T4 above was assigned to the more general and abstract conception *doing research*. Throughout the whole coding process, the authors collaboratively negotiated the coding of the data. For this purpose, we repeatedly compared our understanding of the data to achieve greater precision and consistency (see, e.g., Corbin & Strauss, 1990). In addition, we used, for example, a clear protocol of codes and memoing to improve reliability through transparency.

Results

Students' conceptions about the work of mathematical scientists

Based on the coding procedure described above, we identified the following conceptions of students (research question 1): Students believe mathematical scientists …

- do the same kind of mathematics as the students in the classroom but on a higher level,
- optimize existing procedures,
- teach mathematics,
- conduct didactic research, and
- carry out professions that require mathematical calculations.

The majority of the 14 students ($n = 11$) believe that mathematical scientists *do the same kind of mathematics* as they do in their mathematics classroom but *on a higher level*. When asked for similarities and differences between what mathematical scientists do and what students do, S4, for example, answered on a rather general level: "[…] of course, we do something slightly different, but somehow also the same." S6 responded more concretely: "[…] [mathematical scientists] also calculate like we do. But I think they get much more difficult tasks and have to solve much more complex things with their heads." Another example for the conception that mathematical scientists do the same kind of mathematics as school students do but on a higher level, can be found in the following statement from S8: "[…] they [mathematical scientists] also convert formulas, do calculations and, yes, they also simply look at things like triangles […]. So of course, it's much more complicated what they do at universities than here in schools." S3 added that mathematical scientists "also have to figure things out and also do math with their heads and with calculators and with computers maybe even." S6 also mentioned, in addition to mental arithmetic, the use of the calculator, the set square, and various shapes as other similarities between what mathematical scientists do and what students do. Moreover, from the perspective of students, mathematical scientists often use "things that we don't even know here at school yet" (S5), because the students "still do the somewhat simple things and try to figure them out. They [the mathematical scientists] do the difficult ones one step above" (S12). Furthermore, mathematical scientists apply mathematical knowledge, whereas students learn mathematics: "[…] we [students] sit to many in a room and learn there, but I think […] [in] science, there they sit alone and already calculate, so they don't learn, but already apply the knowledge" (S5).

Some of the students ($n = 4$) also revealed the conception that mathematical scientists *optimize existing procedures*. For example, from the perspective of S1, mathematical scientists deal with "how to calculate something or how to make something simpler than it really is now. […] And mathematicians […] also try to bring their own way in or find a simpler variant." S10 also believes that mathematical scientists try to "simplify new or the mathematical rules students have […] [and] find new ways to solve something."

In addition, from the perspective of some students ($n = 3$), mathematical scientists *teach mathematics*: "I think teaching. […] Yes, teach other people and instruct them" (S4). Also for S1, mathematical scientists "must also be able to explain things to people or also represent things in a simplified way." Furthermore, S2 even focuses on *didactic research* as mathematical scientists conduct interviews and test different (teaching) materials – similar to the present study.

Some of the students ($n = 3$) referred rather to other *professions or areas in which mathematical calculations are required*, for instance, to the application of mathematics in economics or in handcraft. When asked for typical activities of mathematical scientists S7 answered: "I would imagine now, with business I would imagine just something, with numbers, with orders."

Teachers' conceptions about the work of mathematical scientists

With regard to research question 2, we observed the following conceptions of mathematics teachers: Mathematics teachers believe mathematical scientists …

- do mathematical research,
- teach mathematics,
- solve abstract problems, and
- provide bases for models.

Most of the teachers ($n = 4$) named "*mathematical research*" (e.g., T1) as a typical activity of mathematical scientists. From the perspective of T3, mathematical scientists conduct research in order to develop new or to optimize existing procedures: "[…] research, connect any theorems and find something new or a faster way somewhere […]." A similar conception was also shown by T4 who considers mathematical research mainly in the context of deducing and proving: "that they [mathematical scientists] want to explore various relations in more detail and make assertions which they then perhaps try to prove somehow with the help of given theorems or somehow deduce things themselves, so that they can then somehow prove their assertions or relations which they want to show […]." Moreover, T4 added that mathematical scientists actually find out new things, whereas students find out what has already been found out: "that what the students can discover […] has already been discovered, […] and they have to think about it, […] to understand it […]. And what an applied mathematician does, for me, is to find out something new." T3 also mentioned that a goal of mathematical research is to find out what is actually new through deducing and proving, which is a difference between what mathematical scientists do and what students do. In contrast, according to T3, students only use mathematical knowledge: "[mathematical scientist] apply what they already know and try to prove things and the students […] only use, but don't get anywhere with it, but are always confronted with the same tasks." There is also a large discrepancy from the other teachers' perspective between what mathematical scientists do and what students do. For instance, T2 differentiates as follows: "So I would say at school, you don't learn mathematics at all, you learn calculation. You actually learn calculation."

In addition, a few teachers ($n = 2$) identified *teaching* as a typical activity of mathematical scientists. For example, T5: "Mathematics teaching in science […] [for the] respective students […]." Furthermore, T1 named *solving abstract problems* as a typical activity of mathematical scientists: "[…] a lot of dealing with abstract problems." T2 mentioned *creating the basis for models* "in order to be able to use them in the real world."

Possible relations to mathematics teaching

With respect to possible relations to mathematics teaching (research question 3), the teachers' answers show that the teaching of typical activities of mathematical scientists plays rather a subordinate role in their classes. In the mathematics lessons of T3, for instance, typical activities of mathematical scientists are taught "rather seldom". If anything, the teachers try to teach deducing or proving as typical activities of mathematical scientists, as evidenced by the following statements: "[…] so one tries to proceed very logically and to conclude things deductively again and again […]" (T1) or "Now, classic example: Pythagorean theorem. You just let them prove it" (T2).

From the perspective of the teachers, the following reasons often prevent the teaching of typical activities of mathematical scientists in mathematic classes:

- the requirements in graduation,
- the lack of time,
- the abilities of the students, and
- their own distance from the university context.

The majority of teachers ($n = 3$) are hindered from teaching typical activities of mathematical scientists mainly by the *requirements in graduation* and the *lack of time*. For instance, T3 said that typical activities of mathematical scientists are not required in the curriculum and, consequently, not required in the final exams: "since it is not really intended by the curriculum, it's of course always difficult with regard to any final exams, where only pure calculation is required or the same standard formulations are somehow tested, to take time and say: 'We will do it anyway.', because you actually know that they don't need it at least for this exam and most of them don't need it later either." T1 also emphasizes – besides the lack of time – that class tests often do not require typical activities of mathematical scientists: "But what is required in class tests, for example, is a completely different matter. So, the whole system is a bit ambivalent."

Another reason for T1 and T3 why the teaching of typical activities of mathematical scientists plays a rather minor role in the classroom are the *abilities of the students*. Among others, T1 emphasizes the "discrepancy between the level at which one has to work in school in some cases […] and what is required later in the university context […] or what would be needed for exact mathematical work." T3 also stresses that there is seldom the opportunity to teach typical activities of mathematical scientists and that then often the majority of students are not able to follow: "[…] from time to time, you try to tickle out a little bit, especially when you notice that the attention is there and that a setting arises where you can think a little further and one or the other is perhaps at a point where it is also possible. But the majority can't follow and at this point it is always difficult to promote this [typical activities of mathematical scientists] in a larger group […]."

In addition, T3 also considered their *own distance from the university context* as a further reason: "The longer you are away from university work, I would say, the more insecure you feel about being able to pass on such activities."

Discussion and implications

To conclude, the results of our exploratory interview study show that students have inadequate and limited conceptions about the work of mathematical scientists. The majority of the students believe that mathematical scientists mainly calculate – as they also do in their own mathematics classes – but on a higher level. Rock and Shaw (2000) as well as Picker and Berry (2000) found similar conceptions about mathematicians in students. Our results are, moreover, in line with previous findings on students' epistemological beliefs about mathematics (e.g., Köller et al., 2000; Schoenfeld, 1988). Specifically, we found that the schematic-algorithmic orientation of mathematics is also present in students' conceptions about the work of mathematical scientists. However, in everyday life as well as professional contexts, challenges are increasingly posed that cannot be met by the schematic application of mathematical rules. Rather, mastering these challenges requires the use of mathematical tools to process and evaluate them, such as problem solving, reasoning or modeling (Hammer et al., 2016). Our results are especially critical in light of the fact that we surveyed mainly students with a high interest and good grades in mathematics. These students may also be interested in studying mathematics at a university after having graduated from school. But their limited conceptions focusing on the schematic-algorithmic orientation of mathematics may be particularly problematic in the university context: The mathematics curriculum at a university initially focuses on the scientific character of mathematics and, especially, mathematical proving, and not on the performance of calculations. Students' limited conceptions about typical activities of mathematical scientists may lead to unrealistic expectations about the requirements of mathematics studies which, in turn, may hinder the effectiveness of individual learning processes (see Rach et al., 2014). If already students with a high interest and good grades in mathematics have inadequate and limited conceptions, it raises the question what conceptions students with low interest and/or poor grades in mathematics have about typical activities of mathematical scientists. Further research should therefore also investigate the conceptions of students with low interest and/or poor grades in mathematics.

Consequently, the results of the present study highlight the need to change students' conceptions about typical activities of mathematical scientists and to foster more adequate conceptions. As mentioned above, it is therefore essential to know where these conceptions arise from in order to be able to derive specific interventions for fostering more adequate conceptions. The present study suggests that students' conceptions are based on their classroom experiences. Mathematics classes, in turn, are influenced by teachers' beliefs related to mathematics (Stipek et al., 2001). Our results additionally show that teachers have limited conceptions about the work of mathematical scientists, too, as the teachers who participated in our study named only some of the important activities of mathematical scientists, usually remaining rather vague about the concrete activities. Although the majority of the teachers identified doing mathematical research – often in connection with deducing and proving – as typical activities of mathematical scientists, they did not describe it in more detail and did not name further activities mathematicians consider as important, such as conjecturing, generalizing, and exploring or communicating (see Brandt et al., 2016). This result may be attributed to the teachers' own classroom experiences

as students, too, and also to their experiences from studying mathematics at university. During studying mathematics at university, the teachers probably gained only a few insights into the work of mathematical scientists. In lectures, mathematics is "formal, precise, ordered and abstract" and is often presented only "in 'finished' form" (Hersh, 1991, p. 128), but not the way mathematical scientists actually work and figure things out, for example, by conjecturing, generalizing, and exploring or communicating. Therefore, it is also necessary to broaden teachers' conceptions about typical activities of mathematical scientists.

One promising opportunity to foster more adequate conceptions about typical activities of mathematical scientists in both students and teachers relates to offering insights into the work of mathematical scientists. This could be achieved, for example, by cooperating with mathematical scientists as role models or mentors who tell students and teachers about their work or by using narratives written by and about mathematical scientists. Another possibility to promote more adequate conceptions about typical activities of mathematical scientists is to carry out these activities by oneself. One potentially promising approach could relate to the authentic contextualization of learning settings. Authentic learning contexts try to provide authentic activities that reflect the way the knowledge will be used in real life (Herrington & Oliver, 2000). With regard to mathematics teaching, an authentic learning activity may include mathematical modeling with hands-on experimental tasks (see Carreira & Baioa, 2018). However, both such visits of mathematical scientists and such tasks are always very time consuming. As the findings of our interviews with mathematics teachers show, there is a lack of time in school to teach typical activities of mathematical scientists. Therefore, it would be useful to teach typical activities of mathematical scientists outside the classroom. One possibly fruitful opportunity may be offered by out-of-school labs. Projects in out-of-school labs aim to promote adequate conceptions about science and scientists by enabling students to authentically experience scientific ways of thinking and working (Scharfenberg & Bogner, 2014). As part of such projects, students could, for instance, also collaborate with real mathematical scientists. Unfortunately, real mathematical scientists often do not have the time to work with students. For this reason, Stamer, Pönicke et al. (2019), for example, used videos as part of a project in an out-of-school lab in which scientists could be observed at work. The results showed that students recognized all explicitly intended authentic scientific activities in the videos. Given this finding, observing mathematical scientists at work also appears as a beneficial way to foster more accurate conceptions about mathematical scientists and their work in students. For future research, it would additionally be interesting to examine the effect of those authentic insights on students' interest in and their attitudes towards mathematics.

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Making Sense of Integer Story-Interpretation Problems

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Abstract: Exploring students' conceptions of integers is more complex than simply explaining the elements of integer knowledge and certainly is challenging to describe how those elements are structured. In this paper, I highlight how fifth graders restructured their whole-number knowledge elements to establish an integer knowledge structure by exploring their interpretations of two integer story-interpretation problems. Students with correct integer order and value interpretations were most successful in solving these problems. Students who knew negative numbers are less than positive numbers but had difficulties interpreting integers' values were more successful than those who relied on numbers' absolute value. However, they attempted to use the negative signs in their number-sentences. This study informs the importance of triangulating students' integer knowledge elements, the process of forming an integer knowledge structure, and further highlights the significance of using problem-solving situations that allow for eliciting diverse mathematical thinking and learning processes.

With introducing negative numbers, the knowledge elements around order and value, minus sign interpretations, addition and subtraction, and associated mathematical language requires restructuring to form a coherently structured integer knowledge system. From whole-number knowledge to integer knowledge, students need to make sense of multiple meanings of the minus sign (i.e., unary, symmetric, and binary; Vlassis, 2004, 2008), distinguish between absolute value ($|-5| > |-3|$) versus linear value ($-5 < -3$), and interpret the meanings of addition and subtraction while accompanying them with the mathematical language (i.e., directed magnitude language; e.g., adding a negative number is getting *more negative*; Aqazade & Bofferding, 2021; Bofferding, 2014, 2019). These knowledge elements may seem mutually inclusive. However, some students may have developed one or more of their whole-number knowledge elements into integer knowledge elements without framing a coherent structure of integer knowledge among them. For example, one can distinguish the linear values versus absolute values by connecting to the directed magnitude language (e.g., -5 is more negative than -3) but may not integrate the directional aspects of more and less with values when adding and subtracting with negative integers (Aqazade, 2021; Aqazade & Bofferding, 2021). To develop a coherently structured integer knowledge system, the knowledge elements need to be reorganized into a theory or schema (Aqazade & Bofferding, 2021). Thus, it is crucial to provide problem-solving situations that allow for students to exhibit their interpretations of knowledge elements individually and collectively within the knowledge system. Such problem-solving situations can depict a more holistic view of students' knowledge development and open space for their diverse mathematical thinking. By drawing from and building on prior research around students' integer knowledge (e.g., Bishop et al., 2014; Bofferding, 2014; Whitacre et al., 2017), in this paper, I aim to illustrate a more holistic picture of how students' integer knowledge elements were in formation towards establishing a coherent integer knowledge structure using a particular problem-solving situation (i.e., story-interpretation problems). I argue that using story-interpretation problems challenged students to rethink their integer knowledge elements and revise or restructure them for forming a cohesive integer knowledge structure. Thus, this work provides perspectives on learning processes and problem-solving situations within domain-specific knowledge.

From whole-number to integer knowledge

To develop integer order and value knowledge elements, students need to make sense of the numbers' order and how it relates to their values. When introducing negative numbers, integer values can be represented as absolute value ($|-7| > |-2|$) or linear value ($-7 < -2$) perspectives (e.g., Bofferding, 2014). Prior studies have explored students' interpretations of integer order and values when comparing or ordering integers (e.g., Whitacre et al., 2017). For example, Whitacre et al. (2017) investigated students' reasoning about integer comparison by having them find the *larger* number between a pair of integers. They found comparing two positive numbers was the easiest and comparing two negative numbers was the most difficult. Bofferding and Farmer (2019) used temperature context to explore how students responded to different integer comparison question phrasing (e.g., most hot, least cold). Students performed better on *most cold* than *least hot* comparisons. They also did better with *most hot* for positive-number-only comparisons and *least cold* for negative-number-only comparisons.

With negative numbers, not only does the minus sign take different meanings (i.e., binary, unary, symmetric) but also adding or subtracting integers involves a directional movement (e.g., Bofferding, 2014;

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Vlassis, 2004, 2008). For example, adding a negative integer no longer relates to getting more or larger rather it represents *more* in the negative direction or downwards on a vertical number line (Bruno & Martinon, 1999). Previous related work focused on detailing students' addition or subtraction solution strategies and their understanding of minus sign meanings for open number-sentence or story problems (e.g., Aqazade & Bofferding, 2021; Bishop et al., 2014; Whitacre et al., 2014). For instance, Murray (1985) found students' correct responses to integer addition or subtraction problems often happened when they could ignore the negative signs, operate as numbers were positive, and append the negative signs to their answers (e.g., -9 – -4 → 9 – 4 = 5 → -5 or -3 + -5 → 3 + 5 = 8 → -8), which refers to *add or subtract make negative* strategy leveraging the symmetric meaning of the minus sign (see Aqazade & Bofferding, 2021; Bofferding et al., 2017; Vlassis, 2004, 2008). Using *counting up or down from a negative number* strategy (e.g., 8 + -3 is -3, -2, …, 5) representing the unary meaning of the minus sign was a less common strategy (Aqazade & Bofferding, 2021; Bishop et al., 2014; Bofferding et al., 2017; Vlassis, 2004, 2008). Often, students who did not know about numbers below zero ignored the negative signs and add or subtract the numbers' absolute values (e.g., 4 + -6 = 10; i.e., *absolute value* strategy) or treated the negative signs as subtraction signs showing the binary meaning of the minus sign (e.g., 4 + -6 → 6 – 4 = 2; Aqazade & Bofferding, 2021; Bofferding et al., 2017; Vlassis, 2004, 2008).

Although several integer knowledge elements were implicitly involved in the prior research, this work explicitly unfolds students' interpretations of integer knowledge elements and the extent to which they represent a structured knowledge system. Thus, the purpose of this paper is to describe the triangulation among students' integer order and value interpretations, integer addition and subtraction and minus sign interpretations, and associated directed magnitude language. I used integer story-interpretation problems involving temperature and directed magnitude language and sought to explore the following research questions: When solving integer story-interpretation problems, how did fifth-grade students' order and value knowledge elements relate to (a) their knowledge elements of the directed magnitude language and addition or subtraction as represented in their number-sentences? and (b) their drawn thermometers?

Methods

Participants and setting

Forty fifth-grade students (24 girls and 16 boys) participated in this study from an intermediate school in the Midwest, United States with 73% economically disadvantaged and 12% English-Language-Learners.

Data sources and analysis

I used task-based interviews involving a problem-solver (student) who interacts with one or more problem-solving situations and an interviewer (researcher) who follows up with nondirective questions (e.g., "can you tell me more about that?"). The goal of task-based interviews is to delve into students' complex problem-solving processes (Goldin, 2000; Maher & Sigley, 2014). In this study, students individually solved and explained integer-related test items: order and value items (e.g., circle the temperature that is most cold? 15, -27, 10); directed magnitude language items (e.g., when it gets 5 degrees more hot, where does the arrow on the thermometer change to?); story-interpretation items (see Table 2); and integer addition and subtraction items (e.g., 8 – 12 =).

To answer the research questions, I first classified students' responses to integer order and value items into *whole-number, transitional,* and *integer* categories that describe their interpretations of order and value knowledge elements (see Table 1). Second, using these categories, I aimed to explain students' responses to the story-interpretation items, which contained three parts: (a) directed magnitude language terms, (b) writing a number-sentence, and (c) drawing a thermometer. In this paper, I only focused on two story-interpretation problems (see Table 2). I chose items that target the temperature change from a positive to a negative number and crossing zero (item 1) and within negative numbers (item 2).

Table 1
Categories of Students' Responses on Integer Order and Value Items (see Bofferding, 2014)

Interpretation of order and value	Description	Example(s)
Whole-number	Ignoring the negative signs, comparing, and ordering negative numbers based on their absolute value or in reversed order.	Ordering based on absolute value 0, -1, 2, -5, -7, 10. Reversed ordering -1, -5, -7, 0, 2, 10. Choosing -20 as the most hot temperature among -20, 12, and 0.

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Transitional	Distinguishing the positive and negative numbers as negative numbers being smaller than positive numbers. Ordering negative numbers as below zero and correctly. Comparing the negative numbers sometimes based on their absolute values and sometimes correctly based on their linear values.	Choosing 12 as the most hot temperature among -20, 12, and 0. Choosing -19 as the most hot temperature among -14, 0, and -19.
Integer	Ordering the integers correctly. Comparing integers correctly based on their linear values.	Ordering -7, -5, -1, 0, 2, 10. Choosing 12 as the most hot temperature among -20, 12, and 0. Choosing 0 as the most hot temperature among -14, 0, and -19.

Table 2
Two Story-Interpretation Items

Item #	Story-interpretation
1	If South Bend's temperature changes from -20 to 15, which of these terms can explain this change? The temperature got _____. Circle all the terms here that would work. *more hot, more cold, less hot, less cold* How did you decide? Write a number sentence that shows this change. Draw a thermometer that shows how this change happens?
2	If West Lafayette's temperature changes from -33 to -22, which of these terms can explain this change? The temperature got _____. Circle all the terms here that would work. *more hot, more cold, less hot, less cold* How did you decide? Write a number-sentence that shows this change. Draw a thermometer that shows how this change happens?

In the analysis of students' responses to each story-interpretation item, for the directed magnitude language terms, I identified whether they relied on only one term (e.g., less or cold for less cold) or the compound terms. For writing a number-sentence, I marked whether it was with or without negative signs and whether it represented a correct temperature change (see Table 3). Further, I categorized students' solution strategies for their written number-sentences. If students did not use any negative signs in their written number-sentences, I classified their strategies as *whole-number*. Among students who made use of the negative signs in their written number-sentences, I characterized their strategies as *absolute value* (i.e., adding or subtracting integers' absolute values), *add or subtract make negative* (i.e., adding or subtracting integers' absolute values and appending the negative sign to the answer), or *counting up or down from a negative number* (i.e., starting at a negative number and counting towards a positive or negative direction) (e.g., Aqazade, 2017; Aqazade & Bofferding, 2021; Bishop et al., 2014; Bofferding et al., 2017; Murray, 1985). Finally, for drawing thermometers, I identified numbers' placements and orders on the thermometers and the directional movement for the temperature change based on students' explanations and drawings.

Table 3
Written Number-Sentence Categories

Number-sentence		Description	Examples
Without negative signs	Incorrect change	Not including negative signs and not showing the correct temperature change.	Item 1: 20 – 5 = 15 or 20 – 15 = 5 Item 2: 33 – 11 = 22 or 33 – 22 = 11
	Correct change	Not including negative signs but correctly showing the appropriate temperature change.	Item 1: 20 + 15 = 35 Item 2: Not applicable
With negative signs	Incorrect change	Including negative signs but not showing the correct temperature change[a].	Item 1: -20 – 5 = 15, -20 – -5 = 15, -20 – 15 = 35, -20 + 15 = 35, -20 + 15 = -35, -20 – 35 = 15, or 15 – 35 = -20 Item 2: 33 – 22 = -11, -33 – 11 = 22, -33 – 22 = 11, -33 – 22 = -11, -33 – -22 = -11, -33 + -11 = -22, or -22 + 11 = -33

	Correct change	Including negative signs and correctly showing the temperature change.	Item 1: 15 – -20 = 35 or -20 + 35 = 15 Item 2: -33 + 11 = -22, -33 – -11 = -22, or -22 – -33 = 11

[a] Some of the written number-sentences in this category are mathematically correct but do not fit with what the item was asking in terms of showing the temperature change.

Findings

Based on the responses on integer order and value items, 10 (26%), 18 (46%), and 11 (28%) students were classified in the whole-number, transitional, and integer categories, respectively.

Directed magnitude language terms

Temperature change from -20 to 15

Two, ten, and all students from the whole-number, transitional, and integer categories respectively chose both "more hot" and "less cold" correctly. Mina(whole-number)(1) chose "more cold" and by relying on numbers' absolute values explained, "Because twenty is like going less and then to fifteen, it got more cold." However, by knowing negative numbers are smaller than positive numbers, students' choices in the transitional category were correct. For instance, June(transitional) said, "I decided that by thinking because it's negative twenty and this [15] doesn't have a negative, even though it's a small number, it's not a negative so it's a bigger number." Students' incorrect choice of directed magnitude language was due to focusing on one term of the compound terms; relating them to numbers; choosing only one of the two correct compound terms; relying on numbers' absolute values; or a mix of these reasons.

Temperature change from -33 to -22

None of the students in the whole-number category correctly chose both "more hot" and "less cold." Seven students from the transitional category and all students from the integer category correctly chose both of them. For example, Jane(integer) said, "Because thirty-three is a bigger negative number and bigger negative numbers are colder in temperature-wise, and since twenty-two is less than thirty-three, it made thirty-three to twenty-two, you know we got hotter." Reasons for students' incorrect choice was similar to the temperature change from -20 to 15. For example, Cruz(whole-number) chose "more cold" and "less cold" by relating terms to numbers, pointed at -33 saying, "This is more cold" and then at -22 saying, "This is less cold." Lane(transitional) chose "more cold" and "less hot" by relying on numbers' absolute value, "So if it's thirty-three…and if it goes to twenty-two, then the temperature is dropping down. That means it's like going to get colder."

Written number-sentence without negative signs

Students' number-sentences varied depending on how they interpreted the integers' order and values and whether they attempted to make use of the negative signs (see Tables 4 and 5). For the incorrect temperature change from -20 to 15, both 20 – 15 = 5 or 20 – 5 = 15 demonstrated students' *whole-number* strategy. Similarly, for the incorrect temperature change from -33 to -22, 33 – 22 = 11 or 33 – 11 = 22 both represented the *whole-number* strategy. For the correct temperature change from -20 to 15, several students from the whole-number and transitional categories wrote 15 + 20 = 35. For instance, Jasmin(transitional) said:

> I went from negative twenty at this one all the way down to zero. And then I counted how many positive degrees there were with how many negative degrees there were, and I added them together to get thirty-five degrees. So that would be how many there would be to get to fifteen.

Written number sentences with negative signs

Temperature change from -20 to 15

Negative signs in students' number-sentences were used differently (see Table 4). For the incorrect temperature change, students often solved their written number-sentences by relying on the *absolute value* strategy. A few students like Mila(transitional) (-20 + 15 = -35) used the negative sign with its symmetric meaning and applied the *add make negative* strategy. Choosing correct numbers but not writing the operation correctly, Joshua(transitional) (-20 – 15 = 35) explained "because it's getting more hot," he needed to subtract the numbers, "So basically, you'd have to subtract twenty. Then that would equal zero and then it'd be fifteen. So, you have to do the twenty plus the fifteen, and it equals thirty-five." Similarly, Bob(integer) (-20 – 35 = 15) added 15 and 20

to find 35 but was not sure whether to subtract 35 from -20 or add it. Many students like Bob seemed to know the distance between -20 and 15 but were not successful in representing it in a number-sentence.

Liv(transitional) wrote a mathematically correct number-sentence, 15 – 35 = -20, but did not represent an appropriate temperature change from -20 to 15:

> Since it's a negative number again, how you would normally do it is five minus five equals zero. Then you have one minus three which you can't do. So, you have to go to the negatives. If you do minus three, it'll be negative two – so negative twenty.

For the correct temperature change, some students like Ariana(transitional) (-20 + 36 = 15) miscounted or Landon(transitional) (15 – -20 = -15) who wrote a correct number-sentence showing the change but applied the *subtract make negative* strategy, miscounted, and answered the number-sentence incorrectly. Another example is Cody(integer) (15 – -20 = -5) with a correct number-sentence but and an incorrect answer. He explained, "Because you can just take away subtraction symbol and do fifteen minus twenty." Thus, Cody actually ignored the negative sign and solved 15 – -20 as if it was 15 – 20. Several students wrote a correct addition number-sentence involving a negative number (i.e., -20 + 35 = 15). For example, Corbin(transitional) explained, "Because if you add these two, you would get thirty-five. So, then you would add thirty-five to twenty which would get you positive fifteen."

Table 4

Categories of Students' Written Number-Sentence on Temperature Change from -20 to 15

Written number-sentence category		Order & value interpretation category	Number-sentence
Without negative signs	Incorrect change (n = 8)	Whole-number (n = 4)	20 – 15 = 5
		Transitional (n = 4)	20 – 15 = 15, 20 – 5 = 15, 20 – 15 = 5
	Correct change (n = 4)	Whole-number (n = 2)	20 + 15 = 35
		Transitional (n = 2)	20 + 15 = 35
With negative signs	Incorrect change (n = 13)	Whole-number (n = 4)	-20 + 15 = 35, -20 – 5 = 15, 15 + -20 = __
		Transitional (n = 6)	-20 + 15 = 35, -20 + 15 = -35, -20 + 15 = 15, -20 – 15 = 35, -20 – 15 = 15, 15 – 35 = -20
		Integer (n = 3)	-20 – 35 = 15, 15 – 35 = -20, 15 – 25 = -20
	Correct change (n = 14)	Transitional (n = 6)	-20 + 35 = 15, -20 + 36 = 15, 15 – -20 = -15
		Integer (n = 8)	-20 + 35 = 15, 15 – -20 = -5

Temperature change from -33 to -22

For the incorrect temperature change, students often applied the *absolute value* or *add/subtract make negative* strategies (see Table 5). For example, Kori(whole-number) wrote -33 – 11 = 22 using the *absolute value* strategy, "You subtract thirty-three from eleven that makes twenty-two." Greta(integer) wrote 33 – 22 = -11 and said, "All I had to do was to subtract thirty-three by twenty-two and add the negative sign," which illustrated the *subtract make negative* strategy. Anna(integer) wrote -33 + -11 = -22, "Because minus twenty-two is technically more than minus thirty-three because minus twenty-two is closer to zero" but she was not sure whether to write -11 or 11. Some students wrote a mathematically correct number-sentence (i.e., -33 – -22 = -11) without showing a correct temperature change. For example, Jessica(whole-number) said, "Since it got lower, you subtract to get the actual lowest number," showing the *subtract make negative* strategy. For the correct temperature change, for example, Liv(transitional) wrote -33 + 11 = -22 demonstrating the *counting up from negative* strategy:

> If you were adding negative thirty-three to eleven, it's like minusing, but instead, it's a negative. It's flipped. It would be negative twenty-two…It will get higher up to negative twenty-two. So, you would have to add because that's getting higher.

Cody(integer) with writing -22 – -33 = 11 represented a more sophisticated strategy. He explained, "Because I would take away minuses and you switch the numbers so it would be negative thirty-three minus negative twenty-two that would be negative eleven [but wrote eleven]."

Table 5

Categories of Students' Written Number-Sentence on Temperature Change from -33 to -22

Written number-sentence category		Order & value interpretation category	Number-sentence
Without negative signs	Incorrect change (n = 11)	Whole-number (n = 6)	33 – 11 = 22, 33 – 22 = 11, 33 + 22 = 55, 22 + __ = 33
		Transitional (n = 5)	33 – 11 = 22, 33 – 22 = 11
With negative signs	Incorrect change (n = 22)	Whole-number (n = 4)	-33 – 11 = 22, -33 – -22 = -11
		Transitional (n = 9)	33 – 22 = -11, -33 – 22 = 11, -33 – 11 = 22, -33 – -22 = -11, -33 + -22 = -11
		Integer (n = 9)	33 – 22 = -11, -33 – 22 = -11, -33 – 11 = -22, -33 – -22 = -11, -22 + 11 = -33, -33 + -11 = -22
	Correct change (n = 6)	Transitional (n = 4)	-33 + 11 = -22, -33 – -11 = -22
		Integer (n = 2)	-33 + 11 = -22, -22 – -33 = 11

Drawn thermometers

Temperature change from -20 to 15

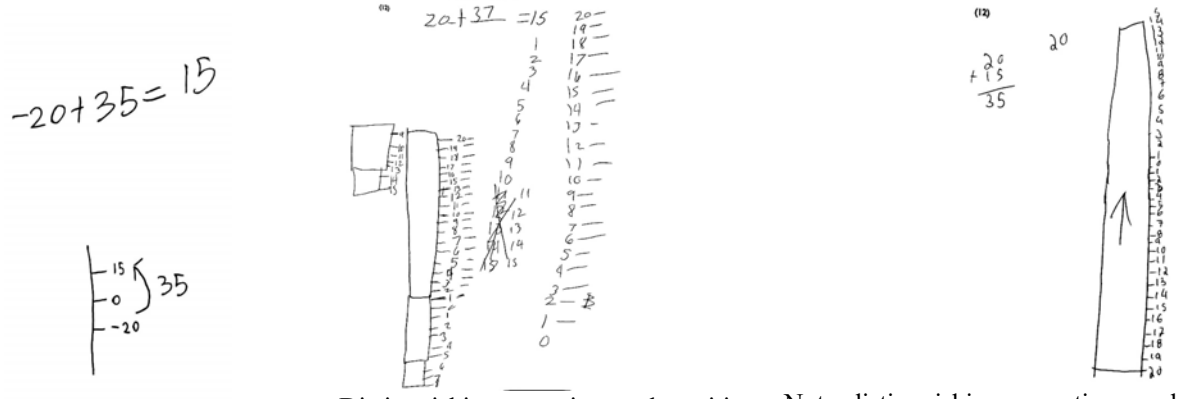
Because of ignoring the negative sign and relying on numbers' absolute value, four students from the whole-number category and five students from the transitional category put the -20 on top and 15 on the bottom of their thermometers and indicated the downward movement to show the temperature change. Among these students, even those who included the negative signs in their number-sentences, all except for Mila(transitional) (-20 + 15 = -35) solved them using the *absolute value* strategy. All these students' number-sentences were aligned with their directional movements on their thermometers (e.g., subtraction is moving downward; see Figure 1). Overall, even students who could distinguish positive and negative numbers—but could not differentiate the linear versus absolute value—often indicated the temperature is "going down."

Temperature change from -33 to -22

Similar to the temperature change from -20 to 15, students who relied on the numbers' absolute value or ignored the negatives did not correctly demonstrate the temperature change from -33 to -22. They placed the temperatures on the thermometers as if they were all positive numbers. For example, Jade(whole-number) put -33 on the top of her thermometer and said, "So it's thirty-three right here and it goes down." Overall, four students from the whole-number category, eight students from the transitional category, and two students from the integer category put the -33 on top and -22 on the bottom of their thermometers and indicated the downward movement to show the change from -33 to -22 (see Figure 1).

Figure 1

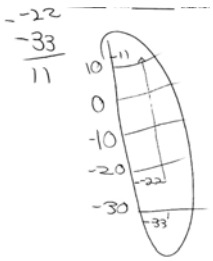
Examples of Students' Drawn Thermometer



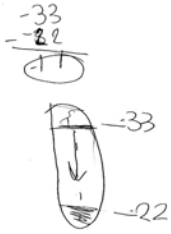
-20 at the bottom and 15 at the top: Kristen(transitional)

Distinguishing negative and positive numbers; -20 at the top and 15 at the bottom: Lucy(transitional)

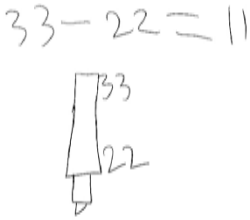
Not distinguishing negative and positive numbers; -20 at the top and 15 at the bottom: June(transitional)



-33 at the bottom and -22 at the top: Cody(integer)



Distinguishing negative and positive numbers; -33 at the top and -22 at the bottom: Kate(whole-number)



Not distinguishing negative and positive numbers; -33 at the top and -22 at the bottom: Max(whole-number)

Significance, contribution, and implications

In attempts to promote better learning, it is essential to understand what processes are involved in one's learning. Understanding these processes helps develop learning environments that support more effective learning experiences. In this study, using story-interpretation problems provided a space to unfold such processes of fifth-grade students and their problem-solving approaches. These story-interpretation problems allowed for eliciting students' conceptions in a problem-solving situation. By focusing on the concept of integers, I explored how students made meaning of different elements within the integer knowledge system and the extent to which these elements represent a structured system.

Overall, because students from the whole-number and transitional categories were still making sense of integers' order and values, it was not surprising to see a looser structure among their knowledge elements when solving the story-interpretation items. Consequently, having a more robust structure for order and value knowledge elements among students in the integer category led them to interpret the story-interpretation items more accurately. Although students in the whole-number category often ignored negatives when interpreting integers' values and had difficulties making sense of the directed magnitude language terms, some of them wrote number-sentences with negative signs, illuminating their attempts in extending the minus sign meanings by using the *add/subtract make negative* or *count up/down from negative* strategies. Students in the transitional category were more successful than those in the whole-number category when interpreting the numbers' values but some of them still reversed the negatives on their drawn thermometer and had difficulties writing a number-sentence, suggesting their integer knowledge structure was still in formation.

The results of this study contributed and added to the research on understanding students' integer knowledge development (e.g., Bofferding & Farmer, 2019; Whitacre et al., 2017). For example, although Bofferding and Farmer (2019) detailed students' different responses based on numbers and language involved in the comparison items, they did not provide evidence into the connection between their integer value knowledge and their interpretation of directed magnitude language. In this paper, students' choice of directed magnitude language terms for a temperature change provides such evidence and shows how using directed magnitude language could draw students' attention to both direction and the absolute value of which the temperature changes (e.g., the temperature change from -33 to -22 reflects a decrease from the absolute value perspective but shows an upward movement on the thermometer; see Bofferding, 2014, 2019). Further, students' drawn thermometers were additional evidence to describe their consistency between integer values and directed magnitude language interpretation, which suggests the importance of using an instructional model in determining the coordination between value and directed magnitude elements. Overall, the combination of asking students to choose the correct directed magnitude language term and drawing thermometers could potentially draw their attention to the differences between numbers' absolute value versus linear value. Unlike other studies (e.g., Whitacre et al., 2014), in the story-interpretation items, writing a number-sentence to "show the temperature change" highlighted how numbers' type and direction that temperature changes influence students to write an addition versus subtraction problem. Further, despite presenting the temperatures with their formal notations, the story-interpretation items still represented a realistic contextual problem because of asking to "show the temperature change." Thus, the results of students' responses to story-interpretation items opened a new window into ways in which students can generate a number-sentence relevant to story problems.

Together, the implications of this study highlight the importance of mathematical language as represented in students' choice of directed magnitude language terms. Students' directed magnitude language interpretations not only influenced their term choice, but also in some cases, was reflected in their written number-sentences and drawn thermometers. Perhaps, ways in which students make sense of mathematical language could tell a more cohesive story about how they think mathematically, rather than just their work with numbers and operations. Thus, mathematical language should become one of the central knowledge elements in

mathematics instruction. In addition to using mathematical language in the story problems, asking students to demonstrate their thinking in a different way by drawing a thermometer is essential to extend their access to mathematics and exhibit diverse ways of knowing and doing mathematics.

Endnotes

(1) I included students' categories for interpretation of order and value knowledge elements (whole-number, transitional, integer) in the parentheses after their pseudonym.

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The aRithmetic Discourse Profile as a tool for mapping students' subjectifying and mathematizing discourse

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Abstract: We present a new tool for mapping students' arithmetic discourse, named the aRithmetic Discourse Profile (RDP). The tool was developed based on the commognitive theory (Sfard, 2008). Its main goal is mapping students' mastery of arithmetic routines on a continuum between ritual (procedure based) and explorative (goal-based) participation. In addition, the tool maps the subjectifying statements of students (statements constructing their identity in action) to assess the affective aspects of the student's performance. We exemplify the tool on 3 tasks performed by 12 7th grade students. The findings show various possible relations between subjectifying and ritual/explorative performance.

Introduction

By the time students finish elementary school, they are supposed to have mastered the arithmetic discourse – the discourse on whole numbers, fractions, and the four operations that are used to manipulate these mathematical objects. Yet the learning of arithmetic often fails at certain points, and students arrive with insufficient skills to middle school and the demands of algebra, which is built on arithmetic. Moreover, students often develop, during the process of getting initiated into the mathematical discourse (through the gate of arithmetic) identities of failure. They come to endorse narratives about themselves such as "I am no good with numbers" or "I don't understand fractions" (Heyd-Metzuyanim, 2015). These identity narratives constrain their participation in mathematical activities and may often lead to disengagement, thus harming not just the learning of arithmetic but the learning of more advanced topics too.

Currently, there are little tools that can assess, holistically, the mastery that students have achieved of the arithmetic discourse. By "holistically", we mean that the tools relate both to the mathematical aspects of the discourse (often termed the "cognitive" elements) and the identity-related aspects of this discourse (often termed "affective"). Tests that assess mathematical disabilities or difficulties (e.g. Chinn, 2020; Dowker, 2019) are useful for determining which specific mathematical skills students may be lacking, yet they do not relate to the affective aspects of their participation. In contrast, tests that assess anxiety or attitudes towards mathematics (e.g. Hopko, 2003), do not relate to the mathematical skills of the student. Moreover, most tests of mathematical "knowledge" are built on paper and pencil techniques and focus on the end-result: whether the student's answer to a task is correct or not. Yet much information about the processes of participation, procedures employed and identity narratives produced along the way are lost this way. For this, a more processual approach for assessing students' mastery is needed – one which is based on examining their talk, not just their writing. In this work, we propose a novel tool, named the aRithmetic Discourse Profile, whose aim is to assess the extent to which a student mastered the arithmetic discourse, as well as their subjectifications – the identity stories that they produce while engaged in this discourse. Our aim in this paper is to introduce the tool, demonstrate its application and examine the results that can be obtained from applying it to a set of 12 students whose discourse was examined with it.

Theoretical Background

The theoretical framework employed for this study is the commognitive one (Sfard, 2008). This theory is used for several reasons: first, it has established a useful explanation of students' learning of mathematics as progression from ritual to explorative participation (Lavie et al., 2019; Sfard & Lavie, 2005). Ritual participation is characterized by rigid rule-following and reliance on external authority of experts. For example, imitating the teacher who is saying "fifteen" and writing "15" by writing the numerals 1 next to 5 without being able to name the "1" as a "ten". In accordance with the view of learning as becoming a participant in a community of discourse, Sfard and Lavie (2005) show how such participation is an unavoidable stage of learning, since at the initial phases of getting introduced to a certain discourse, learners are so unfamiliar with the objects on which this discourse is about, that they can only thoughtfully imitate others. Gradually, as they come to *objectify* the signs and symbols introduced to them, for example, as they come to see "15" as an object made up of certain parts (1 ten, 5 units), they become more explorative in their production of narratives about these objects. That is, they employ routines to manipulate these objects in flexible ways, and based on their own authority, or agency. Most importantly, their

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participation is *goal oriented*, that is, they employ certain procedures with the goal of the task in mind, rather than being satisfied with following the steps of an imitated procedure.

Previous works within the commognitive framework showed that the location of a student on the ritual-explorative continuum may be tightly related to their identity narratives – namely, those endorsable stories a student tells about herself (and others tell about her) that are reifying (talk about attributes of a person rather than about her actions) and significant to the storyteller (Sfard & Prusak, 2005). The relation between ritual participation and identity could be seen, for example, in the case of a student who described herself as "good in math" but "not good in fractions" and who indeed performed relatively exploratively in the discourse on whole numbers yet ritually in tasks that included rational numbers (Heyd-Metzuyanim, 2015). This student managed to achieve high grades in middle school due to diligent and hard work of following teacher-authored rules in algebra. Yet towards high-school, her ritual participation in the mathematical discourse widened so much that she failed her exams and ended up in a low achieving group. This case illustrated the need for early assessment and profiling of students "ritual pockets" of mathematical performance, even those students who achieve good grades, so that such "pockets" of ritual participation do not widen and lead to the development of a general identity of failure. The conclusions from this reported study, however, were based only on a single case-study. There is thus need of more rigorous examination of the relation between students' mathematizing and their concomitant subjectifications, namely those utterances that they communicate about themselves. Other studies of subjectifying activity (e.g. Heyd-Metzuyanim & Sfard, 2012) have also pointed to the importance of examining *implicit* subjectifying actions, namely those actions that are not expressed explicitly (such as "I'm not sure") but non-verbally or indirectly (e.g. by making a statement and waiting for the teacher to approve, ending the utterance with a questioning intonation, etc.). These implicit subjectifications are often even more potent in forming a story of a student as incompetent than the stories told explicitly out loud.

The idea to use a discursive lens to profile students' discourse has been employed and tested almost two decades ago, in one of the earliest commognitive works, by Ben-Yehuda (Ben-Yehuda, 2003; Ben-Yehuda et al., 2005). In her dissertation, Ben-Yehuda examined the discourse of 14 7th grade students, attempting to capture the unique characteristics of discourse of students with low achievements. This work showed the rich utility of the discursive framework and established the initial format of the tool, namely a "think aloud" interview where the student is given a set of arithmetic tasks aligned with the standard arithmetic curriculum. In addition, it showed evidence that students experiencing difficulties often did not talk about mathematical objects as existing of themselves but as symbols to be syntactically manipulated on the paper using memorized and meaningless procedures. However, since the theory of learning as progressing from ritual to explorative participation did not yet exist at that time, the characteristics found in Ben-Yehuda's study were still rather scattered. Moreover, the work did not result in a systematic coding scheme for analyzing students' discourse and did not enable placing a certain students' profile on a continuum (or several axes of continua) between ritual and explorative performance.

A much more recent work (Lavie et al., 2019) provided the missing conceptualization of operationalizing exactly what it means to participate ritually, or enact a ritual routine. This work followed the development of the numerical discourse of a 2.5 years old boy, over two years. It defined a routine as a pair of task (a situation that requires a certain action) and a procedure (a sequence of steps for achieving the goal). Lavie and colleagues showed through extraordinary detail how the young boy's routine of answering the task "where there is more?" *de-ritualized* according to the following characteristics: (a) it became more *flexible*, that is, more procedures were employed, alternately, to achieve the same task; (b) it became *bonded*, namely, sub-procedures became linked to each other in a way that the output of a step served as the input of the next step; (c) it became more *agentive* in the sense that the boy initiated the procedures and sub-procedures on his own, rather than looking for guidance from the adult who interacted with him; (d) the focus of the child, in enacting the routine, turned *from the procedure* to *the goal* of the task, where the importance lay in what it is that is to be achieved through the procedure In the current work, we add to these characteristics some additional ones, taken from other works that examined ritual participation and were more tailored to the discourse of older students: *objectification* (discussed earlier) and *mediation* (important when seeking to see to what extent the task is performed with the aid of a teacher). Finally, since we are dealing with issues of mastery of a school-discourse we are also interested whether the procedures employed by the students and the narratives derived from these procedures are *canonical* or not (or "mathematically correct").

With relation to the above characteristics of ritual/explorative participation, and seeking to understand the relations between them and subjectifying utterances, we ask in this paper:

1. What is the profile of students' participation on an axis between ritual and exploration, as obtained from the RDP?
2. To what extent does the ritual/explorative participation of students, as captured by the RDP tool, cohere with students' subjectifications?

Method

Our analytical tool was developed as a secondary data analysis, on data collected by the first author (Heyd-Metzuyanim, 2011). The data consists of arithmetic interviews conducted with 12 7th graders. The interviews were conducted as part of a larger study where the author taught the 12 students in groups over a period of 5 months, in an out of school "course". The course was broadly defined as "mathematics enrichment" and the original study was aimed at examining interactions between emotional and cognitive aspects of learning. The students were placed in three groups (each of 4): Low achieving, middle-high achieving, and excelling. The excelling group consisted of 4 boys who came from an accelerated mathematics and science classroom (to which entrance was based on very high grades in elementary school mathematics and other subjects). Placement in the low and middle-high achieving group was based on reports coming from the school and the students' parents.

The arithmetic discourse interviews were originally conducted to serve as a form of baseline, to examine the progress of the students during the course. However, they were never systematically analyzed. All the interviews were conducted by the first author, in a one-on-one setting. Students were asked to think out loud as they solved the problems (Young, 2005). When they were not successful and asked for help, the interviewer attempted to scaffold the task, yet mostly she refrained from giving feedback on the correctness of the results. Interviews were videotaped with two cameras, one pointing at the student's face and one on his writing. Written artifacts were collected too.

The interview protocol was based on Ben-Yehuda's study (Ben-Yehuda, 2003) and consisted of 24 tasks (some of them very short) that had potential to illuminate various aspects of students' arithmetic discourse. For the present study we chose three tasks for analysis (the full protocol appears in (Heyd-Metzuyanim, 2011)). These tasks were (1) A word problem which asked students to calculate how much would cost a shirt and a pair of pants if two shirts cost 200 Shekels (local currency) and 3 pair of pants cost 300 Shekels ; (2) the task Multiply in your head 25×99; and (3) calculate $\frac{1}{2} + \frac{1}{10}$. We chose these three tasks as they spanned a relatively large domain of arithmetic skills, namely – solving word problems (using addition and multiplication), multiplying whole numbers and manipulating fractions.

Method of analysis

The first stage of analysis consisted of marking verbs, nouns and pronouns, which would highlight the subjectifying and mathematizing talk. Pronouns and verbs usually indicate subjectifying ("I think", "I don't know", etc.) whereas mathematical nouns indicated objectification ("two thirds of nine *is* six"). The second stage consisted of mapping the routines enacted by the student into the structure of task-procedure, including the sub-tasks and sub-procedures involved (examples will be shown in the findings section). The third stage, which is the main stage of analysis, is coding the routine according to the criteria given in table 1.

Table 1 - Criteria of analysis for ritual-explorative routines

	Criterion (X, X)		Analytical actions	Characteristics of an explorative routine	Characteristics of a ritual routine
	Explorative	Ritual			
	X = 0/1	X = 0/1			
1	Objectified /syntactic mediation. Note: Can receive (1, 0) for objectified mediation or (0, 1) for syntactic mediation		Searching for evidence that the nouns signify numbers/quantities and not just the signifier of the number	In whole numbers, relating to the place value of the numeral. In fractions: relating to different realizations of the fraction as the same, including fraction as operator, part of whole, part of quantity, etc.	In whole numbers: relating to operations as signaling procedures on digits rather than on the whole number. In fractions, relating separately to the numerator and denominator.
2	Flexibility Note: can also receive (0, 0) if no conclusive evidence is found		Look for multiple procedures that are associated with the same task.	More than one procedure is associated with the main task OR a non-standard procedure is applied to the task.	Relying on only one procedure while showing rigidity and reluctance to use any other procedure.
3	Agency/External authority Note: coding is done on procedures and sub-procedures.		Look for subjectifying discourse; examine verbs/pronouns and non-verbal signals	Mathematizing with high confidence (no hesitations, question marks, no looking for approval).	Talking with question marks; Verbally or Non-verbally seeking approval from the interviewer; Relating to external

	Possible codes: (1, 0); (0, 1) and (1, 1)	that indicate the confidence.	Spontaneously articulating mathematical narratives	authority for justification (e.g. "that's what I learned in school")
4	Focus on goal or on procedure Note: coding is determined according to main procedure. Therefore, can only receive (1, 0) or (0, 1)	Look for verbs indicating doing (e.g. "I add") vs. being verbs indicating the result ("it is…");	Talking about the result, checking it, or explaining it spontaneously	Talking about the actions of the procedure. Ending the procedure without relating to the reasonableness of the result.
5	Bondedness Note: considered in relation to the full task. Therefore, can only receive (1, 0) or (0, 1)	Examine the procedure; sub-procedures and the bonds between them.	Each sub-procedure feeds the next sub-procedure. The narrative of the result of sub-procedure N serves as the input of sub-procedure N+1.	There is a disconnect between a certain sub-procedure and its following one OR sub-procedures using different realizations are not treated as the same.

The final three characteristics were coded in a binary fashion, getting either a score of (1, 0) for explorative, or (0,1) for ritual performance. *Canonical procedures* were coded as explorative if all the steps in the procedure aligned with standard mathematical procedures. *Canonical narratives* were coded as explorative if the end result of a procedure (e.g. the end result for the task "two thirds of 9" was "six") was canonical. *Mediation* was coded as (1, 0) if the procedure was fully initiated and enacted by the student, and (0, 1) if some parts of it were mediated by the interviewer.

Subjectifying was coded in the following way: statements that included direct reference to the self and one's actions or mental states (but not just descriptions of mathematical actions), were coded as "explicit subjectifying". These were coded as negative (-) if they included a negative statement about oneself (such as "I don't know" or "I don't think I can do this") and (+) if they were positive ("I can do this" or "this is fun"). Notice that "this is fun" was coded as explicit subjectification since the assumption was that a reference to oneself is implied in the statement ("this is fun *for me*"). Non-verbal emotional expressions and statements that communicated lack of confidence (such as smiling embarrassedly or asking "is this right?") were coded as *implicit negative subjectifications*. Although lack of negative subjectifications (implicit or explicit) could be interpreted as implicitly subjectifying confidence, we did not code for positive implicit subjectifications, since it was impossible to discern between "neutral" affective communication and "confidence". There were thus only three codes for subjectifying: two for negative (explicit and implicit) and one for explicit positive.

Reliability was assured through the following procedures: Two coders developed the coding criteria (the 1st and 2nd author), and then trained the third author on 20% of the data. Following that, the third author blind-coded an additional 20% of the data achieving sufficient agreement. Next, the third author coded the full set of 5 tasks, while the two other authors monitored reliability by double coding (blindly) 25% of each task. The overall Kappa of these blind codings was 0.85.

Findings

Overall findings from three tasks

Table 2 - overall codings of 12 students' on three tasks. Numbers indicate the difference between exploration and ritual elements of the routine.

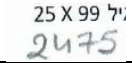
Task/Student		Shirts&Pants	Subjectifying Exp	Subjectifying Implct	$\frac{1}{2}+\frac{1}{10}$	Subjectifying Exp	Subjectifying Implct	25×99	Subjectifying		Total
Dana	LA	-8	-	-	-4	+		-6	-	-	-18
Hili	LA	6		-	N/A	-	-	N/A	-		N/A
Hila	LA	4	-	-	-4			-6	-		-6
Naor	LA	6		-	-4		-	-5	-		3
Edna	MA	4		-	3	-	-	2	-	-	9
Idit	MA	8			-3		-	-1	-	-	4
Dan	MA	7			8	+		-1		-	14
Ziv	MA	6		-	5		-	5		-	16
Ram	EA	7			7	-		8	-		22
Gabi	EA	7			7			8			22

Yoram	EA	7			8			8			23
Amir	EA	7			8			7			22

Legend: LA = Low achieving group; MA = middle/high achieving group; EA = excelling group; Exp = Explicit; Implct = Implicit; + indicates positive subjectifications; - indicates negative subjectifications

Regarding the first RQ, we see high variance in students' performance on the three tasks. While some students performed almost fully exploratively (e.g. Yoram, Gabi and Amir), some students enacted the routines ritually (Dana , Hila), or completely disengaged (Hili). Some students (e.g. Edna, Idit) showed mixed performance, with mostly explorative participation in the "shirts and pants" word problem, along mixed routines or ritual routines in the adding fractions and multiplying two-digit numbers tasks. We see in these results evidence for the validity of the RDP since the performance was mostly in agreement with students' general achievements in school (as operationalized through their placement in the three achievement groups).
Regarding the second RQ, we see general coherence between the placement of students in achievement groups, and negative subjectifications: the lower the group, the more negative subjectifications (more "-" in the top part of the table). We also see consistency within students with relation to subjectifying, which hints at the stable mathematical identities (reified stories about oneself) that students have developed by this age. Thus, some students, such as Gabi, Yoram and Amir, never subjectified (neither negatively or explicitly positively), while others subjectified negatively very often (Hili, Edna). Yet others (such as Dana) subjectified both negatively and positively. Indicating much attention to oneself and one own's performance in the process of mathematizing. Another observation coming from Table 2 is that students in the low achieving group tended to subjectify negatively even when performing relatively exploratively (e.g. Hila in the word problem; Edna in $\frac{1}{2}+\frac{1}{10}$). Finally, when comparing the three tasks, the word problem was overall performed most exploratively, while the other two tasks (multiplication and adding fractions) were quite similar in the indexes of ritual and explorative participation. However, even in the word problem where almost all the students showed mastery, some students still subjectified negatively, communicating lack of confidence, or negative evaluations of their performance. Thus, in conclusion, we saw general coherence between ritual performance and negative subjectifications, with a tendency of overly-negative subjectifying in some students' discourse. We now move to exemplify some instances of coherence and incoherence between ritual/explorative performance and negative/positive subjectifications.

Example of coherence between ritual/explorative and subjectifications

	Speaker	**What is said (what is done) – *Explicit subjectifications marked in italics.* Implicit subjectifications marked in shadow.**	Written product 
1	Edna	(Reads the task "calculate in your head 25×99", mumbles) *I don't think I can do it* (…) you can do two times nine and then five times nine and then add it up? Or is that actually.. You can subtract from this (unclear what "this" refers to)	
2	Interv.	Umm you can… but I think there's a more effective way. Because the 99.. it's very close to something	
3	Edna	Do like 100 and then take away one?	
4	Interv.	OK	
5	Edna	I.. I know, but *I don't know* how much to take away from this (smiles shily, fumbles with her pencil) … *I don't know*	
6	Interv.	If you call this 25 times, or actually 99 times 25 (Edna: OK) Will that help you?	
7	Edna	No (giggles) (Interv: No?) Take away from this 25?	
8	Interv.	OK so try it	
9	Edna	A hundred, umm like.. it's simply 2500 (Interv. OK). I think.. and then take away 25 that's… two thousands.. four hundred.. seventy five	
10	Interv.	Good	
11	Edna	Is it right?	
12	Interv.	A-ha	

The routine Edna employed for the task of multiplying 25×99 was coded as follows: Regarding *Objectification*: her routine was coded as explorative (1, 0) since she related to the product of the multiplication (2500) as an object ("it's simply 2500") [9], and since she saw the multiplication by 99 as meaning that one 25 needs to be "taken

away" from the 2500. The criterion of *flexibility* received a mark both on the explorative and the ritual columns (1, 1). The reason for "rigidity" (ritual) was that, initially, Edna did not show signs of employing spontaneously more than one procedure for the task. The first procedure she suggested ("you can do two times nine and then five times nine and then add it up" [1]) led her to a dead end ("I don't think I can do it" [1]). However, when the interviewer suggested another procedure (signaling it with "calling it 99 times 25") Edna picked up this prompt and associated with the task the procedure of multiplying 25 by 100 and taking away 25, a procedure that she completed successfully. This was taken as an indicator of flexibility since although the procedure was suggested by the interviewer, Edna saw the "sameness" in both her suggested (yet unperformed) procedures, and the one suggested by the interviewer. *Agency* also received a mixed code (1, 1). Evidence of agency were seen in deciding to employ the 25X100×=2500 sub-procedure, as well as the decision to take away 25 from 2500. Evidence of reliance on external authority were found in relying on the interviewer for hinting which procedure to use, as well as asking for confirmation at the end [11]. The criterion of *focus on goal/procedure* received only a mark of exploration (1, 0), as there were no indications of focus on the procedure. The whole performance was tailored towards reaching the narrative of what the product of 25×99 is. Moreover, Edna even envisioned initially two alternative procedures for accomplishing the goal [1], but discarded them as impossible (or difficult) for her to perform. The focus was thus never on simply enacting a certain procedure, but on choosing a procedure that would both fit for the task at hand, and be doable. With relation to *Bondedness*, the whole procedure and sub-procedures were bonded with each other. We found no indication of disconnect between the sub-procedures. Therefore, the criterion was marked as explorative (1, 0). In addition to these criteria, the criteria of *canonical procedures* and *canonical narratives* both received an exploration mark (1,0). Finally, the criterion of *mediation* received a ritual score (0, 1) since the choice of procedure was mediated, as well as its monitoring. Thus, in summary, the routine received 7 marks for exploration, 5 for ritual, and the difference mark was 2, which marks a "mixed performance" routine, with some tendency towards exploration. However, Edna's subjectifications are negative. She communicates both explicit [1, 5] and implicit subjectifications of lack of confidence [5, 7, 11]. Thus, Edna's subjectifications give hardly any hint of the explorative, or agentive parts of her routine.

Example of incoherence: ritual performance, positive subjectification

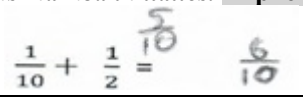
	Speaker	**What is said (what is done) – *Explicit subjectifications marked in italics.* Implicit subjectifications marked in shadow.** Written product: $\frac{1}{10}+\frac{1}{2}=\frac{2}{12}$
1	Dana	Oh, great! This, this- oh, *this is fun*. You do one plus one equals.. ah (writes) two
2	Interviewer	Umhm
3	Dana	Like this, and then ten and two, twelve (with confidence)
4	Interviewer	OK

The routine Dana employs for the task of adding $\frac{1}{2}+\frac{1}{10}$ was coded as follows: Regarding *Objectification*: her routine was coded as syntactic (ritual) (0, 1), since she treats the nominator and denominator as two whole numbers with no relation between them ("you do one plus one" [1], "and then ten and two" [3]). The criterion of *flexibility* received a mark of rigidity (ritual) (0, 1) because there was no indication that Dana had any other procedure to employ, and because of the deterministic "you do" declaration. *Agency* received an explorative code (1, 0) since Dana showed no hesitation, talked with confidence and came up with the procedure on her own. The criterion of *focus on goal/procedure* received a ritual mark (0, 1) since Dana only talked about steps in the procedure (adding the top numerals and bottom numerals), talked about actions ("you do") and showed no interest in the result (she did not even name the $\frac{2}{12}$ as "two twelfths"). With relation to *Bondedness*, the routine was coded as ritual (0, 1) since the two sub-procedures were not bonded (adding 1+1 and adding 2+10), neither was there any bondedness between these two sub-procedures and the task of adding half and a tenth. The criteria of *canonical procedures* and *canonical narratives* both received a ritual mark (0, 1). Finally, the criterion of *mediation* received an explorative score (1, 0) since the choice of procedure was not mediated and there was no intervention on the part of the interviewer. Thus, in summary, the routine received 2 marks for exploration, 6 for ritual, and the difference mark was -4, which marks a ritual routine.

Yet, despite this ritual performance Dana's subjectifications were positive. She communicates both explicit subjectifications of feeling confident "this is fun" [1] and implicit subjectifications of confidence [1, 3]. Thus, Dana's subjectifications give hardly any hint of the ritual nature of her performance.

Example of coherence: explorative performance, positive subjectification

The last example is taken from Dan's interview. Here is how he solved the task of adding $\frac{1}{2}+\frac{1}{10}$.

	Speaker	What is said (what is done) – ***Explicit subjectifications marked in italics.*** **Implicit subjectifications marked in shadow.** Written product 
1	Dan	(Reads from the sheet) "Solve the exercises", um calculate this?
2	Interviewer	Uh yes you need to solve, yeah. You can do it in writing
3	Dan	No, *I don't need to calculate, I don't have to calculate*
4	Interviewer	How?
5	Dan	Oh *I can do it quickly* (Interviewer: OK). So this equals uh.. 6 divided by 10.

The routine Dan employs for the task of adding $\frac{1}{2}+\frac{1}{10}$ was coded as follows: *Objectification*: his routine was coded as objectified (explorative) (1, 0), since he effortlessly samed $\frac{1}{2}$ and $\frac{5}{10}$ and since he talked about "six divided by ten" which is not the standard way of calling the fraction (standard would be "six tenths"). The criterion of *flexibility* received a mark of exploration (1, 0) because he chose a non-standard procedure (naming $\frac{1}{2}$ as $\frac{5}{10}$ and then adding the two fractions in his head). *Agency* received an explorative code (1, 0) since he showed no hesitation and came up with procedure on his own. The criterion of *focus on goal/procedure* received an explorative mark (1, 0) since Dan's focus was on the result, and he even explicitly said that he can "do it without calculation", referring to being able to come up with an answer without following the standard procedure taught in school. With relation to *Bondedness*, the routine was coded as explorative (1, 0) since there were two sub-procedures (realizing $\frac{1}{2}$ as $\frac{5}{10}$ and then adding $\frac{1}{10}$ and $\frac{5}{10}$) and they fed one into the other. The criteria of *canonical procedures* and *canonical narratives* both received an explorative mark (1, 0). Finally, the criterion of *mediation* received an explorative score (1, 0) since the choice of procedure was not mediated and there was no intervention on the part of the interviewer. Thus, in summary, the routine received 8 marks for exploration, 0 for ritual, and the difference mark was 8, which marks a highly explorative routine. Dan's subjectifications cohered with the explorative nature of his routine. He communicated both explicit subjectifications of feeling confident "I don't need to calculate" [1] and "I can do it quickly" [3] and showed no subjectifications of hesitation.

Discussion

Our goal in this research was to develop a holistic tool for mapping students' arithmetic discourse along the ritual-explorative axis, as well as to map their subjectifying (identity construction) discourse. We asked what the application of this tool to the discourse of 12 students, solving 3 tasks, would reveal. We also wished to examine to what extent the ritual or explorative performance of students is in coherence with their subjectifications – namely their evaluations of themselves as they work on the tasks. Our findings revealed that the students' ritual/explorative performance was highly varied and it was generally consistent with their placement in the different achievement groups. Low achieving students generally performed more ritually than their high achieving peers. These findings add credibility to the theory of learning as advancing from ritual to explorative participation, as it shows that students who have mastered the arithmetic discourse (and are thus probably achieving highly on school mathematics tasks) perform mostly exploratively on the given tasks, while low achieving students have not mastered the discourse and thus perform ritually.

In relation to the question of coherence between subjectifications and performance, our findings showed that the students' subjectifications generally agreed with students' ritual/explorative performance, with ritual enactments of routines accompanied more by negative subjectifications than explorative enactments. There was also coherence between the identity of the student as low, middle/high achieving or excelling (as seen in the placement of students in groups) and their subjectifications: the lower achieving students subjectified more negatively than the high-achieving students. However, there were also interesting inconsistencies. One was where students subjectified negatively, but their performance was relatively explorative. The other (rarer) occurrences were when students evaluated their performance positively but their performance was highly ritual.

These findings strengthen the validity and utility of the RDP tool. The validity can be derived from the agreement between the scores on ritual/explorative performance on the three tasks and the general achievement and mathematical identities of the students. The utility of the tool can be found in the nuanced view of students' performance, which, for example, can reveal certain students' over-tendency to negatively evaluate their performance, as well as certain tasks (such as adding fractions) that may be susceptible to over-confidence (students' subjectifying positively despite their ritual performance).

This report has been concerned with only three tasks out of the 24 that are included in the RDP. Future work should examine if other tasks significantly change the picture obtained by the analysis of these tasks. Thus, this work is limited in the ability to generalize from the findings to the general arithmetic discourse of students. It is also limited by the small number of participants, a regular limitation in highly work-intensive methods such as discourse analysis. Finally, the RDP mostly contains standard calculation tasks, not complex problems that involve modeling or literacy, nor does it include non-arithmetic parts of the mathematics curriculum such as geometry or statistics (data analysis). Thus, one should be careful in deriving from its results conclusions about the general mathematics discourse of students.

Nevertheless, the RDP has multiple avenues for future development and utility. First, the main utility of this tool is in examining interventions aimed at increasing explorative participation. Current paper-and-pencil tools are not sufficiently discriminative to examine such minute developments. Second, the RDP can function as a diagnostical tool for examining "pockets of ritual participation" that need to be attended to. As reviewed earlier, such "pockets" may widen over time and lead to generalized failure, despite students' effort and aspirations (Heyd-Metzuyanim, 2015). Finally, learning to use the tool and analyze students' discourse with it, may teach teachers to turn their attention towards processes of ritual and explorative participation. Although it is highly improbable that a teacher could expend the effort of analyzing each of their students with this tool, some experience with it may still go a long way. As shown in professional development efforts in the past (e.g. the CGI professional development program, (Franke et al., 1998)), when teachers become familiar with a certain theoretical lens that helps them better understand their students' learning processes, this can, by itself, change their teaching practices to be more attuned to their students' needs.

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Designs for Grounded and Embodied Mathematical Learning

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Abstract: Findings synthesized across five empirical, laboratory- and classroom-based studies of high school and college students engaged in geometric reasoning and proof production during single and multi-session investigations (346 participants overall) are presented. The findings converge on several design principles for embodied mathematical thinking and learning. *The Hidden Village* is presented as an instance of an embodied learning environment that uses the narrative context of a visual novel to instantiate these design principles and investigate their influences on mathematical thinking and learning, and to inform a broader theoretical framework of grounded and embodied learning. The interplay of theoretical, empirical, and design considerations of grounded and embodied learning reframes learning, transfer, and assessment, offering promising new pathways for an emerging class of learning environments.

Grounded and embodied learning

Grounded and embodied learning (GEL) offers a framework for understanding and designing for meaning making based on body-based processes. These GEL processes include actions, gestures, operative speech, and collaborative movements, as well as processes for supporting simulated action and imagination. Evidence is mounting that GEL is also activated during interventions, such as when learners are prompted to perform directed actions or are prompted to engage in simulated actions. This paper summarizes a set of interwoven empirical, theoretical, and design advancements for mathematical reasoning and their implications for teaching, learning, learning environment design, and assessment.

The **theoretical contributions** offer hypothesis-driven inquiry into the nature of learning and meaning making through body-based experiences, and principled guidance for the design of learning technology and educational experiences. **Empirical** contributions span several laboratory- and classroom-based studies of high school and college students and high school teachers; in all, some 346 participants who engaged in 5 single and multi-session investigations. These investigations provide evidence of the role of embodied processes for meaning making in support of mathematical reasoning and theoretically guided design principles to promote learning.

Design advancements to technologies for embodied thinking and learning serve as essential instantiations of theoretically derived hypotheses, as well as vital spaces in which embodied behaviors are elicited and data collected. Empirical findings and theoretical progress inform improvements in learning environment design that then make possible further theoretical and empirical advancements. In the final section, we explore how the interplay of evidence, theory, and design offer pathways for progress on complex issues facing GEL, such as generalizing research, bridging research and practice, and the emergence of designs and design principles.

Theoretical Frame: Grounded and Embodied Mathematical Cognition

Assumptions About Cognition

Memories, experiences, and meaning are constructed through the continuous *interactions* among environmental, social, cognitive, motoric, and perceptual processes of a highly dynamic, self-regulating organism, via a *perception-action loop* (Neisser, 1976; Varela et al., 1991). The cognitive system is a *predictive architecture*, continually anticipating responses to sensorial input from the environment and from within (Clark, 2013; Glenberg, 1997). People engage in cognitive processes that *extend* beyond the individual actor. Task-relevant knowledge is *embedded* in the situations in which activity unfolds and is *distributed* across actors, objects, and space (Clark & Chalmers, 1998). People can regulate distributed resources through cognitive *offloading* (Hutchins, 1995; Wilson, 2002). Finally, to be meaningful, new ideas, abstractions, and symbolic representations must be *grounded* in one's lived, sensorimotor experiences (Harnad, 1990; Glenberg et al., 2004).

Several scholars have synthesized evidence-based design principles for fostering embodied learning (Abrahamson et al., 2020; Lindgren & Johnson-Glenberg, 2013; Johnson-Glenberg et al., 2014; Skulmowski & Rey, 2018), with considerable overlap on these considerations: Motoric engagement; cognitive relevance of actions (aka "action-concept congruency"); and presence, including virtual, sensorial, and social immersion.

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Integrating Linguistic and Body-Based Processes

Mathematical cognition emerges from the interplay of symbolic, verbal, and sensorimotor knowledge and processes. Symbol systems are important disciplinary representations that codify formal knowledge, yet their arbitrary, abstract, and amodal (i.e., ungrounded) nature poses challenges for learners (Nathan, 2012). Oral language serves as a source for consciously grounding symbol systems, expressing meaning, and representing abstract relations (Koedinger, Alibali & Nathan, 2008). Sensorimotor processes offer a complement, through nonverbal and nonsymbolic forms of knowing based on one's lived experiences. Through the cognitive mechanism of conceptual metaphor, bodily processes can be the basis for grounding foundational mathematical concepts, such as number, as well as the means to *link* to more advanced topics (Lakoff & Núñez, 2000).

Gestures are spontaneous acts of the body—most typically the hands and arms—used during mathematical learning and teaching that integrate naturally with public speech (social communication) and inner speech (verbalizable thinking) to make direct indexical reference to the world (deixis), depict worldly objects (iconics), and represent abstract relations (metaphorics) (Alibali & Nathan, 2012). Gesture has three special qualities relevant for embodied mathematical cognition. First, it can manifest simulated actions (Hostetter & Alibali, 2008). As an example, one does not merely imagine *100* as a symbol, but as a location along a mental number line, with a corresponding gesture that may sweep to the right of the body's central axis. Second, gestures can add abstract as well as sensorimotor information from actions into the cognitive encoding of a task. In effect, gestures help to *schematize* the most important qualities of task-relevant actions—physical and simulated actions—that can facilitate the formation and generalization of task-relevant cognitive processes for future use (Kita et al., 2017). As such, gestures "provide a bridge between concrete actions and more abstract representation" (Goldin-Meadow & Beilock, 2010, p. 672). Third, gestures express multimodal knowledge that cannot be verbalized, and which may be unconscious or as yet linguistically and symbolically unformed.

Action-Cognition Transduction: How Actions Produce Ideas

Cognitive processes have historically been framed using computer-based metaphors. Within this metaphor, a "central processing unit" governs the behaviors of "peripherals" such as perceptual systems, and output devices in the form of actuators such as our hands, that act upon the world (Eisenberg, 2002). We readily accept that our thoughts can (often) control our actions. *Action–cognition transduction* (ACT) explains how, in reciprocal fashion, body movement can induce mental states and actions through the complex coupling of feedforward and feedback interactions (Nathan, 2017). This alternative cognitive architecture places the function of peripherals as also central to cognition, through means such as gestures, eye gaze patterns, epistemic actions, and cognitive offloading (Kirsch & Maglio, 1994; Wilson, 2002). Actions, in this view, literally change our minds.

Geometric Reasoning and Mathematical Proof Production

Embodied approaches to thinking and learning confront some unique challenges regarding mathematical proof. Proof is a central disciplinary practice among mathematicians, serving as the primary method for testing claims, constructing knowledge, and disseminating research (Lakatos, 2015). Geometry is the primary scholastic content area for k-12 students learning to produce mathematically valid proofs and is used to explore properties of space and shape (Lehrer & Chazan, 2012; NCTM, 2000; Stylianides, 2007). As a topic of advanced mathematics, it is steeped in abstractions and formalizations to make universal claims that go well beyond personal experiences. Formulating proofs does not rest on well-rehearsed procedures. It requires the development of mathematical intuition along with logical, generalizable, and goal-directed, operational thought (Harel & Sowder, 2005).

Despite its importance, educational systems struggle to cultivate proof practices (Dreyfus, 1999). As examples, students rely on tautological claims without cultivating true insights about the phenomena of interest and tend to overgeneralize claims derived from specific examples (e.g., Healy & Hoyles, 2000). This prompted our inquiry about ways to promote GEL of proof practices.

Theoretically Guided Research Questions

We report on the findings from several empirical studies designed to explore the following questions: (1) What are the emerging cognitive principles for GEL of geometry proof? (2) How can these principles inform the design of computer-based embodied learning experiences?

Empirical Support for GEL of Mathematical Reasoning

Dynamic Gestures Enact Simulated Actions to Facilitate Geometric Reasoning

This first study (Nathan et al., 2020) asked: *Is geometric reasoning associated with participants' gesture production?* Secondarily, we wanted to know: *Does the strength of the relationship between geometric reasoning*

and gesture production depend on participants' mathematical expertise? We analyzed video recordings of 46 mathematics experts and 44 non-experts recruited from a large US midwestern university who evaluated the truth of conjectures about geometric properties (Table 1). We used logistic regression for binary outcomes (0/1) to model accuracy of intuition (snap judgments), insight (gist), and proof. A valid proof had to show reasoning that is logical, operational, and generalizable across the class of mathematical objects under consideration.

Table 1
Truth value, insights, and proof for example mathematical conjectures.

Conjecture Text	Truth	Insight	Proof	Cognitively Relevant Directed Actions
The area of a parallelogram is the same as the area of a rectangle with the same length and height	True	(1) States a parallelogram is a rectangle tilted or pushed over. (2) States area of a parallelogram and a rectangle have the same formula.	(1) Shows cutting off a triangle from the parallelogram, or rearranging the area makes them congruent. (2) State all rectangles are parallelograms thus the formula for area is the same.	
Given that you know the measure of all three angles of a triangle, there is only one unique triangle that can be formed with these three angle measurements	False	States similar triangles or infinite/many triangles	(1) Gives specific counterexample (2) Visually shows scaling or discusses scaling and similar triangles	

Analyses provide empirical support for claims that geometry proof production is an embodied activity, even when controlling for math expertise, language use, and spatial ability. We coded for *dynamic depictive gestures* that portray generalizable properties of shape and space through enactment of transformational operations (e.g., dilation, skewing; Garcia & Infante, 2012; Nathan & Walkington, 2017). *Dynamic depictive gestures* (Figure 1) are contrasted with non-dynamic depictive gestures that may trace or merely refer to mathematical objects and their transformations. Non-dynamic depictive gestures were associated with correct mathematical intuitions (p = .004). Dynamic depictive gestures were more likely to be associated with correct insights (p = 0.042) and mathematically valid proofs (p < .0001) than when no such gestures were made. Furthermore, experts significantly out-performed non-experts and were more likely to produce dynamic gestures (79%) than non-experts (52%).

The benefits of dynamic gestures were replicated among undergraduates from a large, southwestern university (N = 108). There, production of dynamic gestures was associated with mathematical insights (d = 0.45, p < .05) and mathematically valid proof (d = 0.74, p < 0.001), but production of any gesture was not (Walkington et al., 2019). Dynamic gestures may allow participants to explore generalized properties of shapes and space, thus supporting their geometric reasoning. This suggests that gestures, as simulated actions, provide an alternative account of mathematical reasoning than that of symbolic cognition. This raises questions of whether and how to design learning experiences that elicit gestures in service of mathematical thinking and learning.

Directed Actions Foster Reasoning and Performance Benefits Through Video Game Play: The Importance of Cognitive Relevance

To explore how eliciting gestures impacts mathematical reasoning, we developed *The Hidden Village* (THV), an embodied video game that uses the *visual novel* genre (Cavallaro, 2009). We explored to questions: *Can we use directed actions to elicit dynamic gestures that will enhance geometry proof performance?* And *Does the cognitive relevance of the directed actions used in the game matter?*

A player mimics movements of in-game "villagers" doing activities such as dance and play (Figure 2). THV uses 3D motion-capture technology via the Kinect™ sensor array to track player motion in real time to determine if the player has performed the intended directed action. *Directed actions* are carefully chosen movements curated from prior sessions of successful mathematical reasoning. Once the directed actions are repeatedly matched, the player reads a geometry conjecture (Table 1), decides if it always true or ever false, provides an explanation in speech and gesture (which is recorded), and then chooses a multiple-choice response.

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Completing each conjecture cycle earns a knowledge token and reveals a bit more of the map of THV.

In this experiment (Walkington et al., 2021), 85 high school students (65 female) from a program for soon-to-be first-generation college students were recruited. Forty-eight identified as Hispanic, 26 as African American, 5 as Asian, 3 as Caucasian, 2 as other race/ethnicity, and 1 had race/ethnicity data missing. Each student played eight conjectures. Cognitive relevance of the directed actions to each conjecture was manipulated within-subjects (4 relevant, 4 irrelevant). For example, a conjecture poses "The area of a parallelogram is the same as the area of a rectangle with the same length and height." The cognitively relevant directed actions in Table 1 schematize the conjecture's mathematical relations (Nathan & Walkington, 2017). The *irrelevant* directed actions are recycled actions from other conjectures to vary relevance while controlling for physical complexity. Conjecture order was counterbalanced using an 8-item Latin square factorial design. Participants were not informed that any of their directed actions were relevant to the conjectures they were being asked to prove.

Data were analyzed using mixed effects logistic regression models with repeated observations of students solving conjectures nested within student. Participant ID was made a random effect with an additional random effect for conjecture. Condition (relevant v. irrelevant) was not a reliable predictor of gesture usage on its own. Still, when participants were cued with relevant actions, they showed superior proof performance compared to times when cued to make irrelevant actions, *provided* they made any gestures ($d = 1.13$, $p < 0.01$), or, more strongly, when they made dynamic depictive gestures ($d = 1.56$, $p < 0.01$). Similar advantages for cognitive relevance were observed for performance on mathematical insight ($d = 1.02$, $p < .01$) and intuition ($d = 1.00$, $p < .01$), *so long as* students produced dynamic gestures during their explanations.

The results suggest that cognitively relevant directed actions contribute to superior mathematical reasoning. This beneficial influence is not direct, however, but appears to be *moderated* by the role of dynamic gestures during students' multimodal explanations. This may be because explanatory gestures help to schematize relevant mathematical information (Kita et al., 2017), thus enabling students to make better use of the conceptual information they obtain via action-cognition transduction when they perform directed actions that are cognitively relevant. Comparable actions that are not cognitively relevant offer fewer benefits to mathematical reasoning.

Collaborative Gestures Enhance Geometric Reasoning Via Extended Cognition

Collaboration offers another potential way to increase students' production of dynamic gestures during mathematical reasoning, supporting enhanced performance. When high school students (N = 51) from a school district in the Southwestern US were observed playing *The Hidden Village* in groups, they operated as a form of distributed system, with mathematical thinking extended across multiple members of the group in speech as well as gestures. Walkington and colleagues (2019, 2021) documented several types of *collaborative gestures,* defined as "gestures that are physically and gesturally taken up by multiple learners, holding a meaning that is explicitly dependent upon the gestures of interactional partners." Forms of collaborative gesture that students exhibited included (Figure 3): echoing (55.5%), as when a gesture was repeated; mirroring (24.4%), as when an observer matches the speaker's gestures at the same time; alternating (20%), as when an observer proposes an alternate gesture to advance the group's mathematical line of thinking without copying (as in echoing); and joint gestures (15.5%), as when multiple learners use their hands conjointly to form a single mathematical object or idea.

They found that gestures--especially collaborative gesture production--contributed significantly to student performance. When group members did not gesture, students generated the correct insight 12% of the time. In comparison, the correct insight was produced more often with non-collaborative gestures (39%) and far more often with collaborative gestures (72%). Extending body-based resources across multiple participants, as well as other resources, reveals additional ways embodiment facilitates cognition.

Embodied Knowledge Transfer and the Travel of Ideas

One of the hallmarks of learning is to foster transfer, the conditions in which prior experiences facilitate learning and extend its reach to novel, but related areas of performance. Goldstone, Landy, and Son (2008) demonstrate how perceptual learning transfers "not through acquiring and applying symbolic formalisms but rather through modifying automatically perceived similarities between scenarios by training one's perceptual interpretations" (p. 329). In this small-scale study (Kirankumar et al., 2021), 12 students in a Title I high school played THV in small groups during Day 1. On Day 2 they used the THV-Conjecture Editor (Figure 4) to co-create new game content for their classmates. In so doing, they had to create cognitively relevant directed actions that would foster mathematical learning among their peers for Day 3, but without telling them—only through game play.

Group A chose to create the *ABC Reflection* conjecture (which is false)*: Given three points A, B, and C, and their reflected images about a line, A', B', and C', then ∠ ABC and ∠ A'B'C' are not equal.* Within-group analyses of their collaborative co-design (Day 2) showed that students regularly produced dynamic depictive gestures while investigating which directed actions would assist new players in forming the proper geometric

relations relevant to proving their conjecture. Between-group analyses (Day 3) showed that students in Groups B and D learned some insights and proof elements by playing the *ABC Reflection* conjecture from Group A.

The spontaneous gestures produced by students in Group D following Group A's directed actions demonstrated that game play provided an embodied conceptualization of reflection. The gesture made by a student in Group B reveals an understanding of reflection based on the directed actions performed by their teammate. This is demonstrated using a hand flip rather than whole arm/torso flip, showing how the student tracked the key invariant relation (angular measure), mapping that relation across contexts and bodies through the student's own body movement. The action (hand flip) performed in the new context can activate common cognitive states through transduction, which highlights the invariant relation in its new setting. This highlight helps establish the mapping by preserving what must remain invariant as it travels across contexts and physical settings.

These two cases provide preliminary insights into how ideas can "travel" via embodied engagement through game content creation and game play. It illustrates how "transfer is an embedded process, situated in a particular physical and sociocultural learning context" (Nathan & Alibali, 2021, p. 52).

Discussion

With these empirical findings in mind, we revisit the research questions. For the first question, we highlight several emerging design principles for GEL of geometry proof. One principle is the apparent cognitive benefits of *integrating linguistic and body-based processes*: Gestures are multimodal linguistic forms that both express and influence students' mathematical reasoning in ways that are both nonverbal (intuition) and verbal (insight and proofs), even when controlling for spatial ability and prior math education. Dynamic gestures in particular are shown to support the simulated actions (Hostetter & Alibali, 2008, 2019) needed for hypothesizing and generalizing universal truths about space and shape, which is central to geometry proof practices.

A second principle is that the *cognitive relevance of directed actions* is critical for designing effective interventions to enhance the quality of students' proofs. This builds on the notion that decentralizes cognition by recognizing that cognition and goal-directed actions mutually and reciprocally influence one another through transduction (Nathan, 2017). The mapping of concepts to relevant actions is, however, not a simple one-to-one relationship, which illustrates its complexity while also inviting tremendous variety for the designer. This design constraint appears to rest on the degree to which learners use explanatory gesture (again, integrating linguistic and bodily processes) to schematize the key mathematical relationships through movement (Walkington et al., 2021).

Creating collaborative contexts is a third principle shown to foster the kinds of gestures that are beneficial to mathematical reasoning (Walkington et al., 2019). In addition, the collaborative interactions that arise in these contexts support the formation of distributed knowledge exhibited by students' collaborative gestures, and the tightly coupled interactions that foster shared meaning. The final principle is *designing for embodied transfer by supporting production of prior actions*. Transfer emerges from the embodied nature of learning and the natural tendency of learners to predict the world and build cohesion across their learning experiences (Nathan & Alibali, 2021). In this sense, transfer is the default mode for engaged learners. Recurrent action sequences can bridge the travel of ideas across contexts, and educational environments need to be designed with this in mind. It also underscores how transfer is inherently embedded in socially mediated interactions among learners with teachers, peers, and technologies, allowing ideas to "travel" among groups and across contexts.

The second research question asks how these principles inform the design of computer-based embodied learning experiences. We explored these design principles in the context of *The Hidden Village* (THV), a visual novel used to engage players in embodied mathematical reasoning. THV is designed to integrate linguistic- and body-based processes during learning and performance assessment. It does this by eliciting from players the movements that were curated from prior sessions of successful mathematical reasoning. Following this, THV collects data on players' nonverbal intuitions (i.e., snap judgments) about the truth of the mathematical conjectures of interest. It then elicits these movements during players' multimodal explanations and justifications. In this way, it strives to bridge the chasm between exemplar-based concrete thinking and generalized abstractions that are central to mathematically valid proof production.

THV draws on the power of collaboration to engage players in the formation of distributed knowledge. Collaborators are shown to do far more than share knowledge verbally and symbolically. In addition, people come to recognize the representational power and expressiveness of both their own bodies and that of their collaborators. These interactions require establishing a shared understanding as well as offering ways to extend their own embodied thoughts onto the world around them. THV also explores the power of collaborative co-creation of new mathematical content to share with others. Creators come to recognize some of the ways their novel mathematical ideas become grounded in movement. They can then use movement as a means for transmitting generalizable concepts to others, who demonstrate them through their own movements. By recognizing transfer as an inherently embodied process, THV offers alternative ways to build shared knowledge. This raises considerations about the

role of the body in assessment, as learners may exhibit understanding through movements before they are aware of new emergent meanings or before they can verbalize new ways of thinking (Church & Goldin-Meadow, 1986).

Here, we have looked at the close relationship among empirical evidence, theory building, and design to investigate pathways for progress on complex issues facing GEL. We believe this work starts to establish an empirical basis for theorizing how linguistic and bodily knowledge among individuals and groups serve advanced mathematical reasoning, and the technological designs to support these types of social and embodied interactions. Still, this work has several limitations. One is the provisional nature of many of these empirical findings, which must face replication using larger and more varied samples, conducted with less direct input from the original research team. Another is that the principles themselves need to be tested with other digital platforms and using a broad array of student outcome measures before they can be really regarded as well established and generalizable. Our interest is to foster this additional research and the scrutiny it offers for theory and design. We take these initial steps as promising forays into a new class of theories and technologies for grounded and embodied learning.

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Figure 1

Participants reasoning about a conjecture. (a) Left*. A dynamic depictive gesture simulates transformations to reveal generalizable properties. (b)* Right*. Non-dynamic gesture of static properties of a simulated triangle.*

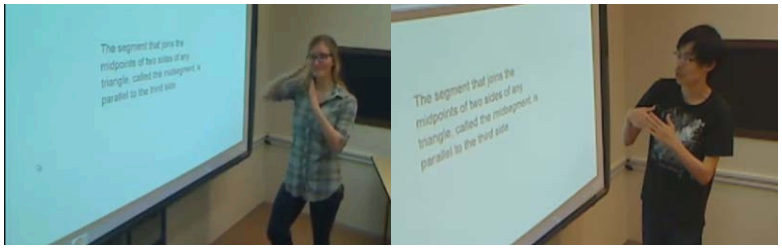


Figure 2
Flow of The Hidden Village. Bottom row from left: *(a) Meet a villager, (b) mimic directed actions of avatar, (c) free-responses in speech and gesture for a mathematical conjecture, (d) select a multiple-choice response, and (e) receive a knowledge token and expose the village map.* Top row: *Game play in a high school classroom.*

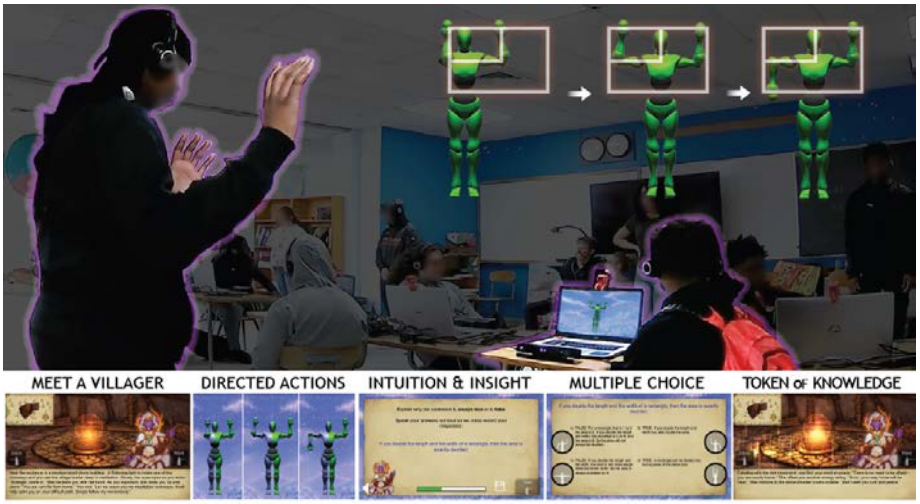
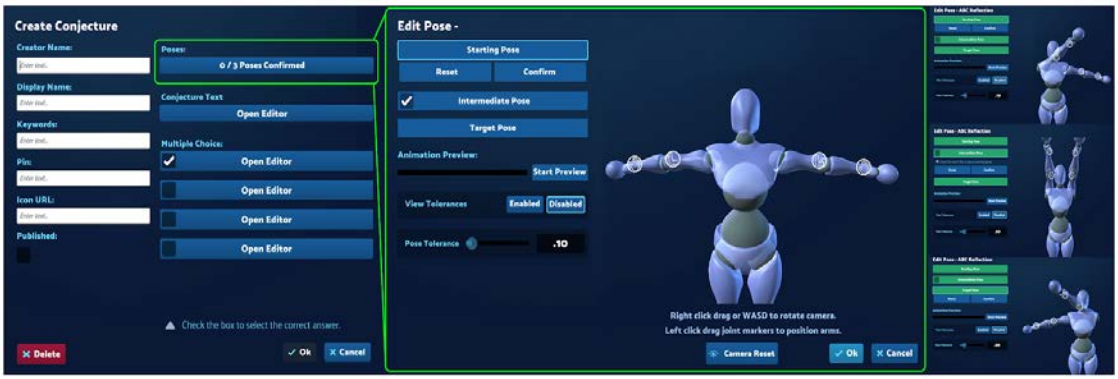


Figure 3
Example collaborative gestures (1) echoing, (2) mirroring, (3) joint gesture.

Figure 4
Left. *THV Conjecture Editor to create new conjecture for future game play.* Middle. *THV Pose Editor to create directed actions.* Right. *A new directed action sequence.*



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Implicit and Explicit Emotion Regulation for Conflict Resolution: Narrative and Self-Compassion as Anti-Bullying Training

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Abstract: Bullying poses a risk for equity and justice in learning. It can compromise learning achievement and hinter task performance. Emotions are key to handling bullying, thus need to be understood for the development of anti-bullying technological supports. We investigate effects of combining implicit and explicit emotion regulation strategies on empathy and conflict resolution styles among adolescents in a school bullying context. Based on dual-process framework of emotion regulation (Gyurak et al., 2011), the experimental group engaged in self-compassion induction as explicit regulation in combination with narrative construction as implicit regulation whereas the control group completed narrative construction only. The combination of implicit and explicit regulation was associated with significant increases in self-compassion subscales of self-kindness and mindfulness. It also elicited indicators of prosocial conflict resolution style: namely other-inclusion behavior and a tendency to inclusive choice of beneficiary from the bystander perspective. Effects on empathy were not larger with additional explicit support.

Theoretical background

Bullying can take forms of direct physical or verbal aggression, indirect manipulations of social relational structures (Björkqvist et al., 1992), or even recently emerging forms of aggression through digital media (H. J. Thomas et al., 2014). Recent findings support that bullying does not only concern those who are directly involved in an incident (e. g., Dodge & Price, 1994; Hodges et al., 1997), but is rather a socially grounded group process through which even seemingly less involved members of a peer group, so called bystanders, can contribute to reinforce, moderate, or prevent incidents of bullying (Peets et al., 2015; Salmivalli et al., 1996). Bystander behaviors affect adolescents' perception of the victimized (Gini et al., 2008) and such social contexts can determine how they behave in bullying incidents (Salmivalli et al, 1998). Targeting the group as a whole and enhancing general levels of empathy of its members are, thus, regarded as crucial aspects of systemic intervention/prevention measures against bullying (Kärnä et al., 2011).

Bullying poses a risk for equity and justice in learning contexts as it compromises learning achievement, especially for the unsupported and repeatedly bullied students (Juvonen, Wang, & Espinoza, 2011) and diminishes performance due to attentional deficits related to processing negative emotions (Dolcos et al., 2020). Bullying is a source of socio-emotional conflict, which often leaves bystanders, especially, at an emotional limbo (Hilt et al., 2019). It may thus render them unable to take vital anti-bullying actions. Therefore, emotions in bullying situations and their regulation need to be understood to develop anti-bullying technological supports. *Empathy,* as a commonly investigated emotional compound in the context of bullying, refers to one's reactions to the observed experiences of another (Davis, 1983). It is widely accepted that empathy consists of cognitive understanding of mental states of others (*perspective taking*) and emotional responses to perceived emotional states of others (Davis, 1983). Other-oriented emotional responses (*empathic concern*) signify concern for others, altruistic motivations (Batson et al., 1987), and regulation of one's own negative emotions (e.g., *personal distress*) (Eisenberg & Fabes, 1995; Panfile & Laible, 2012). Previous research has shown positive associations between empathy and defending behaviors of bystanders in bullying incidents (see van Noorden et al., 2014 for a review), who may become catalysts in conflict resolution and whose situational behaviors may depend on the regulation of their own negative emotions.

Emotions arise when one recognizes personal relevance in social contexts and assigns meaning to the experience. Thus emotions are malleable recursive processes where an emotional response to a situation can change the meaning assigned to the emotion-provoking situation (Gross & Thompson, 2007). Through such iterative emotion generative processes, we may influence which emotions we experience, when and how we experience and express them (Gross, 1998b). According to the dual-process model, emotional responses are modulated by the interplay of two ways of *emotion regulation* (ER): *explicit* processes, which require conscious effort, some level of metacognitive monitoring, and awareness, and *implicit* processes, which are evoked automatically by the stimuli and do not necessarily involve metacognitive processes (Gyurak et al., 2011). One might benefit from explicitly learning and using strategies (e.g., reappraisal or detachment) by assigning different meanings to emotion-provoking situations or maintaining a distant observer perspective (Gross, 1998a, 2002;

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Kalisch et al., 2005). At the same time, engaging in such explicit regulation processes may routinize and trigger these strategies automatically, making them implicit in the long run (Gyurak et al., 2011). Hence, explicit ER seems to interact with implicit ER. While conscious effortful explicit processes might not be possible or advisable at all times, e. g. when attention needs to be focused on the learning tasks, implicit processes are activated automatically (Dolcos et al., 2020). However, helpful implicit processes might not be cultivated without support. Thus, the interaction of implicit and explicit ER needs to be examined and compared to only implicit processes.

Using narratives to implicitly induce reliable emotions in realistic conditions has enhanced scientific understanding of human emotions (Jääskeläinen et al., 2021; Kanske et al., 2015). Numerous studies of bullying have also used narratives in the form of fictional characters or hypothetical episodes to elicit relevant responses from young people allowing for interpretations of their perspectives and attitudes (e.g., Bosacki et al., 2006; Jeniffer et al., 2006). In addition, *narrative construction* is suggested as a strategy to down-regulate negative emotions as it allows for expression of emotions, coherent restructuring of the events (Pasupathi et al., 2017), and active meaning-making based on one's experiences (Plowman et al., 1999), thereby attenuating intensity of emotional impact. Therefore, it can be considered as an implicit ER without the need of conscious effortful processes and yet reflecting automatic emotional responses to a situation that may become transparent to oneself.

Self-compassion (SC) is conceptualized as being kind and understanding to oneself rather than judgmental (*self-kindness*), interpreting one's personal experiences as part of human experience (*common humanity*), and being aware of one's painful thoughts and feelings without over-identifying with them (*mindfulness*) (Neff, 2003). Dispositional SC is positively correlated with ER (Finlay-Jones et al., 2015), empathy (Neff & Pommier, 2013) and prosocial behavior (Welp & Brown, 2014). Explicit long-term training of SC increases levels of dispositional SC among adolescents (Bluth et al., 2016) and supporting SC through simple instructions mediates effects of situation-specific self-related negative emotions (Leary et al., 2007).

Following the dual-process framework of emotion regulation, we explore the potential of narrative as implicit ER strategy that can reveal one's own emotional responses, and self-compassion as explicit ER strategy that may shift attention to these emotional responses. The two together, may influence how one experiences the bullying situation and one's own role in it, and increase empathy and prosocial behavior. We investigate the following research questions: Is conflict resolution promoted through SC induction and narrative construction? Do the positive effects of SC induction transfer to bystanders in conflict situations like bullying? Can inducing SC in combination with narrative construction promote empathy and prosocial behavior beyond what narrative construction alone can promote? We hypothesize that additional SC induction will have stronger effects than narrative construction alone, when assuming the bystander role in bullying situations and will:

H1: increase levels of self-compassion,
H2: increase levels of empathy, and
H3: increase prosocial conflict resolution: other-inclusion behaviors and inclusive choice of beneficiary.

Method

Participants

We recruited 30 female participants, aged 15-16 from two classes of a girls high school in Korea, to control for gender differences with females showing higher use of ER strategies (McRae et al., 2008), empathy and prosocial behavior (Barr & Higgins-D'Alessandro, 2007) than males. They were all first-year students, randomly assigned to each class upon admission to the school. They had not acquainted their new classmates and the school staff when the experiment started since the school had been closed due to pandemic. 16 students were in experimental group and 14 students were in control group. To avoid confounding effects from class or teacher, each group was invited to Google classroom respectively two weeks before school opening and completed all the tasks online.

Procedure

Dispositional self-compassion and empathy were first measured before the intervention. After two weeks, subjects all engaged in implicit ER task (narrative construction) to avoid prompting effects. The experimental group completed additional explicit ER task (SC induction) prior to implicit regulation, to set the scene for more empathic reactions during implicit ER task. Right after the intervention, dispositional self-compassion and empathy were measured again. Self-constructed narratives of subjects were analyzed for behavioral responses.

Explicit emotion regulation

Instructed SC induction was adapted from Leary and colleagues (2007). It consisted of one trigger question and three self-compassion questions. We referred to the Revised Cyber Bullying Inventory (Topcu & Erdur-Baker, 2010) to compose the trigger question to reflect the predominance of online interactions as a means of

communication among adolescents. Subjects in experimental group were asked to recall their unpleasant online communication experiences with the details of the situation and their emotions and behaviors evoked by the incident. After that, they were to answer three open questions implementing subcomponents of SC: a) Try to think of ways that other people would also experience similar events and feelings like what you experienced (common humanity), b) Imagine your friend who is always supportive and understanding, who knows your strengths and weaknesses, wrote a message to you and that made you feel much better and comfortable. What would have the friend written? (self-kindness) c) Try to describe your feelings about the experience in an objective and unemotional way (mindfulness). Upon completion of this task, they proceeded to implicit ER task.

Implicit emotion regulation

Implicit ER task consisted of a video clip and subsequent narrative construction. We prepared an edited excerpt from the movie *Bang Bang You're Dead* directed by Guy Ferland (2002). A diagram introducing three main characters with their pre-existing relational conflicts was presented prior to watching the excerpt. The video starts with the *protagonist*(P) arriving at school, shows him getting verbally and physically teased by the *antagonist*(A) and his friends, practicing a play script with his *friend*(F), and ends where he almost physically gets into a fight when a rehearsal with the theater team was interrupted by the *antagonist*. Narrative construction was operationalized as follows. Subjects were told to imagine as if they were the screenwriter and continue to write the story by answering open questions about the characters and the conflict. Subjects were to describe what decisions or behaviors each of the three characters would make and the reasons behind them. Finally, subjects were to describe how the story should end, in other words, how the conflict should be resolved.

Measurements

Self-compassion

The Self-Compassion Scale for Youth (Neff et al., 2020) was used to measure dispositional SC before and after intervention. It consists of 17 items, three subscales for compassionate (self-kindness, common humanity, mindfulness) and three for uncompassionate responding (self-judgement, isolation, over-identification). Subjects rated how they act towards themselves in difficult times on a 5-point scale ranging from 1 (almost never) to 5 (almost always). The uncompassionate subscales were reverse coded. Item analysis showed marginal to high internal consistency across subscales and time (pre: α = .436~.840, post: α = .488~.839). The total scores for pre- (α = .842) and post-measurement (α = .828) indicate high internal consistency.

Empathy

Interpersonal Reactivity Index (Davis, 1983) was used to measure empathy traits. Three subscales of IRI were included: *perspective taking* (PT), *empathic concern* (EC), and *personal distress* (PD). Subjects rated how well an item describes themselves on a 5-point scale ranging from 1 (does not describe me well) to 5 (describe very well). An item from EC had a negative value in item discriminatory power at post-measurement, therefore was not included in the analysis. The item analysis indicates marginal to acceptable internal consistency (pre: α = .547~.781, post: α = .638~.803).

Table 1

Coding scheme description and example responses for other-inclusion behavior

Category	Description	Example response
Self-oriented	Behaviors or decisions intended to relieve one's own safety, feelings, desires, or concerns	F refuses to help P because she doesn't want to get involved in his trouble.
Close-vicinity	Behaviors or decisions intended to care for, or affected by understanding of people in close vicinity, compromising the intention to alleviate one's own safety, feelings, desires, or concerns to support for theirs	P stops confronting A and football team because he doesn't want to cause any problems to the theater team
Distant	Behaviors or decisions intended to care for, or affected by understanding of not only those in close vicinity but also distant party (opponent party), taking into account safety, feelings, desires, or concerns of the distant party	A recognizes he shouldn't have pranked on P. He apologizes to P and asks for forgiveness.

Conflict resolution style: Other-inclusion behavior and choice of beneficiary

Two types of CRS were measured as indicators of prosocial behaviors using directed content analysis (Hsieh & Shannon, 2005) of subjects' self-constructed narratives: *other-inclusion behavior* and *choice of beneficiary*. *Other-inclusion behavior* was operationalized as descriptions of character behavior that allow inferring how subjects may behave themselves in reality. We devised a coding scheme (see Table 1) to represent self-other interaction in conflict situations based on previous works on conflict resolution (Kurdek, 1994; Neff & Harter, 2002). *Choice of beneficiary* was measured as predictions of the story ending. The coding scheme was based on the two-dimensional taxonomy of the conflict handling mode (Thomas & Kilman, 1974, cited in K. W. Thomas, 1992). We borrowed the concept of one's *choice of beneficiary* referring to the extent to whose welfare is optimized among the conflicting parties (see Table 2) (K. W. Thomas, 1992). Two independent raters annotated participants' narratives separately for statistical analysis. After the first iteration, the coding schemes were reviewed and modified. The second iteration reached the alpha value of .81 ~ .86 across characters for other-inclusion behavior and .86 for choice of beneficiary (Hayes & Krippendorff, 2007). The remaining differences were resolved upon consensus.

Table 2
Coding scheme description and example responses for choice of beneficiary

Category	Description	Example response
Avoidance	No resolution of the conflict. Conflicting parties are at stalemate, no improvement or change in the conflict situation	Despite efforts of F, P goes on to seek his own revenge on football team.
Partisan	Optimize the welfare of one of the conflicting parties, while the other party yielding	What A did to P gets discovered by school authority and A gets dispelled from school.
Joint-welfare	Concerns of both conflicting parties are dealt with by a certain extent of improvements or compromise from both sides	A stops bullying because he knows what he did was wrong while P focuses on theater play.
Systemic	Extension of conflict resolution to the general population in the group or establishing constructive relationship between conflicting parties	After A apologizes and P accepts the apology, the three become good friends.

Figure 1
Means of IRI and SCS-Y between conditions after intervention

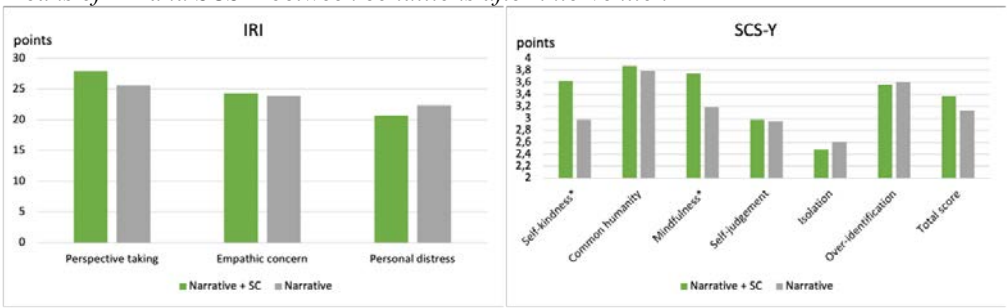
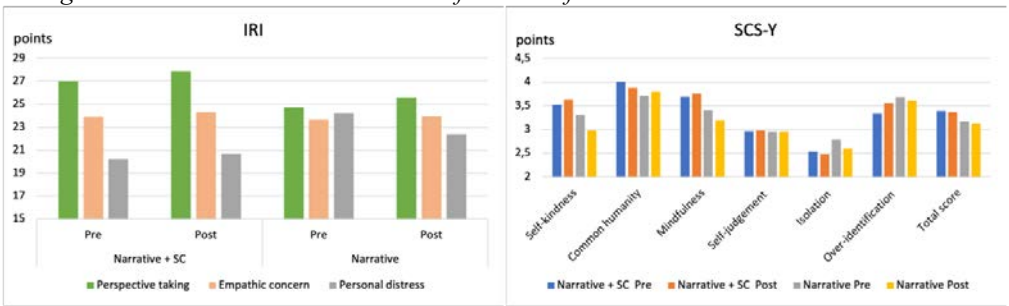


Figure 2
Changes in IRI and SCS-Y mean scores before and after intervention within each condition



Results

Self-compassion and empathy

Levels of SC showed no significant differences between the two groups before intervention. We performed independent *t*-test with posttest results to see if SC induction elicited significant differences in SC. Significant differences were found in subscales of SC ($t(28) = 2.293$, $p = .03$, *Cohen's d* = 0.839) and mindfulness ($t(28) = 2.813$, $p = .009$, *Cohen's d* = 1.03), but not in the total score ($t(28) = 1.242$, $p = .225$, *Cohen's d* = 0.454), partially confirming *H1* (see Figure 1). SC induction greatly affected subscales of self-kindness and mindfulness, but not overall dispositional SC.

Levels of PT and EC increased in both groups (Figure 2). However, there was no significant difference between the two groups after intervention (PT: $t(28) = 1.793$, $p = .084$, *Cohen's d* = 0.656; EC: $t(28) = 0.32$, $p = .751$, $d = 0.117$; PD: $t(28) = -0.997$, $p = .328$, *Cohen's d* = -0.354). Before intervention, a significant difference was observed in the levels of PD between the two groups ($t(28) = -2.476$, $p = .02$, *Cohen's d = -0.906*), but not after intervention. PD decreased with narrative construction only ($t(13) = -1.97$, $p = .07$, *Cohen's d* = -0.49), but increased with additional SC induction ($t(15) = 0.465$, $p = .649$, *Cohen's d* = 0.13). Other than expected, narrative only decreased the levels of PD but in combination with SC induction, increased it. *H2* is rejected.

Table 3

Frequencies and estimates of binary regression of other-inclusion behavior with condition as predictor

	Category	Narrative + SC (n = 16)	Narrative (n = 14)	*B (SE)*	*OR (95% CI)*	*p*
Protagonist	Self-oriented	8	10	.916 (.775)	2.50 (0.548, 11.41)	.237
	Close-vicinity	8	4			
	Distant	0	0			
Antagonist	Self-oriented	13	13	1.099 (1.219)	3.00 (0.275, 32.746)	.368
	Close-vicinity	1	0			
	Distant	2	1			
Friend	Self-oriented	1	6	2.42 (1.165)	11.25 (1.146, 110.461)	.038
	Close-vicinity	15	8			
	Distant	0	0			

Table 4

Frequencies and estimates of multinomial regression of choice of beneficiary with condition as predictor

Category	Narrative + SC (n = 16)	Narrative (n = 14)	*B (SE)*	*OR (95% CI)*	*p*
Avoiding	2	8	Reference		
Partisan	8	4	2.079 (1.00)	8.00 (1.127, 56.793)	.038
Joint-welfare	3	1	2.485 (12.00)	12.00 (0.773, 186.362)	.076
Systemic	3	1	2.485 (12.00)	12.00 (0.773, 186.362)	.076

Other-inclusion behavior and choice of beneficiary

Logistic regression was used to analyze behavioral responses represented in self-constructed narratives. EPV (event per variable) number of 10 suffices to run the logistic regression (Peduzzi et al., 1996) and the 95% confidence interval for odds ratio measured above 1 suffices to say that an association can be assumed from the model (Field, 2013). For the ease of comparing with other character behavior assessment, the responses for scales

of *close-vicinity* and *distant* of *antagonist* behavior assessment were merged to run binary logistic regression. *Other-inclusion behaviors* showed a large variance across three characters in the video (see Table 3). The variance can be attributed to differences in *close-vicinity* between the two conditions. The behavior of the *friend* was assessed as more caring for or being affected by other people in *close vicinity* (protagonist, in this case) in the experimental group, which we expected to be the effect of SC support. *Choice of beneficiary* represented in the narratives missed significance between the two groups ($\chi^2 = 7.714$, $p = .067$), in accordance with H3. As shown in Table 4, significant variance of the regression model stems from the contrast between *avoiding* and *partisan*. The experimental group were more likely to resolve the conflict in favor of one of the conflicting parties than to avoid the conflict situation, as expected for SC support.

Discussion

Combining *SC induction,* as explicit ER support, with *narrative construction,* as implicit ER support, showed expected changes in adolescents' self-compassion and prosocial behavior, although not all hypotheses were supported. The combination of explicit and implicit regulation showed significant increases in SC subscales of *self-kindness* and *mindfulness*, and more constructive conflict regulation. For conflict regulation, *other-inclusion behavior* from the bystander perspective was more frequent in the constructed narratives with additional SC support. There was also a tendency for *inclusive choice of beneficiary*. The combination tended to report resolving the conflict of bullying in favor of the victimized, than avoiding the conflict situation. Differences in empathy were not significant: *perspective taking* and *empathic concern* increased for both, whereas *personal distress* decreased for narrative construction, as expected, but surprisingly increased with additional SC support.

Significant differences in the subscales of *self-kindness* and *mindfulness* align with previous work that suggests training in SC facilitates a transition towards a more compassionate balance of SC components (Bluth et al., 2016; Phillips, 2019). By combining explicit and implicit strategies, we found supportive evidence after only a short SC-based intervention. SC support increased PD, possibly because it enabled adolescents to attend to and become more aware of the suffering of others, having soothed themselves first. The role of awareness in how explicit SC supports ER processes needs to be examined further, to provide a differential account of its effects, based on kinds and levels (implicit - explicit) of promoted awareness, and its reflection processes that are triggered.

Lack of significant differences in PT and in EC between conditions can be attributed to the metacognitive elements of SC which entails acting with awareness (Solem et al., 2015). Explicit SC support may have increased both the understanding of the mental states of the protagonist and subjects' self-oriented emotional responding alike, especially in combination with narrative-based support. This might have prohibited expected implicit other-oriented emotional responding. However, we also found that prosocial behavior, important for the defender bystander role, was induced without significant increases in PT and EC. This aligns with previous results that would predict that SC results in active prosocial responses with less empathy (Welp & Brown, 2014), after having dealt with socio-cognitive conflict through self-soothing. SC support elicited a tendency to resolve the bullying situation in favor of the victimized which may suggest that SC can contribute to create a supportive social environment for the victimized. This aligns with systemic approaches on bullying with an emphasis on an ecological entity (Cowie & Jennifer, 2008). Thus providing technological anti-bullying supports for bystanders may create a new social context and foster equity and justice at school.

These results point to differential effects of implicit narrative-based and explicit SC instruction. They thus contribute to the discussion of the interplay between socio-emotional and cognitive aspects, particularly with regard to implicit vs. explicit support and socio-cognitive conflict resolution. Both implicit and explicit strategies evoke PT and EC, but only additional explicit SC support increases self-oriented PD and prosocial behavior. A possible mediating effect of SC on PD through soothing needs to be tested. This study shows important first results on how self-compassion induction in addition to standard narrative can promote constructive conflict resolution and a transition to healthy compassionate mindsets among adolescents. Since narrative has been associated with the development of the self, it is worth testing its long-term effects. These effects, however, should be tested in vivo in relation with other factors that can account for one's behavior in bullying contexts, such as sociometric status, needs, and expectancies of social network of a peer group (Salmivalli et al., 1998). Since this study tested a female population to control for gender effects, transfer to a mixed-gender population also needs to be tested.

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Navigating the Conceptual and Critical Demands of Data Literacy in High School Spaces using Firsthand Data

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Abstract: Curriculum efforts to promote data literacy continue to evolve in K-12 spaces to meet the larger need of developing data-informed citizens. The learning objectives of these efforts tend to shift from conceptual data literacy objectives such as demonstration of adequate statistical reasoning to critical data literacy objectives such as empowering students to design, collect and analyze data to serve their needs. However, most studies do not delineate between these objectives, often giving an incomplete picture of student understanding of data, and the effectiveness of the curriculum in meeting these two data literacy objectives. In this paper, we study the outcomes that emerged from a curriculum unit designed to empower students to collect, analyze and present data from their neighborhood. We specifically evaluate the conceptual and critical data objectives of 14 high school students. Our findings indicate that students struggled to demonstrate equal competence in conceptual and critical data literacy goals.

Introduction

Among the many needs to make educational content relevant for application in the knowledge economy, there is a growing effort to develop teaching and learning practices that promote data literacy in K-12 classrooms (Frank et al., 2016; Gebre, 2018; Wilkerson & Polman, 2020). In the current knowledge economy, big data is ubiquitous, with corporations and governments using data from individual's everyday behaviors (e.g., shopping habits, social media interactions, and voting preferences) —a development that is only going to increase in coming years (Borges-Rey, 2016; Deahl, 2014; Pangrazio & Selwyn, 2019). However, individuals continue to be limited in their ability to understand the nature of data and often perceive it as an objective statistical measure, rather than understanding how data is collected, manipulated, and used, often without their permission (Borges-Rey, 2016; Pangrazio & Selwyn, 2019). This effort to develop a data-informed citizenry has ignited heightened interest in educational research to curate curricula that enable students to actively engage, reason, and critique activities and products involving data (Wilkerson & Polman, 2020; Wolff et al., 2016; Lee et al., 2021). This is evident in emerging standards and coordinated curricular efforts to promote "data science for everyone" (Lee et al., 2021; Ridgway, 2016; Wilkerson & Polman, 2020).

However, current curricular efforts often fail to capture the conceptual data objectives (e.g., ability to draw accurate inferences, interpret central tendencies, read graphs) and critical data perspectives (e.g., ability to engage in data production process, critique inherent bias in data) needed to develop data informed citizenry - often simplifying the objectives or measuring one over the other, as opposed to both (Irgens et al., 2020; Philip et al., 2018; Lee et al., 2021). Consider for example, the use of mobile sensors and firsthand data. Most data literacy curricula that use sensors and firsthand data value activities that involve learners posing questions for data analysis, designing experiments and visiting sites for data collection (Hardy et al., 2020; Manz, 2012). These studies measure students' ability to engage meaningfully in data literacy practices such as sampling and measurement, developing a sense of agency and ownership over data, and drawing inferences based on their knowledge of the context, which data literacy objectives that are largely critical in nature (Hardy et al., 2020; Stornaiuolo et al., 2020). Conversely, less emphasis is provided in these studies to evaluate students' ability to statistically or quantitatively reason with data which includes traditional statistical skills such as reading a graph, identifying variability, boundaries of drawing inference (Lee & Wilkerson, 2018; Rubin, 2020; Irgens et al., 2020). Importantly, there exists conflicting evidence on the effectiveness and the value addition of using firsthand data. Studies have shown that student's proximity with data sets interferes with their ability to draw accurate inferences, often discounting the variability they observe during the data collection process (Hug & McNiell, 2008; Konold, 2015; Lee & Wilkerson, 2018). There are very limited studies that have evaluated both conceptual objectives and critical data literacy perspectives in K-12 interventions (Irgens et al., 2020; Philip et al., 2018; Pfannkuch et al, 2018).

To meet the larger goal of developing data-informed citizens, it is imperative that studies on data literacy evaluate both conceptual and critical data objectives (Irgens et al., 2020). If both objectives are not attended to with equal emphasis, there is a risk of developing student knowledge and skills of statistics alone without the ability to critically assess the purposes of data use that can preserve individual agency and well-being. Likewise, without a core understanding of how to access or read data products, being able to make accurate critiques of data applications will be sacrificed (Irgens et al., 2020; Lee et al., 20201; Philip et al., 2018). This study aims to address the above concerns. We first present the design of a curriculum and instruction intervention on the topic of bioinformatics that has one of its central aims as promoting students' conceptual

and critical competencies in data literacy using firsthand data. We then evaluate the conceptual and critical data objectives of 14 high school students who engaged with the curriculum. We analyze students' conceptual and critical understanding of data literacy using Rubin's (2020) data literacy framework and Hardy et al.'s (2020) data production framework asking the following research questions 1) In what ways did students demonstrate an accurate understanding of conceptual objective and critical data perspectives? 2) What constructs of conceptual objectives and critical perspectives did they struggle to demonstrate accurately?

Theoretical framework

Learning scientists have defined data literacy in multiple ways, often with the primary objectives fluctuating between the conceptual and critical focus (Hardy et al., 2020; Kjelvik & Schultheis, 2020; Rubin, 2020). For example, Rubin (2020) conceptualizes data literacy as the ability to work with statistical elements of data that include computing aggregates, accounting for variability, and drawing accurate inferences among others. Notice that the primary objective of data literacy with the conceptual focus here is on quantitative reasoning which is the ability to engage with numerical information found in graphs, equations, and descriptive statistics to critically engage with data collected from real-world phenomena. On the other hand, Hardy et al. (2020) define data literacy as the ability for students to understand data as produced, which is through the interaction between human intent, disciplinary tools such as sensors, and the limitations of the context within which data is collected. Here, a critical focus of data literacy is on student's ability to engage with data production practices, i.e., to be able to make active decisions in the design, collection, analysis and communication of data with the broader intent of turning data into knowledge that benefits the student or their larger community. While there is overlap across both definitions on the ability to read data critically and use authentic data sets, they differ in the granular focus of their primary objectives. These objectives, if taken separately, would reflect different learning goals when translated into classroom settings. (Irgens et al., 2020; Lee et al., 2021; Wolff et al., 2016).

Defining conceptual and critical data objectives

While multiple frameworks that speak to conceptual needs of data literacy exist (Kjelvik & Schultheis, 2020; Rubin, 2020), in this paper, we use Rubin (2020)'s five parameters to study the conceptual understanding of students' data literacy because of the framework's focus on the contextual factors that shape and influence the nature of data. The framework includes five critical objectives on working with data, which can be briefly explained as follows: 1) *context,* the "who, where, what, why and how" of data collection that shows its purpose and surrounding circumstances; 2) *variability,* the nature of data that varies in value over time and space; 3) *aggregate*, summarizing data as a set of values and understanding what it does and doesn't reflect about its distribution; 4) *visualization,* visual displays of data, deciding how the data is displayed and understanding what choices are made in the process; and 5) *inference*, drawing conclusions based only on the data without using outside assumptions. These are the constructs we measure as a parameter of conceptual understanding of data literacy in this study.

There exist three interconnected views of critical data literacy: 1) data literacy as comprehension; 2) data literacy as critique; and 3) data literacy as participation (Irgens et al., 2020). The first two views conceptualize critical understanding of data as the ability to not only comprehend the variability and human bias within the data production process but also critique how data is inherently politically, socially, and racially constructed. In this paper, we focus on the third perspective of critical data literacy which is data literacy as participation. The primary focus here is to actively engage with data production practices, which include making active decisions about the design, collection, analysis, and communication of data with the broader intent of turning data into knowledge that benefits the student or their larger community (Hardy et al., 2020; Irgens et al., 2020). Hardy et al. 's (2020) data production framework provides a lens to study student's engagement as data agents by analyzing three core data perspectives; a) *material:* the ability to understand that data is produced as a result of negotiations between instruments such as sensors and the material world, b) *disciplinary:* an understanding of the disciplinary nature of tools and inquiry practices, and c) *human*: an understanding that data products cannot be delineated from human intentions that drive the production and design of data. In this paper, critical data literacy is measured by analyzing the degree to which students developed these perspectives. Combining these two lenses, which speak to both conceptual and critical data objectives, helps us measure student outcomes that speak to both their statistical reasoning abilities and their ability to critically engage with data production practices.

Methodology

Context

In this section, we provide a brief overview of the NSF-funded project within which this smaller study was housed. The larger project focused on developing a curriculum and instruction for teaching bioinformatics in high school biology classrooms. The curriculum spanned approximately 16 lessons, or about 20 hours of instruction, and guided students in

problem-based learning (PBL) investigation on the topic of air quality and asthma in urban environments. For this smaller study, we focused on the data literacy components of the broader bioinformatics unit. We mapped the data literacy unit activities onto the instructional recommendations of Rubin (2020) and Hardy et al. (2020) to ensure the conceptual and critical data objectives were being met (Table 1). These activities were introduced across three phases intended to build student familiarity with 1) data tools, 2) data collection and analysis, and 3) real-world data production. Students collected air quality measures (carbon monoxide (CO) and particulate matter (PM)) with portable sensors and phones in different neighborhood locations. Students then analyzed the class dataset to compute averages and compared their findings to Environmental Protection Agency (EPA) data that was stored on a project-constructed website. This website allowed students to make visualizations of their own data and view visualizations of air quality data around the U.S. for comparison. Based on their data analyses students presented solutions to address the disparities that they saw in their urban areas as compared to other urban, suburban, or rural areas.

Table 1

Curricular activities that align with recommendations from Rubin (2020) and Hardy (2020)

Curricular Recommendations	Curricular Activities
Variability: Use data sources that are likely to vary both in space and time (R).	- Students collect air quality data from four different locations or from some location at four different times of the day and discuss how the measured data changes over time/location.
Aggregate: Engage in discussions about the intent of computing aggregates in statistics and reflect on what aggregate values communicate and what it doesn't (R).	- Reflect on the rationale of computing mean and median. - Debate if mean or median is a better representative of a sample and why? - Conduct a t-test to compare averages between two locations.
Visualization: Engage in self-expression and revealing patterns (R).	- Visualize data using bar graphs. - Discuss alternate visualizations such as infographics and pie charts.
Inference: Discuss what we have learned applies beyond this particular dataset? (R).	- Teacher engages in-class discussion on how generalizable the data collected from their specific data sample is. - Students report findings, their analysis, and possible recommendations.
Material: Provide students with the opportunity to manipulate data collection and analysis tools (H).	- Follow procedures to operate the mobile sensor for data collection and accumulate data on Google Sheets. - Practice collecting data using mobile sensors in and outside school. - Analyze the data accumulated from the sensors and compute the mean of all readings collected using data analysis tools.
Humanistic: Provide students choices in setting purposes for data production (H).	- Select the problem they want to explore using data on the issue of asthma. - Select a variety of neighborhood areas to investigate the issue of asthma.
Disciplinary: Provide students with the opportunity to design data collection and analysis in a goal-directed manner reflective of most science-inquiry processes (H).	- Set research questions for the data investigation process and present rationale for expert (teacher) approval. - Conduct rehearsals of data collection planning for contingencies. - Revise the data collection plan based on the trials with the sensors. - Students report findings, their analysis, and possible recommendations.

Participants

For this study, we report the findings from one biology teacher, Sam, who had 17 years of teaching experience and taught at a public high school in the northeastern U.S. He was nominated as a desirable teacher by the director of science in the school district to select an ideal population (IES & NSF, 2013) and designated a model teacher. This study reports on data collected from 14 students from his class. There were 11 11th graders and 3 12th graders of which, 10 were female and 4 were male students, who self-reported to be 42.86% Asian or Pacific Islander, 35.71% White, 7.14% for African American, Hispanic, and others respectively. Most of the students did not have prior experience working with data.

Data Sources and analysis

We collected and analyzed data from three sources: 1) students' final project reports, 2) student focus group interviews, and 3) classroom observation notes. *Students' final project reports* included detailed write-ups on the data inquiry process. Students were provided with a project template and a rubric to include their group's research questions, their description of the data collection sites, the inferences they made about the data, and the rationale behind their reasoning. They worked in groups to complete the project. There were five project reports in total. *Student's focus group interviews* included student reflections captured from two student groups. The interviews probed insights into the data collection and design process where students discussed the problems they encountered while using the sensors and Google Sheets. Finally, the *classroom*

observation notes captured detailed descriptions of the classroom interaction and teachers' instructional practices, activities taking place including materials distributed to students, and conversations that occurred during the data collection process.

Students' final projects and interview transcripts were used as the primary data source for our analysis, while observation notes provided additional evidence to triangulate our claims. To address the research questions, we reviewed students' final projects and interview transcripts to identify parts that illustrated an understanding of data. These segments of data were then extracted to a spreadsheet and analyzed for instances that demonstrated critical and conceptual data objectives using an internally developed coding manual. The coding manual included eight categories, five reflective of conceptual and three reflective of critical data literacy. The definitions which were derived from our two theoretical frameworks. After reviewing the segments of data, we adapted the coding manual to better capture students' understanding of data as demonstrated in the curriculum. There were 182 segments of data that emerged from this process. The interrater reliability test from the larger study was conducted by two raters with 38 of the 182 segments (21% of the data) yielding an alpha score of .85 which is an acceptable level of agreement.

From these segments, for this paper, we extracted 41 segments from Sam's students and categorized the segments of data across the eight categories of data literacy using the coding manual. In addition, the segments of data were further examined by first and second authors to determine if they were reflective of an accurate understanding of the category it was coded for. For example, the following segment of data "This place is very important to this project because every day this chemical plant would let out pollution, 386,000 tons of hazardous air pollutants into the atmosphere each year." was coded as evidence of an accurate understanding of 'context' because students' choice of data sites reflected intentionality and alignment with their larger research question. We coded segments of data as inaccurate understanding of the 'context' if it did not include detailed information of data collection site, description of the sites is random information that does not align with the research question. Table 2 shows accurate and inaccurate categorization manuals for critical data literacy.

Table 2
Categorization manual for conceptual and critical data literacy (Category and Definition)

Accurate	Inaccurate
Context: When student descriptions of data collection sites reflect intentionality and alignment with the research question for their projects.	**Context:** Student description of data collection sites are random information that does not align with the research question.
Variability: Student reflections refer to interferences caused by context, sensor etc. to the data collection process.	**Variability:** Student does not report any fluctuations experienced during the data collection process
Aggregate: When making references to central tendencies students compare results to a universal standard in order to draw conclusions. They refer to and explain outliers.	**Aggregate:** Reports only indicate the mean and median values pooled from different data collection sites.
Inferences: When drawing conclusions, students refrain from generalizing their findings beyond the scope of data and refrain from using "always" or "never." The reports mention the variability they observed during the data collection.	**Inferences:** The student reports draw conclusions without accounting for the variability observed during the data collection process.
Material: Students discuss the troubleshooting strategies employed during the data collection process.	**Material:** Students only refer to issues faced during the process of data collection or analysis.
Humanistic: Students refer to the factors that pertain to community or personally relevant factors that motivated them to pursue certain data questions and sites over others.	**Humanistic:** Students make no reference to community or personally relevant factors that motivated the design of the data production process. The description appears generic.
Disciplinary: By referring to the research questions, parameters of data collection site etc. These are often instances laid out during the planning stage.	**Disciplinary:** There is no reference to the steps that went into planning for the data collection or analysis.

Findings

Across the five final projects, the segments of data that were coded for accurate critical data perspective were slightly more than those coded for accurate conceptual data objectives. Out of 41 segments of data coded as accurate, 40.74% were assigned to conceptual objectives while 59.26% reflected critical data objectives (Table 3). The findings are organized to report accurate and inaccurate demonstrations of conceptual and critical data.

Table 3
Summary of data coded as accurate or inaccurate

	Con* # (%)	Var* # (%)	Agg* # (%)	Vis* # (%)	Inf* # (%)	Total # (%)	Mat** # (%)	Dis** # (%)	Hum** # (%)	Total # (%)

Accurate	7 (63.64)	0 (0)	3 (27.27)	1 (9.09)	0 (0)	11 (100)	1 (5.88)	10 (58.82)	6 (35.29)	17 (100)
Inaccurate	0 (0)	3 (23.08)	2 (15.38)	4 (30.77)	4 (30.77)	13 (100)	0 (0)	0 (0)	0 (0)	0 (0)

*Conceptual perspectives: Con = Context, Var = Variability, Agg = Aggregate, Vis = Visualization;
**Critical objectives: Inf = Inference, Mat = Material, Dis = Disciplinary, Hum = Human nature of data

Students' accurate and inaccurate demonstration of conceptual data objectives

Out of the total 11 accurate references made to conceptual objectives, 68.29% references were made to context, and 31.71% were made to aggregate. This is indicative of the fact that students understood the context-dependent nature of data - choosing to be intentional in aligning the selection of the data sites to the research questions they wanted to answer and exhibited confidence in being able to curate, analyze and present data that serve their personal interests and community needs.

Among the five conceptual data literacy concepts, the most frequently and accurately referenced construct was the concept of 'context'. These included rich descriptions of data collection sites communicating the intentional selection of these sites. These descriptions indicated that students understood the context-dependent nature of data, often communicating in the final report important details that shaped their data collection and analysis process. For example, in the excerpt below, students describe the three data sites from where data was collected, providing details of the site that could influence the research question they were investigating which was whether the air quality is better in areas that were less crowded and had more greenery such as the example below,

> Using the sensor and the app on our phone we collected data at five locations around [School]: 1) 17th and [Blue] St.: There were no cars passing by [...], 2) Community College Underpass: There were a few smokers nearby [...] There was also a bus docking and lots of cars passing by, 3) Outside Dunkin Donuts: [...] but there were a lot of cars passing by [...]

In the above excerpt, students signal to context-related information such as the number of people, the number of cars, and the quality of greenery at the sites which were present during the process of data collection. This reveals that students understood the need to capture and provide as much information present across data sites that may be relevant to the nature of inquiry the data collection process was being conducted for.

The second category of conceptual data literacy that appeared more frequently in the student's final data reports was the 'aggregate' code. An 'aggregate' view of data signals a conceptual understanding where students are able to view aggregate values as numbers that summarize trends as opposed to individual data values that are an exact representation of the population (Rubin, 2020). 'aggregate' code was assigned to segments of data where students made references to outliers in their data while reporting the mean scores of the data collected from various sites or when students compared their mean score of Air Quality Index (AQI) to the standards mentioned in the National AQI table while interpreting the data. For example, in the excerpt below, students reference how they interpreted the average calculated across three data sites while referencing the standards of the National AQI table and accounting for an outlier.

> Our PM 2.5 data, in comparison to the AQI, is good, with average levels of 11[...] Our CO data, in comparison to the Air Quality Index, is very poor, at an average of about 18. However, if you leave out one of the data points that is very high in comparison to the others, the CO level average is just 12.84, which falls into the poor section.

In the above excerpt, students not only point to an outlier in the data set but also detail how the omission of the datapoint could change the inference drawn from the data set of the AQI being average to poor. This indicates that students have a nuanced understanding of central tendencies that go beyond just the ability to calculate the mean or median.

The conceptual constructs of 'variability,' 'visualization,' and 'inference' were not referenced accurately in the student's final data reports. Out of 13 inaccurate references, 23.08% was referenced to 'variability,' while 30.77% was referenced to 'visualization' and 'inference' respectively. Errors included the absence of visual representation of data, overgeneralization of inferences beyond the data collected by students, and the omission of variance in the reports. Despite the use of mobile sensors in the curriculum, the segments of data that referred to the 'variability' and 'inference' construct accurately were 0. The low scores indicate that students struggled to critically account for the fluctuations that arose during the data collection process caused by sensors, and the data collection sites in their findings or analysis. For example, when reflecting on the data collection process, a group in their focus group interview referred to how the malfunctioning mobile air sensors posed a problem,

> We were nervous at times that we didn't actually get some data points with the sensors. The Bluetooth connection sometimes would go on and off. So, when we weren't sure, we ended up leaving some sites and collected 7 data points from some sites to make up for the sites we couldn't collect data from.

However, in the same group's final report the students did not mention how the interference caused by the erroneous functioning of sensors or the omission of data points from some sites and the addition of data sources from other sites, influenced the conclusion they drew about the air quality near food trucks. Their final report stated the following finding conclusively, "Our data shows that all of the food distributors have good PM 2.5 levels, but the CO levels are not so good [...] Using the averages of CO and PM 2.5 levels, it is shown that halal trucks have the best air quality." This excerpt indicates that while students experienced material resistance during the process of data collection, they did not account for how these interferences shaped the conclusions they drew about the air quality near food trucks. In their final report, the group did not reference the omission of data sites. This is indicative of the fact that students found it challenging to account for the interferences that may have arisen from the variance in context or sensors. In the final inferences, they made about the data students chose to draw general inferences about the data instead of using a language of uncertainty to communicate the findings or state the limitations of their data collection process. It may also be the case that students may not have had the conceptual understanding of data to understand that the omission of specific data sites cannot be compensated with additional data collected from other sites.

Students accurate and inaccurate demonstration of critical data objectives

Out of the 17 total references made to critical data perspectives, 35.29% was coded as 'human perspective,' 58.82% was given to 'disciplinary,' while only 5.88% was given to 'material perspective.' This is indicative of the fact that students understood the inherently personal nature of data production process and also understood the inquiry driven nature of data production. However, they struggled with troubleshooting the issues that came up during the process of data collection.

Out of the total 17 references made to 'critical perspective, 35.29% was given the 'human perspective' code. This is indicative of students' confidence in being able to curate, analyze and present data that serve their needs. The presence of 'human perspective' indicated that students understood that one can collect, use and analyze data for purposes that may vary from being personally relevant to self or to others. The segments of data coded for 'human perspective' included students' reflections on the personal relevance of the data production process. These reflections varied from broader impacts of community such as clean air, more green space to more personally relevant issues such as quality of air in places that students frequented after school or investigating the correlation between unconventional smoking mediums such as hookah bars and vaping to educate their peers on harmful effects of smoking. For example, a group from Sam's class mentioned their rationale to design their data production process to study the quality of air in a hookah bar as follows.

> But people (peers) think vaping is not as harmful as smoking, and hookah too. They just think smoking is more harmful, but in reality, they are all kind of related to each other. They have the same effect [...] So, we were just thinking of something that would be kind of unique but also have the same idea. So, we came up with hookah […] Going to a hookah lounge is important for our experiment as this place is relevant to our community because it has become a popular hangout spot for our friends.

In this excerpt, students chose to investigate research questions that helped answer a question that was relevant to people in their immediate community. The group chose to investigate a question that would help improve a problem (i.e., increase awareness about the harmful effects of Hookah). As opposed to the narrow belief that data is produced primarily as evidence in evaluating claims, the human perspective promotes the idea that goals and purposes of data production can vary from being conceptual, playful, personally relevant to self or others (Hardy et al., 2020). These segments of data, therefore, demonstrate students' understanding of a human perspective or the variant nature of goals of data produced for humans. We know the more students personalize the goals for producing data, the higher the likelihood that students adopt the mindsets of being able to produce and critically engage with data (Stornaiuolo et al., 2020; Wilkerson & Polman, 2020).

Another code that appeared more frequently in the student reports and interviews were 'disciplinary perspectives' (58.82%). These codes included references that indicated a systematically designed goal-directed inquiry. For example, references made to research questions, the number of trials planned for data collection and use of mobile sensors. The disciplinary codes largely captured the degree to which students systematically planned their data production process prior to stepping out in the field. For instance, in the excerpt below students' detail methods and procedures they engaged in to plan their data collection process.

> How does a chemical plant affect air pollution in the environment surrounding it? Chemical plant Honeywell in Philadelphia, Procedure: First we will test the air in three different locations (School A, B and Chemical Plant Honeywell in [City]). Next, we will record the data (CO, temperature, PM 2.5, and the Humidity) for all locations. The data will be recorded three times for each location for about 30 seconds. Later, we will take all the data and compare the results for all three locations. This experiment will be performed on October 15, 2019.

Here, the group intentionally selected three data collection sites; one site that was closest to a chemical plant and two school sites that were located at a safe distance from chemical plants, to specifically investigate how the chemical plants shape the quality of air in their neighborhood. This is indicative of the fact that students understood the goal-directed nature of the data production process, choosing to be intentional in aligning the selection of the data sites to the question they wanted to answer. They also refer to the number of times and the duration of data collection at each site.

The critical perspective code that appeared the least in the student reports were 'material perspectives.' These included instances from student interviews and reports where students discussed ways in which they troubleshooted the issues they faced during the data collection process. For instance, in the below excerpt,

> Student A: I stayed in the same place and when we were back there, the door was open, but I asked her if she could close it for the experiment, and I did it every five minutes to give it some time. [...] There was no one that was coming in at the time, because I didn't want the air to get out, to affect it. So, I did it when everyone was seated, and people were smoking hookah.

In the above excerpt students refer to the issue of changing conditions at their data collection site and how they troubleshooted this variability by trying to time the collection of air quality data only when the doors were closed. These instances, however, were low. While there were references made to issues of malfunctioning sensors or contextual variance in the student interviews, there were less references made to how these issues were troubleshooted. Also, these variances reported in the student interviews were not referenced during the reporting of the data which explained the low score on accurate 'inferences' discussed earlier in the conceptual data section. The low scores on material perspective indicates that while students were able to note aspects of material setting (e.g., sensors and details of data collecting sites) that would influence the data production process they weren't able to troubleshoot or account for the fluctuations they noted during the data collection process when making inferences about the data.

Discussion

In this study, we examined how conceptual and critical data literacy objectives manifested in a curriculum that used firsthand data to promote both. Our findings indicate that if we want to broaden data literacy from its traditional focus on quantitative reasoning and statistical literacy to include critical reasoning with data production practices, we need to ensure that the rigor of conceptual understanding is also measured. Despite the use of firsthand data students struggled to demonstrate equal competence in conceptual and critical data literacy goals, with most students demonstrating an understanding of critical perspectives of data literacy over conceptual goals.

Our findings on students' conceptual outcomes replicate observations from earlier studies that have shown that student's proximity with data sets interferes with their ability to draw accurate inferences, often discounting the variability they observe during the data collection process (Hug & McNeill, 2008; Knold, 2015; Lee & Wilkerson, 2018). Our findings on critical outcomes also align with previous studies have shown that giving students the agency to decide the nature of data production and investigation is more likely to promote an understanding of data as produced (Hardy, 2020; Stornaiuolo et al., 2020). This variance in student understanding of conceptual and critical elements of data literacy is problematic as the primary goal of critical data literacy is to actively engage with data production practices, i.e., to empower students to make active decisions in the design, collection, analysis, and communication of data with the broader intent of turning data into knowledge that benefits the student or their larger community (Hardy et al., 2020; Irgens et al., 2020). However, in order for students to be empowered as critical agents of data, they need to demonstrate an accurate understanding of the conceptual aspects of data. The lack of competence in conceptual data literacy concepts is more likely to lead to a critical understanding that is not conceptually sound (Jiang & Khan, 2019). The inaccurate understanding of conceptual concepts such as 'variability' and 'inference' is more likely to lead to overgeneralization of data and the drawing of inaccurate inferences (Rubin, 2020), a trend we observed in our findings. Despite the inaccurate conceptualization of 'variability,' in our study, the student groups scored high on critical perspectives aspects of data. This means that students demonstrated the intention to produce data for themselves or for others while being unaware of their misconception of core conceptual data literacy principles. As demonstrated in the result section, while students accurately made note of the variables in the data collection sites during the data collection process, most groups did not make the connection between the variance they noticed during the data collection process and the inferences they drew about the data instead choosing to draw conclusive inferences. Therefore, the efficiency of enactments of critical data literacy is called into question due to the incomplete or inaccurate conceptual understanding of the student groups. Our study adds value to the current debates about teaching data literacy from either a conceptual or critical perspective. We suggest that in order for students to become completely data literate, curriculum and instruction should focus on knowledge and skills that combine both perspectives.

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"With You I'll be Able to Actually Learn Everything": Exploring Learner Experiences With a 'Study With Me' Video

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Abstract: Study With Me (SWM) videos are recordings of individuals silently studying for hours with minimal interaction with the viewers. Despite the lack of any instructional and conversational elements, these unique virtual spaces continue to attract millions of viewers. In this paper, we conducted a Thematic Analysis on the comments generated by viewers for one popular SWM video to understand why viewers engaged with the video and what benefits they may be getting from their engagement. Our analysis revealed four themes: (1) the SWM video provided social support for studying, (2) the SWM video created an idealized structured study experience, (3) the video content creator was seen as a relatable role model and, (4) viewers found the SWM video benefitted short-term and long-term goals. We discuss the theoretical implications on social learning processes and practical implications for designing social aspects of learning environments.

Introduction

Online learning platforms have gained popularity over the years as an important resource for learners. Recently, the Covid-19 pandemic forced learners around the globe to quickly adapt to online spaces as a dominant part of their learning and studying routines. A new phenomenon in online learning is Study With Me (SWM) videos that show a prerecorded video of a person, the *content creator*, studying silently for hours without any direct interaction with an asynchronous audience of *viewers*. Despite the lack of any instructional and conversational elements, these unique videos continue to attract millions of viewers who exhibit a high level of interactivity and engagement through comments posted on these virtual spaces. These public, informal, generally unmoderated, and self-organized online affinity spaces (Gee, 2004) serve a sizeable collection of viewers who seem to receive educational benefits from the experience of observing another person studying. Yet, little work exists to examine how these SWM videos may be supporting viewers during studying activities that are usually done in isolation. To address this gap, we investigated this unique form of social learning by examining an SWM video as a naturally occurring, self-sustaining online affinity space, to expand our current theories of learning and incorporate this understanding into our practice. In this paper, **our goal is to examine the authentic viewer interactions in an online Study With Me video** to understand the learning experience of engaging in these affinity spaces, including why people come to these virtual spaces and what benefits they feel they receive from their visits.

Theoretical background

The need for social interaction during learning may be a strong impetus behind the formation of educational affinity spaces, where people seek out others who share similar interests, activities, or goals. Gee's conceptualization of affinity spaces (2004) provides a useful lens to investigate online asynchronous learning spaces, such as SWM videos, and the interactions taking place around them. Rather than 'communities' to which people 'belong' or of which they are 'members', Gee suggests that we talk of affinity spaces to capture contemporary forms of social affiliation. Affinity spaces are loosely organized social and cultural settings in which participants are connected by some *common endeavor*. Gee's framework allows us to examine the configurations of virtual spaces that characteristically have fluid participation patterns by shifting our attention away from notions of membership in communities towards focusing on people's interactions within these spaces. As such, SWM video sites represent affinity spaces for people studying remotely and asynchronously across the globe.

The role of affinity spaces as a space for interaction where people can engage socially with others in an informal context around a common endeavor is consistent with situated views of learning or learning in authentic contexts. This perspective emphasizes the role of social interactions to deepen learning when participants engage with each other in the learning experience. Social learning theory proposes social interaction, including observing and imitating others, can lead to the acquisition of new understanding and behaviors, because learning is an emergent and co-created social process (Cress & Kimmerle, 2018). The importance of social influences on learning can be seen in modern movements towards collaborative learning spaces where co-creating knowledge happens within the structure of collective problem solving (Miyake & Kirschner, 2014).

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A unique form of social learning exists, where the social interaction occurs passively rather than actively, as in the case of learning in the presence of others. For example, students get together to study in shared spaces, such as libraries, without necessarily sharing any materials or interacting with each other directly. Researchers have shown that some students prefer studying with their friends at libraries because they enjoy their companionship and because simply being in the proximity of others helps their concentration (Bersani et al., 2013). Similarly, research on co-working office spaces such as WeWork, suggests that the passive social presence of others and watching other people working, may lead to increased productivity by improving motivation to work and by providing a sense of energy (Swezey & Vertesi, 2019). In this way, passive social experiences can positively influence learning by supporting motivation or self-regulation, where the structure of a learning space, modeling of good habits, and the implicit and explicit encouragement from others can influence activity (Winne 1995). While some research has been done to establish these passive social influences on learning and behavior, few studies examine why people choose to engage in these behaviors and what benefits they feel they receive.

Online learning platforms are a unique educational medium that provide opportunities for 'anytime/anywhere' learning. Videos as instructional tools have become a prominent approach to online learning, particularly during the Covid-19 pandemic, where videos can be quickly delivered as educational content to millions of viewers on an impressive array of topics. For example, Khan Academy is a leading free online resource that offers instructional videos and materials on hundreds of topics, from math to history, to over 48 million users in over 190 countries (Khan Academy, 2021). These sites can act as a resource for student's self-directed learning, including goal-setting, creating strategies to achieve those goals, and then evaluating those goals (Suciu, 2020).

YouTube represents the most prominent site for hosting educational videos, covering topics from cooking, home improvement and language learning, to geometry, rocketry, and physical education. Commonly these videos include instructors who discuss a topic or demonstrate a skill or technique. YouTube's platform also offers social networking features (Ellison & Boyd, 2007), where its text-commenting facility introduces a resource beyond the content in the videos. YouTube comments provide a space for coherent textual interaction around each video where multiple viewers can engage in asynchronous conversations (Boyd, 2014; Burgess & Green, 2009). These viewer interactions about and around the videos make YouTube an important online space where content is continuously bring transformed through people's ongoing social interactions through reading or posting comments. The use of YouTube as a *social* networking site has implications for how studying with SWM videos may be transformed into a social activity, even though it is at face a passive activity.

Research has shown that the design of environmental and structural features impacts learning and behavior (Taylor, 2009). SWM videos vary widely in their designs including synchronous or asynchronous sessions, the number of people present in the video, length of the videos, background features and whether the video creator speaks out loud or faces the camera. Often SWM content creators make a series of videos over time that are hosted at a YouTube *channel* that presents a curated list of studying videos. The use of these SWM videos as studying tools has exploded over the past few years with many content creators routinely attracting millions of views per video. Thus, SWM videos have emerged as a common learning resource and affinity space for students across the globe that warrants examination within the larger context of learning sciences and educational research.

We have found two early studies of SWM in the literature that have utilized interview data from the viewers and content creators to offer some insight into how people use the videos and the content creator's perspective in making these videos. This early research on SWM studying suggests that viewers are able to personalize ambience at a low cost through their selection of specific SWM videos and get emotional support during their studying (Lee et al., 2021). Additionally, the content creators were motivated to produce content because they sought supervision and connection with others during their studying activities (Wang & Zhang, 2021). However, as research on SWM is limited, we believe an in-depth examination of the content creator's and the viewers' authentic interaction via comments further inform our understanding of SWM as a learning environment and offer insights about theory and practice of learning in affinity spaces and of socially situated learning more generally. These *interactions* within the SWM affinity space, constantly modify and transform the content and space providing a rich source of people's perspectives and social interaction. Through examining these interactions, our goal is to explore *why* users are drawn to studying with these videos, *how* they interact with each other, and *what* outcomes viewers achieve with their studying. Specifically, we ask the Research Question: **Why do viewers view, study, and engage with SWM videos, and what benefits do they believe they get from interacting within this space?**

Method

For this study, we selected a single YouTube SWM video, posted in 2017, from a popular video content creator who has posted dozens of videos on their YouTube channel. This video was chosen as representative of highly regarded SWM, because it has over 7 million views, a significant number of likes (104,667), relatively few dislikes

(2,178) and a large number of comments (4,350) that provide a rich set of viewer responses and interactions within the video space. In this video, the video content creator engages in structured studying, their gaze turned away from the camera, accompanied by a curated music playlist in the background. The video is structured utilizing the pomodoro technique, a time management strategy that breaks down a large task into a series of smaller tasks. This video is 2 hours and 32 minutes long, with timed pomodoro study segments of 25 minutes followed by a 5-minute break. The content creator has a simple study space with minimal décor (See Figure 1). During the video, the content creator can be seen highlighting a book, taking handwritten notes, and reading on her laptop. While the angle of the video switches throughout the video, from the side of her desk to the upper corner of her desk, the content creator never engages in any direct interaction with viewers.

Figure 1
Image from Study With Me video

Our analysis began by downloading all 4,350 comments verbatim from the SWM video post. Next, we removed any indecipherable or irrelevant comments, such as advertising or random symbols. We then conducted a Thematic Analysis (Braun et al., 2016) to analyze the content of the comments. We began with a process of open semantic coding on a subset (20%) of the data and used the semantic codes to generate a series of latent axial codes. The final set of axial codes was defined and reviewed by the three authors and one additional research assistant to resolve conflicts, and then applied to the entire dataset. All four researchers used these codes to iteratively propose and refine emergent themes, and finally reached consensus on four themes that reflect the viewers beliefs and interactions within this SWM affinity space. We present each theme, along with evidence from viewer comments, as quotes, to support those themes below. Quotes are attributed to the comment number from that post, and abbreviations and misspellings left unedited to capture the poster's actual comment accurately.

We reviewed the video and YouTube comments according to the Ethics of Using Social Media Data in Research Framework (Townsend & Wallace, 2017). Based on this framework, we determined that the video and comments were reasonably expected to be observed by strangers, that the participants were typically university students who do not represent a vulnerable population, and that contents of the video and comments did not contain sensitive subject matter. Based on recommendations from Townsend and Wallace, we chose to anonymize the viewer usernames by attributing quotes to the comment number rather than usernames and blur the content creator's face in our illustration of the SWM video.

Results

We found that viewers seemed to build a robust social environment in the SWM affinity space where they often described their feelings, reported their achievements, and engaged in a form of social connection making with the video creator and other viewers through the posting of comments. For example, one viewer explained the many benefits they felt they received from engaging with the SWM video over a period of several years:

> After 4.5 years, I have finally graduated with my bachelors degree. I finished finals a week ago and I wanted to come back by and thank you for making this video. I watched this video countless times and studied "with" you when I didn't think I could possibly get it all done by the deadline. Endless cramming and work on assignments can be lonely stuff, so it was nice to have it feel like someone was there working hard alongside me. Thank you for studying with me all those times ❤️ (#2969).

Detailed comments like this were frequent and demonstrate that the SWM video deeply impacted viewers' studying experiences to the extent that they felt compelled to return to the affinity space and express their appreciation towards the video creator. Our analysis of the video comments resulted in four major themes that help us understand why viewers engaged with this SWM video: (1) the SWM video provided social support for

studying, (2) the SWM video created an idealized structured study experience, (3) the video creator was seen as a relatable role model and, (4) viewers found the SWM video benefitted short-term and long-term goals. We describe each theme below supported by direct quotes from the SWM video comments.

Theme 1: The SWM video provided social support for studying

Our analysis showed that viewers felt the SWM video provided social support to viewers in three main ways, including: (1) the video made viewers feel less lonely, (2) the video site provided a space for social connection making, and (3) the digital presence of the content creator felt like they were actively studying with someone.

First, viewers directly described their experiences with using the SWM video as making them feel less lonely while studying. Viewers often explicitly stated that they were dealing with loneliness while studying such as saying, "This video has been so helpful in keeping me motivated and on track (and not dying of loneliness. I haven't actually spoken to anyone all day)" (#0053). Viewers indicated how watching the video helped them get through emotional or difficult phases in their school life when they felt "extremely alone" and "feeling like I had no friends" (#2299) or through particularly challenging personal times during Covid such as, "I'm watching this as I'm trying to get use to uni life and coping with my mental health… it helped so much especially during quarantine times where no one is around." (#2596). Specifically, viewers wrote they experienced feelings of togetherness during their viewing experience, saying "even though we are studying separately we are all in this together" (#1372) and "love the we're in this together vibe." (#0198).

Second, these feelings of togetherness appeared to be directly supported by the way viewers used the SWM space for social interactions with other viewers. These interactions were often similar to what you might observe in an in-person physical study session or study group, and sometimes included responses to comments from the content creator or led to detailed exchanges between viewers. Viewers asked questions, such as, "Would you mind if i ask you to tell me the name of the song at the very beginning (~04:11)?" (#0218), made suggestions, such as, "would you mind putting in a tiny bell or something at the end of each session?" (#0333), or added compliments, like the "music is superb" (#0276). Some viewers even added humor, for example, "Who's working to exams and drinking coffee like water like i do?" (#0117) that would draw responses, like "This is barely the first week of the term and i am already doing this hahaha" (#0117-3). Many times, viewers stated they spent time reading other people's comments, "Spending my 3-5 minutes reading YouTube comments LOL" (#0643), indicating that the comment section played a social role for viewers. These types of comments demonstrate a way that viewers were reminded they were not the only ones using the video to study making them feel less isolated. These social comments may have provided viewers a break from focusing on their activity and played a role like the conversational snippets people experience in an in-person study session. Additionally, viewers connected through reflections of their own cultures and their opinions and beliefs about school systems and studying patterns. For instance, one viewer responded to a comment that elaborated on studying habits in a viewer's home country, South Korea, by saying, "I am from Nigeria and I can say it's almost similar. You're to study without failing. I'm in uni now and it's by far the hardest task to survive especially when you have lecturers who are not willing to be merciful and make it harder for you" (#0058-19). Overall, viewers engaged socially through comments and this likely helped foster a sense of community and togetherness in the SWM affinity space.

Third, viewer comments suggested that they felt like they were actively studying with the content creator and with other viewers who were watching the video. For example, one viewer commented about studying with other viewers when they said, "It's really nice to be streaming and knowing others are watching or to watch others working. It's like having a friend study with you :)" (#0210). Similarly, a viewer elaborated that they had difficulty studying alone but because of the SWM video they had access to social support remotely, and finished by saying, "studying 'with' someone helps so much" (#1362). Furthermore, viewers brought up the issue of struggling with concentration and described how the digital presence of the video creator provided a support mechanism in terms of monitoring behaviors. For example, one viewer explained that their ADHD condition made it difficult to concentrate but they were able to receive support through the SWM space as they "need some one to monitor me or some to work with" (#1239-1).

Viewers referred to the content creator as their "study buddy" (#008) and described how the content creator helps avoid distraction and instilling beliefs that they could accomplish their tasks. For example, one viewer said, "studied "with" you when I didn't think I could possibly get it all done by the deadline" (#2969), and another said, "When I study, i would usually get distracted very easily. But when i study with you i am able to finish revising so many things in a day" (#2336). Additionally, viewers felt the content creator's digital presence provided social and mental support to help with loneliness. Viewers said, the content creator helped them "get through the toughest and hardest times … you made me feel that someone is here and struggling too"(#2545) and made them "feel like I am not alone and like someone else is making sure that I am studying" (#0400). Thus, the asynchronous nature of the SWM space seems to allow a unique type of controlled and passive social interaction

where viewers can feel socially connected to others and experience a sense of actively studying with someone without distraction.

Theme 2: The SWM environment created an idealized structured study experience

In addition to the social supports, viewers found the SWM video was helpful in generating an ideal mood for studying in two ways, by creating (1) a structured studying experience using the pomodoro technique, and (2) an idealized setting through different environmental features.

The Pomodoro technique utilized by the content creator was lauded as providing necessary structure to the studying process leading to increased levels of productivity. The viewers found that the structure helped them to "work much more efficiently" (#1291) and that the technique is a "great choice for me, because I'm this type of person, who needs to have many little breakes" (#0596). Viewers commented that the length of the pomodoro sessions helped them to remain focused, such as, "First time in my life - studied for 2.5 hrs" (#0382), create a routine where they could "study regularly"(#0399), and effectively incorporate breaks into their study sessions, such as, "The day before tests I'm always in let me get all I can get info mode, so I always forget to take breaks, but this reminds me to take breaks so I absorb the information and not feel overwhelmed" (#0435).

Viewers frequently credited environmental elements, such as the music, movements the content creator makes during studying, the soft lighting in the video and the content creator's cat, as creating the ideal setting for studying, but these were not all universally liked. Often viewers would refer generally to the calming nature of the environmental features, such as one viewer who said, "having a low work ethic and anxiety means that it's always been quite difficult for me to focus. These helped so so much to calm my nerves and keep me on track" (#0708). For others, they specifically mention features, including the music that was often credited as setting the right mood for viewers who commented that the music "is so calm yet give you the push" (#1384), "switches my mind and mood to study" (#0836), and "makes homework enjoyable" (#1154). One viewer said, "I really felt alone when studying by myself but hearing the music and knowing you were studying too gave me motivation," (#1340) indicating that the music enhanced the motivating feeling of working with someone. Music was such a significant element in the video that comments commonly referred to the precise point in the video that helped them study, such as comments that said, "suddenly at 58:18, it was like my books hypnotized me to study more" (#0671), and "at 35:45 the music really helped my studying" (#0606).

Viewers credited small movements of the content creator as supporting a studying atmosphere. For example, "the paper turning or the book flipping that just put you in the studying mode" (#0045). For some, the content creators' pet cat added to the setting, being referred to as "a great supervisor" (#1004) and described as giving "me so much motivation!" (#0906). The lighting in the video was described as creating the right mood as one viewer pointed out, "think the environment and the lighting she study in makes these videos perfect" (#1836). Moreover, these environmental elements induced feelings of calmness in viewers who said the video was "the most peaceful and calm study session" (#2601), helped to "wash away the anxiety" (#0285) and "calm my nervous distraction attacks" (#0361). These comments suggest that rather than the novelty of the video scene, it was the sense of calm and focus supported by the environmental elements in the video that led viewers to repeatedly return to this video during studying, as viewers indicated they "watched this video countless times" (#2969).

Finally, while most viewers felt that the video environment played a positive role by enhancing their studying experience, some described the same features as having a negative effect on them. For instance, viewers pointed out that the music choice was "a little too intensive for studying" (#0274) and the "music and the rhythm is distracting me from concentrating" (#0386). Similarly, some viewers felt the presence of the cat in the video was a source of distraction for them, and they "literally cant stop looking at the cat and not studying" (#0023-1).

Theme 3: The content creator was seen as a relatable role model in the affinity space

We found that video comments frequently referred to the content creator as a relatable role model in two ways, including: (1) she was inspiring and motivational because she embodied the characteristics of the ideal study partner, and (2) she was viewed as a study expert to that could offer studying advice.

First, viewers described in detail how the content creator's studying habits inspired and motivated them. For example, one viewer said, "you seem so focused, that is good and inspiring some how" (#0059) and "seeing you study for that long motivates me to study extra" (#0246). They often described the content creator as someone who embodied the characteristics of the ideal study partner. For example, one viewer said, "sometimes it's great to have someone as motivated as you to keep you going and help you stay disciplined" (#0216). Viewers frequently pointed out the content creators' specific positive study behaviors such as her ability "to study like this without even touching your phone or spacing out while in pomodoro" (#1173), to have "no distraction, no texting, no messages" (#1334), and displaying exemplary behaviors such as, "reading and typing on the laptop at the same time" (#0783) and "if you can keep going so can I!"(#0613). Viewers who identified themselves as students in

medical disciplines in the comments found the content creator particularly relatable. For example, one viewer said, “The process of becoming a doctor is the hardest thing I've ever done and I just keep wanting to give up. You are about 3 years ahead of me but watching you go through the process (and your struggles along the way) make me feel less alone now that I see where you are” (#1183).

Second, viewers saw the content creator as a study expert and sought advice from her on general study questions. For example, viewers asked for “some study tips and tricks that will help during exam time"(#0081) and “any tips with textbook use?” (#0110). They also sought elaboration on particular techniques such as “a specific method for retaining information” (#0083) or dealing with issues while studying such as “I don't how to deal with my studying if i got problem in life, in that case, I have no idea to concentrate on my study. Hope to get advice” (#0196). These comments suggest that the content creator took on a role that is more significant than a silent study partner. The posted comments showed evidence that viewers perceived the content creators’ discipline and good study habits as something to be modelled. For instance, one viewer said “I wish I have the same discipline that you have” (#1936) and another shared, “I have huge problems with discipline and concentration…whenever I start to look around and procrastinate I see you and I'm like "Uhh, I really should be studying" and “get back to it” (#1429). These comments help us recognize that the content creator was seen as a role model who motivated the emulation of similar behaviors in the viewers.

Theme 4: Viewers found the SWM video benefitted short-term and long-term goals

Our final theme demonstrates how the SWM video was used by viewers as a tool to: (1) provide focus and motivation while studying in the short-term, and (2) help them accomplish measurable short and long-term achievements.

Our analysis suggests that the SWM video helped viewers self-regulate as the content creator’s presence, albeit in an asynchronous video, played a role in engaging with the video. They explained that seeing the video creator studying hard and concentrating had a positive effect on the amount of time they studied. For example, one viewer said, “For 21 years i could not study. Now for 2 days i'm studying with you and time flies!”(#0168). Others felt the video broke their “procrastination cycle ”(#1053) to improve their productivity, such as comment #2601 that stated, “Math would normally take me about 3.5- 4 hours to solve 95 questions but today I finished 95 questions in 1 hour!!!”. Moreover, viewers expressed that the SWM video made them feel accountable such as, “it's nice to study "with" someone so i feel like i'm being held accountable when i get off track” (#0292). In these ways, viewers express short-term benefits of improving concentration, productivity, and accountability.

Viewers also attributed visits to the SWM video as helping them in accomplishing specific measurable achievements in the short and long term. Describing the benefits for short-term achievements typically including exams and course work, including “finishing my general chem 1 lab report” (#0302) and “passed my Organic chemistry exam” (#0596). These comments illustrate that viewers turned to the SWM video as a support for their learning in particularly stressful times for high stakes exams and assignments. Additionally, viewers credited the SWM video in helping them achieve more long-term objectives such as completing classes, medical school, or graduating from college. For example, one viewer had used the SWM video to “get through about two months of my EMT class and still going!” (#0655). Another viewer shared they had graduated from business school and “if it wasnt for ur videos at 5am, or midnight or 4 pm, I wouldn’t have been able to study for those exams.” (#0896). Similarly, another viewer said, “I just finished my bachelor degree. I would like to come back to your channel and thank you. Your videos contribute a lot to my success” (#0913). Here, these comments demonstrate how users felt the repeated and prolonged use of the SWM videos benefitted their long-term goals.

Discussion

In this paper, we set out to explore how and why viewers use SWM videos, an online asynchronous version of studying in the presence of others. We examined one YouTube SWM video to see how this virtual affinity space provides social support and opportunities for social interaction during studying activities usually done in isolation.

Our findings suggest that viewers are drawn to the SWM video to achieve short-term and long-term goals, because their studying experiences are transformed by indirect and passive social interactions, the structured studying and idealized video environment, and the positive influence of the content creator as a studying role model. Viewers found the presence of the content creator motivated them to engage in efficient, focused, and prolonged studying behavior, and described the comment space as a way of feeling connected to the content creator and other viewers who were potentially engaged in the same studying experience. We believe these findings provide important insights into the learning experiences of people as they engage in an online, asynchronous studying environment including: (1) the impact of indirect and controlled social interaction on learning, motivation and studying behavior, and (2) the importance and affordances of environmental and

structural features in these learning environments. Here we discuss how our results support and expand on prior work and explore the practical implications of these findings.

First, our findings suggest that social engagement was critical to many of the viewers of the SWM videos, and that people participated in these asynchronous online spaces to find a social space to study. This indirect social interaction took two forms, one as a feeling of collective activity with other viewers, and the other as a passive studying experience with the content creator. Viewers made connections to others across the globe by posting about specific goals and outcomes and sharing their study habits, such as their difficulty in studying for long stretches of time or being easily distracted when studying by themselves. As in prior work, these goal-stating comments and sharing of practices, as self-reflections, can help viewers practice metacognitive skills that are beneficial to self-regulation during their learning experience (Winne, 1995). The results also indicate that the SWM affinity space filled an important gap in viewer's studying experiences by allowing them to access this social space at any time of the day or night, where feeling connected to others despite odd hours helped people stay motivated and focused. This on-demand social experience helped solidify the communal feeling of working with others, as seen in library study groups (Bersani et al., 2013) and towards a common endeavor, as is common in affinity spaces (Gee, 2004), but further provides flexible access to the space and social activity.

We believe that the viewers' perception of the content creator as a role model is unique in that viewers seemed to find the content creator's simple act of studying as inspirational. Viewers often commented on her exemplary studying skills, where the content creator displayed complete focus and attention by keeping her gaze on the computer screen and textbook throughout the video session. Observing the modeling of such positive behaviors by the content creator seemed to have a significant motivational effect on the viewers who wanted to emulate her. This response to the content creator's modeling may represent an important social influence on the viewers behavior. Comments that indicated the feeling of studying with someone and the benefits of seeing the content creator actively working, such as "if you can keep going so can I!" (#0613) demonstrate a type of companionship and camaraderie in the experience similar to research on in-person co-studying (Bersani et al., 2013). We were struck by how much viewers found that this modeling effect works even through a pre-recorded video, and that one well modeled studying session could benefit millions of others. These findings show the importance of co-studying and that it can be accomplished remotely and asynchronously. We believe these findings demonstrate the strength of student needs for social connections, even in passive forms, as motivation and positive social influences during learning activities.

Our second main finding shows that viewers frequently attended to environmental features, beyond the content creator's presence, in the SWM video. These environmental features included the structure of the pomodoro technique, the presence of the content creator's cat, the curated music playlist, the dim lighting, and the video creator's movements (such as highlighting text and concentrating on the computer screen) as creating an ideal ambiance for their studying experience. The elements of the video seemed to be instrumental in drawing people into this space and bringing them back repeatedly because the experience of studying with the content creator evoked feelings of calmness, motivation, and focus, as one viewer said the video "helped so so much to calm my nerves and keep me on track" (#0708). Empirical evidence in research has illustrated the importance of environmental and structural features for the design of learning environments (Taylor, 2009), and our findings help illustrate how this effect holds for asynchronous online learning environments as well. This study has practical implications for improving students learning and studying experiences and suggest that learners may benefit from the design of informal and formal learning environments that include designing for specific environmental features to evoke positive affective responses. Our findings suggest that details, such as lighting, can be influential, and should be carefully considered when creating online learning materials, such as video tutorials, but also for in-person learning spaces, particularly when students are asked to work independently.

These two findings help build on existing theory on social learning in affinity spaces by examining a uniquely passive social learning experience, the SWM video, to understand the naturally occurring, self-sustaining interactions within this space. We used Gee's framework to conceptualize affinity driven interaction in the SWM video to inform our understanding of why these spaces exist and continue to grow. Further investigations into the social interactions of viewers outside of one SWM affinity space, such as in other SWM sites, can help us understand how these affinity spaces connect, and how the movement of viewers across these spaces allows additional opportunities for connection making that support viewers studying and learning experiences. These SWM videos also inform our understanding of social learning, more generally, in demonstrating the strength of passive social influences on studying and learning, where we expand our understanding of shared learning activities (Cress & Kimmerle, 2018) to include asynchronous interaction and passive influences. The practical implications of the study point towards changing our current practices of asking and expecting students to study alone. This study shows that people have a strong social need to feel connected to others and that co-located studying, even when it's in the form of a digital presence, is beneficial to people's learning experiences.

Conclusion

In this study, we demonstrate that asynchronous online affinity spaces such as SWM videos may have emerged to meet the need for learners to experience social connections and positive environmental influences while they engage in otherwise isolated studying activities. We believe this further strengthens arguments for social engagement during all forms of learning, in and out of formal classrooms. We recognize this study is limited in examining one SWM video, and by analyzing only viewer comments as evidence of the activity in the affinity space. We plan future studies to broaden this examination to include multiple videos from multiple content creators, and to look at how individual viewers may interact with different content creators and different videos over time. Future studies may also include interviews or survey-based research of content creators and viewers to include their retrospective perspectives or may include experience sampling or think-aloud studies to examine the actual process of studying with SWM. We also recognize that our study is limited in only examining asynchronous SWM, and suggest additional work to explore how newer platforms, such as Twitch, support synchronous forms of SWM. In summary, the rapid prominence of SWM videos as studying tools demonstrates how valuable social companionship is during learning, and this should impact the way we design all forms of learning. We hope to build on these insights to improve learning experiences for all students.

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Attenuation and Amplification of Agency through Goal Announcements in a Makerspace

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Abstract: Agency in makerspaces is frequently in flux, amplified or attenuated through interactions between the maker and individuals around them. Looking at goal announcements in a makerspace designed to provide no predetermined goals, we see that these moments tend to follow triadic dialog patterns and that makers orient to the potential evaluation through hedging and multimodal demonstration. We argue that maker educators need to carefully attend to how interaction shapes maker agency without assuming that open-endedness alone will suffice.

Introduction

Educators who embrace the 21st century "maker movement" often emphasize the pedagogical values of promoting maker agency, designing to support persistence across moments of failure, and addressing the perceived divide between producers and consumers (Doughtery, 2013; Bevan, 2017). However, recent ethnographic studies of makerspaces have shown that they fall short of these larger promises. Maker activities often take the form of prescriptive assembly kits (Blikstein & Worsley, 2016) and place undue value on high-tech versus cultural making practices (Vossoughi, Hooper, & Escudé, 2016). Moreover, youth deeply engaged in making are frequently required to push against dominant narratives of neoliberal entrepreneurship (Greenberg et. al., 2020) and individualism (Vossoughi et. al., 2021). In particular, these works highlight how educative maker programs can reproduce societal inequities (Ryoo & Kekelis, 2018; Elliot, 2021) unless those inequities are intentionally addressed (Buchholz et al., 2014; Calabrese Barton & Tan, 2019; Lee et al., 2021). Taking inspiration from recent efforts that attend to the microgenetic processes of learning in makerspaces, we focus on how maker ideals are realized or subverted on a moment-to-moment basis.

Focusing on the value of maker agency, this study identifies patterns of intrafamily interaction concerning a critical moment for amplifying and attenuating agency: the public announcement of a goal. Goal announcements - including statements of goals such as "I'm making a house" and statements of lacking goals such as "I don't know what I'm making" - are critical because they mark a point in time in which the maker's intention (which is often studied as a private psychological and cognitive experience) become available to others in the makerspace through verbal and embodied pronouncements. Once a goal has been announced, it becomes a public substrate (Goodwin, 2017) that others can assess, question, or ignore (Pomerantz, 1984). In this way, the statement of the goal has social consequences and represents one kind of moment where a maker's agency is at stake. To this end, we draw on key tenets of discursive psychology to investigate interaction patterns structuring goal announcements in a museum-based maker setting with minimal activity prompts. Building on Shah & Lewis' (2019) examination of the moment-by-moment *amplification* and *attenuation* of power in pair programming contexts, this analysis examines conversational dynamics of amplification and attenuation with respect to maker agency. More specifically, the study focuses on goal announcements in a makerspace to understand how maker agency is attenuated or amplified during intrafamily interactions.

Based on the existing literature concerning maker agency, goals in education, and power in conversation (Philip & Gupta, 2020), we focus on when goal announcements arise, who initiates the goal announcement, the conversational content, and resistance to announcing. To this end, we center the following research question: As a site of potential maker agency, how do public announcements of maker goals unfold in interaction?

Literature review

This work is grounded in three theoretical spaces: student agency, goal announcement, and power as embedded in moment-to-moment interaction. Agency is often conceptualized as the socioculturally mediated capacity to make independent choices and actions (Schlosser, 2019). In this operationalization, the sociocultural emphasis refers to societal and cultural structures – ever-present in individual lives – that shape where individuals are able to exert agency. People in social interaction mediate these sociocultural structures by endorsing, resisting, and revising them at the moment-to-moment scale of conversation (Philip & Gupta, 2020; Shah & Lewis, 2019). From this perspective, we see individual agency as a fluid achievement of the microgenetic structure of a social context. In conversational moments, agency is amplified or attenuated: increased or decreased in a given situation from an ever-present baseline that assumes tensions around agency. In makerspaces, the decision of what to make – the

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maker's goal – is a key opportunity for the enactment of agency, and thus conversations around maker goal announcements provide a window through which to examine these social dynamics. Goals can occupy the space of private psychological experience, or they can be shared outwardly within the course of a making activity, creating a shared focal point in collaborative work or simply a point of departure for understanding the independent actions of others (Strivers & Sidnell, 2016). Because the public presentation of an otherwise private goal might fundamentally change what the interlocutors discuss, what they critique, etc., we would anticipate a degree of tension between withholding and providing public goal announcements. This tension brings maker agency to the foreground of these social encounters.

To even further sharpen our focus on maker agency during goal announcements, we layer into our analysis considerations of interactional power. In particular, we examine power in terms of known structural patterns of conversation. Human conversation is structured around interlocutors taking turns speaking; overlapping speech is rare (Sacks, Schegloff, & Jefferson, 1974). Turns are sequentially organized with immediate next-turns responding to immediately prior turns, known as conditional relevancy. How interlocutors accept or resist the conversational themes set by their interlocutor in the immediately preceding turn throws light on microgenetic exertions of power (Heritage, 2003). For the purposes of our study, we additionally focus on triadic dialog and hedging as lenses through which power plays out. In triadic dialog, such as initiate-respond-feedback sequences frequently documented in classroom settings (Cazden, 2001), the individual who initiates a conversation or topic change holds greater power than the second speaker based on both setting the conversational agenda and later reacting to the second speaker's contribution (Esmonde & Langer-Osuna, 2013; Hutchby, 1996). In turn, the second speaker might resist the conversational agenda of triadic dialog in the contours of their response (Stivers & Hayashi, 2010), including through hedging. Verbal hedges are defined as "downtoning expressions or expressions of tentativeness or possibility" (Johansen, 2020, p 1), functioning as a mitigation strategy to withhold the speaker's full commitment to what they are saying (Hyland, 1996). Hedging allows for full acceptance in the first speaker's conversational agenda but resistance to potential critiques of their contribution.

Makerspace context

The video data used in our analysis were collected in an open-ended makerspace designed and hosted at a large midwestern science museum between October and December 2016. Overall, the designers envisioned a makerspace focused on cardboard boxes as the primary material resource. The designers selected cardboard for its perceived familiarity for families, ability to be manipulated with low tech tools such as scissors, and possibility for post-visit family learning, specifically that families would continue making at home with their own cardboard supplies. Just inside the entrance doors, a single sign provided general rules: "Rules of play: Please do: Build, construct, stack, and mine with the boxes. Please don't: Climb, Throw, Stand On, or Kick the boxes." To the left of this sign, a large pile of employee-donated cardboard materials - including a variety of sizes, thicknesses, and colors - provided source material for visitor making. The only example cardboard creations in the space were pieces left behind by previous visitors. In October 2016, a museum employee wrote "Be Creative" in masking tape on the black wall of the makerspace; from then on, the space included visitor-generated tape graffiti as a prominent visual feature. In terms of design ethos, the designers strived for unlimited material resources (cardboard and tape), easy to use tools (scissors and safety boxcutters), and no predetermined directions in order to foster the maker's agency and imagination.

Method

The above-described data set was originally collected to investigate youth (aged 9 to 15 years old) experiences of failure in makerspaces. We selected this dataset for secondary analysis because the maker educators who designed the space placed high value on maker agency. Additionally, the video data collection procedures involved minimal intervention in participant's authentic maker interaction within a family group. Eight family groups participated in video data collection, resulting in 4.5 total hours of video. Family groups were recruited as they entered the makerspace upon their own accord, meaning the participants all self-selected to engage with this particular museum experience. Only families with at least one child between 9 and 15 years old were invited to participate in the video data collection. Unfortunately, no demographic data was collected beyond the inclusion question during this stage of the original project's data collection.

Data collection

Video was collected with chest-mounted GoPro cameras, allowing groups to move through the makerspace without needing to manage the camera. All video camera placements foreground and background particular features of the environment (Hall, 2000); chest-mounted GoPros capture the wearer's hands and forward facing context along with the audio record of near interlocutors, approximating that individual's experience of the

unfolding moment (Burris, 2017). Based on the interests of the original study, the 9 to 15 year old child wore one chest-mounted camera, and in five cases, an additional family member wore a second chest-mounted camera. Participating families were asked to spend as much or as little time as they wanted in the space and to return to the researcher when ready to leave in order to complete a short interview. For our analysis, we only include the first question of the interview - "What did you make today?" - because it directly related to goal announcements.

Analytic methods

This study uses interaction analysis and draws on the tenets of discursive psychology. Interaction analysis (IA; Jordan & Henderson, 1995) is concerned with microgenetic processes and focused on routine patterns of human action - including verbal, multimodal, and tool-based actions. IA is concerned with the situated nature of knowledge and action, highlighting how people use aspects of the social and material world around them to sequentially and simultaneously understand one another and engage with an activity (Hall & Stevens, 2015). Analytic attention is directed to social and material resources that hold relevance for interlocutors: participants engaged in interaction/conversation. Where interlocutors place their attention is where researchers place theirs. We focus our IA on the identification of patterns in goal announcements across the data set, highlighting the temporal, material, and social aspects of these patterns. Discursive psychology (DP; Wiggins, 2017) is an approach that examines how people reference psychological phenomena in conversation and what social purpose those conversational moves accomplish. For example, a student may respond to a teacher's question with "I don't remember the answer"; a DP analysis would identify what social action the claim of not recalling performs - such as inviting teacher support - setting aside questions about the statement's accuracy (e.g., whether the student actually remembers). We engage with DP to understand the organization of goal announcements, attending to how the interactions shape who has agency over which decisions in the makerspace context.

Initial exploratory analysis

While content logging the data (at 2 min intervals), we noticed a pattern where some youth makers proclaimed, "I don't know what I'm making," while simultaneously engaging in physical making actions such as cutting, taping, or folding. Exploring the content logs further, we noticed that makers seemed to make this statement after being asked by another person about what their creation was, drawing our attention to goal announcements.

We identified clips from the content logs related to goal announcements to conduct an initial exploratory interaction analysis. We selected for diversity in this initial set of clips, specifically choosing examples of goal announcements from different families, points in the making process, ages of interlocutors, and announcement type (e.g., naming a goal or saying "I don't know"). In an effort to capture all relevant context, we segmented clips to include significant time before and after the goal announcement. We then transcribed each clip using Mondada's (2018) transcription system that blends Conversation Analysis conventions with precise multimodal representations. Multimodal transcription also allows us to document how individuals engage with physical objects, particularly important for understanding interaction in making contexts (Fasulo & Monzoni, 2009).

We iteratively analyzed this set of goal announcement clips through multiple viewings, individually and in group data sessions with other researchers (Jordan & Henderson, 1995). Our viewings focused on the turn by turn unfolding of goal announcements, meaning we explored how these moments were initiated and closed, how they differed from one another, and how they were connected longitudinally within a family's making session. Early in this exploratory IA phase, we began articulating interaction conjectures to describe patterns in unfolding goal announcements that were common across clips (Hoey & Kendrick, 2017). To sharpen these interaction conjectures, additional disconfirming cases were identified, segmented, and transcribed.

Data selection: Freezing the analytic frame

After examining 10 total clips during the initial exploratory IA phase, we wanted to investigate how common these moments were across the data set. We froze the two interaction conjectures developed in the exploratory IA phase and developed inclusion criteria, specifically that clips needed to include a) at least two interlocutors in order to be considered an announcement, b) (at least) one interlocutor claiming that the object being discussed was their creation, c) the object and the maker's hands (typically) visible in the video frame, and d) interlocutors focusing on object identification (e.g., naming it). To develop a complete clip corpus, we re-watched every video collected, tagging all moments which met the inclusion criteria. These moments were segmented from the larger video; each clip was bound by a change in the conversational topic or a substantial break in conversation. This process resulted in 88 clips (mean per family group = 11; SD = 5). We then coded features related to our interaction conjectures, including who initiates the discussion about the maker's goal, whether the goal is announced or withheld, use of a hedging word (Johansen, 2020), and physical engagement with the creation. We recognize that coding interaction data requires deep understanding of the phenomena and clear definitions (DeLiema et. al.,

2021; Hammer & Berland, 2014); we are currently engaged in such a concerted effort. For now, we present this coding of the total video corpus to demonstrate the ubiquity of goal announcement interactions in this makerspace.

Results

Our analysis uncovered two consistent interaction conjectures present across goal announcements:

1. Goal announcements in this makerspace follow an overall initiate-respond-feedback (IRF) sequence.
2. Makers orient to the interaction as evaluative, evidenced by hedging and multimodal demonstration in goal announcements.

For the sake of space, we detail two illustrative cases from a single family and then summarize basic spoken elements of goal announcements from the total video corpus.

"Cute dog thing": Announced goals and lack of goals

We begin with an example of two youth makers – Emma and Lily – from the same family. The sole adult in their group – Sara – asks each maker to publicly announce their making goals. This interaction occurred less than a minute into the family's time in the makerspace, just after both youth makers had gathered materials and tools but prior to active construction moves such as cutting, taping, stacking, etc. Transcription conventions include bold font for verbal actions, non-bold font for physical actions, degree signs to note the beginning and end of Emma's physical actions, and asterisks to note the beginning and end of Lily's physical actions.

Lack of goal announced

Our analysis begins at the point that Emma walks over and drops their cardboard materials on the ground near Sara, who is sitting in a chair. Emma begins manipulating the roll of tape as Sara initiates the interaction:

Figure 1

Transcript of Emma's Goal Announcement

1	**Sara:** Emma:	**Do you have something in mind° that you are going to make?°** °Pull tape ----------->°
2	**Emma:**	**(1.6)** **I don know**
3	Emma:	°**(2.8)** ° °Kneels on ground°
4	**Sara:**	**Well why don't you come up with somethin**
5		**(6.0)**

Sara *initiates* the interaction with a question. The structure of a question – such as standard Wh-questions, polar questions, "or" elliptical alternative questions, and declarative questions (Hobbs, 2012) – constrains response possibilities, though resistance to the interactional agenda is always a possibility. The question structure in this case requests a statement from the recipient about the presence (polar yes/no, "do you") of an internal ("something in mind") goal for subsequent and presumed planned actions ("are going to make"). By asking this question, Sara generates a discursive climate in which Emma is asked to provide a polar response to the possibility that they have an intention in their mind that will drive what they make.

Instead of adhering to the yes/no response format, Emma responds with the statement "I don know." In the space of public discourse, this response is relatively ambiguous. Emma could be saying that she lacks a goal or Emma could be saying that she does not know the answer to Sara's questions. With this analysis, we are not attempting to make a claim about whether Emma did or did not have a goal at this point in the activity. The social implications of outwardly stating a lack of goal are the focus of our analysis. Looking at the structure of their *response*, Emma delays their response significantly beyond the 1 second conversational threshold typical of responses (Jefferson, 1989). When they do speak, Emma moves beyond the "required" response of a polar question, indicating they interpreted the question as a request for an actual goal, not just its presence (Stivers & Hayashi, 2010). "I don't know" as a question response can serve many functions beyond a truthful announcement of lacking information, including avoiding the conversational agenda, avoiding assessment, avoiding explicit disagreement, or hedging (Tsui, 1991). We cannot glean Emma's individual agenda with their "I don't know," but we can point to its situated social action of avoiding further pursuit of Sara's question about the goal.

After another substantial 2.8 second pause between conversational turns, Sara gives Emma *feedback* related to the lack of goal, specifically that Emma should establish a goal (line 4). "Well" at the front of turn indicates contrast or rejection of the previous speaker's stance (Schegloff & Lerner, 2009). While the grammatical structure of Sara's feedback is a question, her prosody reflects a statement tone, and neither Sara nor Emma treat the utterance as a question in need of response (line 5). Sara's feedback acts as a directive to Emma, positioning their lack of a goal as something to be repaired.

Goal announced

Just 6 seconds later, Lily, who had been traversing the makerspace to retrieve materials, enters the scene. Lily had been out of earshot during the previous interaction about Emma's goal. The following interaction plays out here:

Figure 2

Transcript of Lily's Goal Announcement

6	**Sara:** Lily: **Sara:** Emma:	***Lily, do you have something in mind *** *sits down, grabs scissors---------->* **that you are going to °make?** °Grabbing tape, Looks at tape->
7	**Lily:** Emma:	**I want to make it have cute eyes ° °and eye lashes** -------------------------------->° °Looks at Lily->
8	**Sara:** Emma: **Sara:** Lily:	**A°°:Oh so you're making a human°°out of it?** ->°°Looks at Sara-------------->°°Looks at Lily----->**or a like a* cardboard person?** *grabs box, flips over--->
9	**Lily:** Lily: **Lily:** Lily:	**No a cardboard (.) cute* (.) dog thing.** ---------------------->****(1.0) * You *know *** *sets down* *picks up tape roll*
10	**Emma:** Lily:	***Lily I can help you with that** *manipulating tape roll------>
11	Lily:	--->* *Pulls tape*

In this short transcript, we see Sara *initiate* the interaction with the same question they previously directed to Emma (line 6). Lily *responds* with a description (line 2), reflecting an interpretation of the initial question as not polar but a request for the goal itself. Specifically, their description highlights two attributes ("cute eyes and eye lashes") and an intention ("want to make it"). Notably, Lily's response has no evidence of hesitation or hedging, indicating full commitment to "cute eyes and eye lashes" as their goal. Sara provides *feedback* via reframing Lily's goal response from attributes to a single thing (line 3; "human", "cardboard person"). The questioning prosody signals Sara's positioning as not knowing, aligning with IRF literature concerning continuation of IRF sequences that lead learners to particular outcomes (Skiveland, Solem, & Skovholt, 2021). Sara's subsequent request for clarification reveals firmer parameters in this moment around what constitutes a goal, namely a bounded thing, not just an attribute. This process of reframing a response parallels research on IRF sequences in formal classrooms, where teachers will guide students to anticipated responses through various re-initiation and feedback mechanisms (Zemel & Koschmann, 2011).

In response to Sara's reframing of their announced goal, Lily *responds* again (line 9), this time crafting a response oriented to the *feedback* from Sara. First, Lily quickly states "No," rejecting the specific potential goal stated by Sara. Lily then states their goal of making a "cardboard cute dog" with a micropause separating each word. While micropauses can indicate the opportunity to end a conversational turn (Sacks, Schegloff, & Jefferson, 1974), Lily's lack of closing prosody and simultaneous physical engagement with the cardboard box act as turn continuations, giving Lily a longer conversational turn in order to construct a response. Lily's word choices – specifically pulling forward the words "cute" and "cardboard" – create a blend between their original goal announcement and Sara's reframing. Lily also meets Sara's request to provide a description of a bounded thing with the addition of "dog" in their goal announcement. Finally, Lily ends their second response with a hedge – "thing" – which moderates their commitment to the entire goal announcement (Johanson, 2020).

After finishing their second goal announcement, Lily waits for a next turn from Sara, indicated by the significant pause after the word "thing" (line 9; Jefferson, 1989). Sara does not perform the anticipated next turn,

so Lily repairs the interactional hole with "You know." Emma further repairs the lack of next-turn from Sara with her own offer of assistance (line 10). However, Lily does not respond to this offer, nor does Emma pursue such a response. However, such offers of assistance provide another type of feedback, signaling that the announced goal is worth pursuing with additional resources.

Analytical synthesis

In both cases, we see maker agency amplified by the deferment to the youth to name their making goal and attenuated by Sara's feedback on those announcements. Following an IRF structure, Sara initiates each sequence with a question, and the sequence is closed with a feedback statement without questioning prosody. Emma announced a lack of goal, an exertion of agency relative to how to approach making, and Sara established the expectation that Emma would need to resolve this omission, attenuating Emma's agency over that decision. This also left open the possibility for Sara to reinitiate the IRF sequence in the future. In contrast, Lily announced a goal based on attributes, which Sara framed as an incomplete response in her continuation of the IRF sequence. Lily's second goal announcement reflected a new orientation to Sara's feedback, shaping the response to include aspects of Sara's reframing and hedging the entire announcement with the word "thing." Both of these moves reflect Lily's orientation towards Sara's feedback as constraining their field of choices, an attenuation of agency. While Sara did not close the IRF sequence with Lily, Emma stepped in and provided a positive feedback turn. These two conversation sequences exemplify our interaction conjectures and demonstrate how they relate to amplification and attenuation of maker agency in small-scale interactions.

Summary of video corpus

To demonstrate the ubiquity of goal announcements and the contours of attenuation and amplification of agency within them, we present an initial summary (see Table 1) of some core verbal features of goal announcement interactions across the eight families in this study.

Table 1

Summary of Goal Announcement Interaction clips (n=96).

Family	Number of Adults	Number of Children	Total Time Making (mm:ss)	Clips			
				Total	Preceding Question	Lack of Goal	Announced Goal with Hedge
A	1	2	18:36	11	6	2	4
B	1	5	49:29	21	11	3	4
C	2	2	22:33	7	5	3	1
D	2	3	15:44	9	5	5	2
E	2	1	59:14	9	7	2	3
F	1	2	49:58	7	3	2	4
G	1	4	17:45	7	4	1	0
H	2	2	44:28	17	7	4	3

Discussion

Power is infused in social interaction, including moments like naming a goal in a makerspace (Philip & Gupta, 2020). Looking across goal announcements in this makerspace, we see maker agency as frequently in flux, constructed by small but impactful moments of amplification and attenuation. Goal announcements typically begin with a question from the non-maker. As seen in Sara's phrasing, the structure of the question may amplify maker agency by framing the maker as the person choosing the goal. However, the questioner also places themselves in the powerful position of first and third speaker in triadic dialog, both setting the conversational agenda and critiquing the second speaker's response. That feedback turn can attenuate maker agency, as we see in Sara's shaping of both Emma's and Lily's goal formulation. The makers orient to the evaluative nature of the triadic dialogue, using hedges to buffer critique and shaping their response to meet the expectations of the non-maker. Announcements of lack of goals – such as Emma's "I don't know" response – are forms of resistance to immediate conversational agendas, preventing the immediate opportunity to evaluate, but from single interactions alone, we cannot see how amplification or attenuation of agency shapes making across goal announcements.

Our next analysis steps aim to examine additional factors influencing agency in goal announcements, including temporal arrangement, interlocutor ages, and individual or collaborative making projects. Since 2016, the museum designers for the makerspace have iterated on the design of the space to include intentional exemplars

and activity prompts ranging from assembly style making to open-ended tinkering (Bevan, 2017) in order to support a wider variety of family engagement preferences. We will compare findings from across makerspace designs to understand how the educational design contributes to attenuation and amplification of maker agency.

Just because a makerspace is designed to support agency does not mean it is experienced this way. When applying these findings to maker practice, we do not advocate for settings in which people never ask makers what they are working towards. Such a directive would likely constrain collaboration, limit joint learning, and undermine other maker values (Vossoughi et al., 2021). We argue instead that supporting maker agency needs to be more intentional than simply not providing goals, which was the design intention in this makerspace. By attending to when a goal announcement is made, who has the power to prompt for that announcement, and perhaps what alternative interaction structures could be used to move away from immediate feedback, maker educators may develop norms that consistently amplify maker agency.

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"Bringing New Things to Light": Examining a Process of Insight-Driven Teacher Learning

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Abstract: Effective teaching relies on practices of reflection and inquiry that must be cultivated throughout teachers' careers. Professional development (PD) can support those practices by positioning participants to develop and build on insights. Using data from a PD program focused on teacher noticing for equity, we draw on practice theory to identify the process and associated practices that emerged through participation in collaborative inquiry. Analysis reveals three phases of activity, consisting of interrelated practices that drove insight-based learning: building awareness, collaborative exploration, and learning through design. Through engaging in this process, participants made unconscious aspects of teaching visible that allowed participants to deepen and expand their insights, and through design, articulated new insights and situated their learning back in the context of their teaching. These findings have implications for designing PD that prioritizes participants' agency to cultivate practices of reflection and inquiry.

Introduction

Teaching has been widely theorized as a dynamic, relational, and responsive discipline that requires practitioners to develop ways of seeing and interpreting that can unveil and support learning processes (Erickson, 2011; Mason, 2002). In this sense, effective teaching relies on practices of reflection, inquiry, and continuous improvement that must be intentionally cultivated throughout a teacher's career (Cochran-Smith & Lytle, 2009; Lampert, 2001). This dimension of teaching, which we refer to as *learning-for-teaching*, consists of adopting and adapting practices, in contrast to propositional knowledge about content or strategies (Ball & Cohen, 1999; Kennedy, 2016). Consequently, we propose that professional development (PD) programs to support learning-for-teaching must elicit and build on participant inquiry and insight to *enable them to develop and implement relevant practices*. This need for a dynamic and participatory PD model presents a challenge for PD designers, who must consider how to create the conditions for participants' insights to emerge and facilitate a process of development that is ultimately teacher-driven (Kennedy, 2016). Doing so requires a deep understanding of the practices and processes of insight-based learning, particularly in the context of developing the ambiguous and contextual aspects of teaching.

We draw on participatory and collaborative research models that position practitioners as both experts and learners. Through collaboration with colleagues and facilitators, practitioners apply, explore, and develop their knowledge of their discipline and contexts to produce insights that support continuous improvement (Bang & Vossoughi, 2016; Engeström, 2011). These models point to prioritizing teacher agency in the context of improving teaching, as we recognize that positioning teachers as experts engaged in practices of continuous improvement entails allowing them to guide the practices and processes of their own learning (Cochran-Smith & Lytle, 2009). In our study, we are concerned with understanding the practices that support the development of learning-for-teaching when PD participants engage in collaborative inquiry. Therefore, we ask the research questions: How do teacher-participants experience insight-driven professional development as a generative process for developing learning-for-teaching? What practices emerge in the process of collaborative inquiry?

Theoretical framing

Teacher agency in professional development

Teacher agency has been theorized as an important dimension of teacher learning (Imants & Van der Wal, 2019; Sancar et al, 2021), which indicates that efforts to support teacher learning in professional development can be characterized by the degree of teacher agency they afford. Kennedy (2016) situates PD programs on a spectrum that begins with prescriptive approaches that instruct teachers how to teach and moves toward programs that position participants to generate their own insights. These insight-driven approaches lie at the opposite end of the spectrum, focusing on generative practices that elicit and leverage participants' insights to articulate and refine concepts for improving teaching (Cochran-Smith & Lytle, 2009; Kennedy, 2016). Borko et al (2011) describe a similar spectrum, moving from highly specified PD programs to highly adaptive programs. Highly specified programs define the goals and the mechanisms that will be employed to produce pre-selected desired outcomes.

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Adaptive programs, on the other hand, respond to the needs and interests of participants to determine the goals and foci of PD. The spectrum of teacher agency to which these authors refer does not indicate that more teacher agency is preferable or more effective. Rather, they suggest that different approaches to PD support different forms of teacher learning.

Developing learning-for-teaching practices

We situate this study in the context of insight-driven PD because we theorize that the practices of learning-for-teaching develop through experiences of co-constructing, adapting, and engaging in relevant practices. For teachers to internalize learning-for-teaching, PD must provide opportunities for participants to develop their own practices of inquiry and building on insight. An extensive body of literature on teacher learning identifies developing practices for ongoing inquiry and reflection as the foundation for continuous learning (Grossman et al, 2019; Lampert, 2001; Mason, 2011). This focus on developing practices is particularly important for supporting teachers enacting responsive, equitable, empathetic pedagogies that require ongoing reflection and insight (Lampert, 2010). In this sense, learning-for-teaching refers to a set of diverse, variable, and evolving practices that drive toward continuous learning and improvement. A PD program to learning-for-teaching must therefore be dynamic and responsive, allowing participants the agency to adopt an inquiry stance toward their own teaching and drive the learning process through insight (Cochran-Smith & Lytle, 2009; Mason, 2009).

In this study, we draw on practice theory to investigate how learning-for-teaching can emerge and develop in the context of an insight-driven PD program. Research on teaching has used the term "practice" to refer to replicable and socially recognized routines, e.g. five practices for orchestrating productive discussions (Stein et al, 2008) or high-leverage practices for beginning teaching (Ball & Forzani, 2011). In contrast, Gherardi (2009) cautions against conflating practices with routines, instead defining practice as "a knowledgeable collective action that forges relations and connections among all the resources available and all the constraints present" (p. 117). It is this sense of practice that characterizes learning-for-teaching: teachers apply and develop their knowledge, in collaboration with both colleagues and students, to forge relations and connections in the process of teaching and learning. Gherardi (2009) adds that "acting as a competent practitioner is synonymous with knowing how to connect successfully with the field of practices thus activated" (p. 118). Accordingly, insight-driven PD aims to develop teachers' ability to forge those relations and connections by positioning them as expert practitioners with the agency to develop their own practices of inquiry and insight. By collaborating to explore, co-construct, and engage in learning-for-teaching practices, participants can activate those practices and embed them in their teaching.

Noticing for equity as an instance of learning-for-teaching

To learn how participants in insight-driven PD programs develop and adopt the practices of inquiry that characterize learning-for-teaching, we examine the case of an insight-driven PD focused on developing teacher noticing for equity. Teacher noticing has been identified as a core construct for teaching that prioritizes the practices of inquiry and reflection we associate with learning-for-teaching. Mason (2002, 2009) calls for developing the discipline to notice in order to support teachers' ongoing learning and insight, while Erickson (2011) draws attention to the highly personal and variable character of teacher noticing. Santagata & Guarino (2011) identify developing teachers' noticing as a core area for teacher education, and van Es & Sherin (2021) argue that adopting an inquiry stance is central to teacher noticing because it positions teachers to be curious about learners in the moment. More recent research reveals the role noticing plays for teachers who are seeking to develop more equity-focused classrooms. Specifically, this work recognizes that teachers develop insight into the ways their own personal histories, the histories of learners, and the histories of schooling shape teachers' noticing in classroom interactions (Kalinec-Craig, 2017; Louie, 2017; Mendoza et al., 2021). Given that this fits with our construct of learning-for-teaching, noticing for equity provides an ideal context to examine how relevant practices emerge and come to be adopted.

Methods

Study Context

This study examines a professional development program called **Co**mmunity **A**nd **T**eacher **T**eams Investigate **E**quitable **N**oticing & **D**ispositions, abbreviated as CoATTEND. This three-year program applied a strengths-based lens to developing teacher noticing for equity in mathematics through participatory action research. CoATTEND began with a series of meetings in which participants discussed key concepts, engaged in thought-provoking activities and reflections, and discussed the nature of inequity and its manifestations in local schools. UCI researchers then conducted a series of classroom observations and used video recordings of these

observations to conduct a noticing interview related to each observation. The noticing interview is like a clinical interview (Hunting, 1997), in which the teacher and a researcher came together to watch and discuss key classroom moments. The observations and noticing interviews were interspersed with additional full team meetings to reflect on the process and discuss emerging themes and insights. During the following year, participants stepped into a co-designer role to create a learning experience for a second cohort of teachers based on the insights and practices that had emerged. This design work involved creating lists of essential topics and concepts, planning a progression of workshops, and identifying formative experiences that could engage and support a new cohort of PD participants.

In addition to developing knowledge about noticing for equity, CoATTEND prioritized "provoking and sustaining an expansive transformation process led and owned by the practitioners" (Engeström, 2011, p. 606). In this program, the subject matter *and* the practices of inquiry were negotiated and co-constructed with participants. Participants assumed increasing agency over the shape of the process to develop new concepts that emerged through their activity and built on their insights, needs, and goals. Rather than aiming to control the process and produce predetermined outcomes, we approach this case with a mindset of curiosity. Having provided participants with opportunities for insight-driven learning and improvement, we seek to learn *what they did with them.* What practices did the participants gravitate to and experience as generative? How did those practices support the emergence or articulation of insights, and how did they position those insights to drive improvement?

Participants and data sources

CoATTEND began with a group of four secondary mathematics teachers and three community educators. Because the involvement of community educators differed from that of teacher participants (e.g. community educators did not participate in noticing interviews), this analysis focuses on the experiences of the four secondary math teachers who participated. All four taught in the same public school district and were identified for recruitment by mathematics teacher educators and their district colleagues on the basis of their demonstrated commitment to equitable teaching. Participants are referred to in this paper by the pseudonyms Jose, Susan, Leah, and Kate.

The primary data source for this analysis is a set of reflective interviews that were conducted with each participant after three years of program activities. Each interview was roughly an hour in duration. Interview questions focused on their retrospective impressions of the program, their memories of impactful experiences and interactions, and their understanding of how program activities supported their learning and development. Developing our analysis of the reflective interviews also relied on artifacts produced during co-design activities in the final year of the project. In the process of designing a program for teacher learning based on their collaboration in CoATTEND, participants identified various impactful and generative components of *their* experience and used their insights to develop a plan for a professional development program. These components, represented in the planning artifacts they produced, provide an outline of their learning process from their perspective.

Analytic Approach

Because participant insight and inquiry are at the center of this PD model, the practices of teacher learning in this context emerged during the course of the program. Gherardi notes that "before action takes place, plans serve only a predictive or organizational purpose" (Gherardi, 2009, p. 122). Centering and building from participant insights means the practices and process cannot be entirely under the designers' control; learning through insight comes to life through the actions that take place in participants' activity and interaction (Ball & Cohen, 1999; Kennedy, 2016). Understanding the practices and processes that generate and drive teacher learning therefore requires a phenomenological lens: how did the participants experience the process? How did they understand the practices involved? How did the practices emerge and interact to drive a process of learning? Regarding similar analyses of emerging processes, Coles (2019) advises researchers to begin with the *last* data collected, arguing that "the final piece of data should exhibit the most stable (meta)patterns" (p. 6). By identifying patterns that became stable and recognizable by the *end* of a phase of research, as opposed to looking for the patterns that researchers sought to enact at the start, analysis remains "grounded rather than evaluative…i.e. the pattern is observable in the data and not based on an evaluation of values or virtues" (p. 6). Consequently, we bracket the theories of learning and the design that informed the professional development program at the start and focus instead on participants' retrospective impressions to map the process and practices of learning to notice. In Gherardi's terms, this is an analysis "conducted 'from within', that is, from the point of view of the practitioners and the activity that is being performed, with its temporality and processuality, as well as the emergent and negotiated order of the action being done" (Gherardi, 2009, p. 117). By centering how the practices in this PD emerged, evolved, and interacted over time from the participants' perspective, we aim to represent a process of teacher learning that was driven and shaped by their knowledge, experiences, needs, and insights.

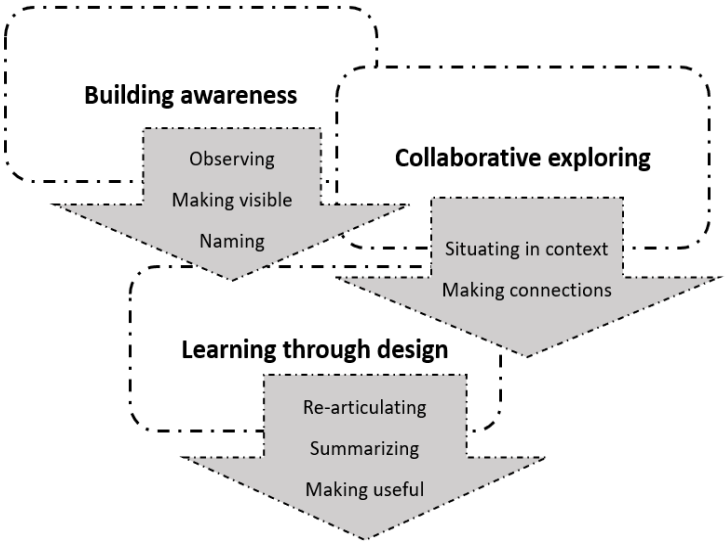
In line with Coles' suggestion, we began with an analysis of reflective interviews to center participants' perspectives on the practices and process that unfolded. We first analyzed these interviews at the word and phrase level with an *in vivo* coding approach (Saldaña, 2011), highlighting terms that participants used to describe essential practices, components, and effects from their experiences in the program. As a primarily inductive technique, *in vivo* coding acts as a "grounding strategy" to develop theory from process data**.** Because we designed the program according to our conjectures about teacher learning, we do not claim this analysis as a fully inductive grounded theory (Charmaz, 2006). Through *in vivo* coding, however, we prioritize induction over deduction and root our claims in empirical data in accord with our research questions; Langley (1999) recommends induction as a means to "explore the interpretations and emotions of different individuals or groups living through the same processes" (p. 700). Our *in vivo* analysis identified over 300 relevant words and phrases, which we reduced to create a set of 54 terms that occurred across the reflective interviews. Based on chronology, patterns, and conceptual links, we organized those terms into categories and used them to produce a visual model of the process that participants described. Langley characterizes visual mapping as an "organizing strategy": it uses the products of the inductive analysis, which grounds the analysis in empirical data, to "descriptively represent process data in a systematic organized form" (Langley, 1999, p. 707). Developing the visual model is therefore both an approach to sensemaking about process data and a way to represent findings.

Findings

Participants' reflections on the CoATTEND PD program indicated three sets of interrelated practices. Although these practices iterated and overlapped throughout the program, participants indicated a sense of sequence that led to representing these practices as phases of activity. These phases lead into each other to drive a process of learning, modeled in Figure 1. Below, we describe each phase of the model and the practices that emerged. Rather than making rigid or deterministic claims about teacher learning, this model is akin to a map of ocean currents - it represents a process in which the elements are in motion and are not strictly separated, but instead intermix and entangle in complex and non-linear ways. At the same time, participants' accounts indicate a sequence and a sense of progress that was consistent across interviews, allowing us to treat the process as a recognizable and reliable pattern of developing activity.

Figure 1

Process model of teacher learning practices in the CoATTEND program



Building awareness

The PD began with a phase of building awareness, in which participants focused on their teaching practices, the contexts of their schools and communities, and the personal and social histories that influence their noticing. Participants voiced an initial impression that the purpose of the program was primarily to observe. Leah described the initial activities as "just always let's look at the interactions, let's look at, you know, and so it was kept really at a level of 'this is what I'm looking at'". By attending to their practice of observing, however, participants came to appreciate the complexity and importance of noticing. To that point, Kate commented that "I thought noticing was simply some kind of just being very, very observant. But I think, as the meetings went on, I realized it was

way more complicated than that and that there was so much more involved with how we see ourselves in the classroom from our historical side and how that changes how we view our students and I think vice versa." In this phase, the group arrived at the insight that observing consists of nuanced practices that must be learned and developed in their own right. Moreover, they found that observing opened up opportunities to engage in deeper practices of reflection and inquiry regarding their teaching.

Engaging in the practice of observation supported a complementary practice of making unconscious aspects of teaching visible. Intentionally observing improved participants' awareness and ability to notice, thereby making unconscious aspects of their teaching and noticing visible to themselves. Kate articulated her sense that observing gave rise to a more complex practices, saying that "I forget all the inner workings of what [teaching] takes because it's just natural now that I don't think about all the little steps to do exactly what I do and I didn't realize I'm multitasking and thinking about kids on so many levels all the time. Which is why I think the noticing took on so many more layers than what I thought it was. It's not just being observant. I think it's more than that." This "layered" dimension of noticing only became visible when participants consciously set their attention to the practice of observing. Leah described the practices of this phase as "bringing new things to light", explaining that "you had done what you did for years and it just became, I guess, internalized. What I think this process did was externalize it, like, bring it out. I think all of us have said, 'Oh, I didn't know I was doing that.'" Likewise, Jose noted that "it was just a little bit of an eye-opener to realize that most teachers are actually doing things that we're looking into, but we don't realize we're doing them. And so that started the process of me thinking about those things." For Jose, making unconscious aspects of teaching visible was the starting point for a larger process of inquiry. Through all these comments, participants emphasized the importance of externalizing unconscious aspects of practice, including habits, assumptions, interpretations, and internalized routines.

That increasing ability to notice, which participants experienced as increasing visibility of the phenomena, also developed in tandem with a practice of naming relevant phenomena and concepts. Lisa commented that "you guys always put into words what I'm thinking but I can't put it into words." Jose described the same naming practice by pointing out that "once everything got integrated and once we got in the know, once we saw what we were doing and we could put labels on everything, everything got laid out in a way that makes sense." This practice of naming enabled participants to refer to their insights clearly, which made it possible to take stock of their progress and made the insights produced through building awareness available as the basis for a new phase of practices. Having names for the concepts and insights that were emerging enabled participants to move forward with exploring their ideas more deeply in the next phase.

Collaborative exploring

The practices of building awareness made the results of observation available for a phase of collaborative exploring; having externalized and named unconscious aspects of teaching allowed for them to be explored, questioned, and connected. In this phase, participants described both deepening and broadening their insights. Susan pointed out that "our activities help to really distill those things out where I had to pinpoint, yeah, this is the moment, or this is the way that I felt." These references to "pinpointing" and "distilling" indicate a practice of focusing in on an observation and refining it to produce a clearer or more detailed conception. At the same time, participants also referred to connecting and contextualizing insights. Susan highlighted these practices by saying that "there's some, like, threads that just all have come together in this project for me of things that were kind of already there, but they're clarified now. It's like everything's coming into focus and now I see how they relate to each other. Whereas before they were just sort of these things that were like floating around out there and they were influencing me, but I talked about them very, as separate entities, not as parts of the whole." In this sense, collaborative exploring involved situating ideas in context and drawing connections that allowed participants to understand their knowledge and practices as a cohesive network.

Across these accounts, participants pointed out that collaboration was a crucial component of the practices in this phase. Kate identified a contrast between collaborating in CoATTEND and the typical collaboration she experienced as a teacher, pointing out that "I don't usually go into other teachers' classrooms and I don't really talk about teaching practices with others like that in that way. I think we talk about, like, 'Oh, where are you in chapter seven?' Or 'How did you do this one thing?' We talk about very simple things to discuss, but nothing this deep." While discussion and collaboration occur in the normal course of teaching, Kate argues that the norms of collaboration in that context do not activate the practices of learning-for-teaching that CoATTEND prioritized. Leah also emphasized the value of collaborative exploring, saying that "I absolutely love having the whole group at the big table and just hearing, and everybody had input and bouncing ideas off each other. I think what we create as a group is big because it's this person's idea and that person, and we come together and create something that obviously you couldn't create alone." This sense that the results of collaborative

exploring were deeper and more expansive than individual reflection could have produced appears in several teachers' reflections.

Learning through design

At this point, the research team and the participants agreed to design a new PD program on the basis of the insights they had developed. This design phase motivated participants to re-articulate and summarize their insights for the sake of making participants' insights useful as the basis of future PD programs. In this phase, participants were motivated to make their insights useful for teacher learning. This sense of purpose was ostensibly aimed at supporting other teachers, but designing also rendered participants' own understanding in more concrete and actionable forms by pushing them to situate their insights back in the context of teaching. Kate described this phase as "trying to create a new language [and] putting what we're doing into a practice that is digestible for people.", adding that "it felt more practical and it was easier for me to see what we're doing based on how are we going to show this to someone else." By working to frame and express their insights in terms that appeal to other teachers, participants returned to an examination of teaching in context and strengthened the connections between their insights and their teaching.

The practice of summarizing helped participants articulate the purposes and the outcomes of the program. Leah described the design phase as "just this big summary of what we'd been through" and emphasized the value of the summarizing practice: "it's a big confidence thing because I don't know, you know, you're thinking 'am I good enough to help with that, did I have enough experience?' But it was neat to see the different things we had done, and then I could kind of join with 'okay, that's, I'm good with that, and I'm not so good with that.'" The practice of summarizing enabled Leah to take stock of her own developing knowledge, leading to increased confidence in the knowledge she had built and a sense for areas of growth that deserved further attention. Susan expressed a similar sense that the concrete character of designing was beneficial, saying that "once we had some headings, then things really started to hum, clicking happened. It wasn't that we were disagreeing before, it was just this like, well, there wasn't a clear goal. So there was a whole lot of talking, which wasn't bad because it deepened our understanding of other things, but this process has felt fun because we see an outcome." Ambiguity regarding the goals and process of the work was a consequence of allowing room for teacher agency. Because the outcomes and practices were not predetermined, participants had to navigate through the uncertainty of building on their own insights without a "clear" goal. While that aspect of the process was valuable and necessary, participants found that these practices of articulating and summarizing the insights they had explored enabled them to make sense of the progress they had made. Susan summed up her impressions with the comment, "I think all of that stuff was really, really important to getting to this place, but now being able to put all of those things together feels good."

Discussion

This analysis reveals the messy process of insight-driven teacher learning, as well as the practices this process entailed. We contend that the dynamic, open character of the process positioned participants to develop new insights, grounded in their knowledge and experience of their teaching contexts, and use them as the basis for improving their practices of learning-for-teaching. In short, we see participants developing the practices of learning-for-teaching by engaging in those same practices of inquiry and reflection in the context of the PD.

Prior research demonstrates the importance of developing these learning-for-teaching practices (Cochran-Smith & Lytle, 2009; Lampert, 2010; Mason, 2009). Moreover, the personal, contextual, and ambiguous dimension of learning-for-teaching practices is central to their enactment (Kalinec-Craig, 2017; Louie, 2017; Mendoza et al, 2021). Because this approach to teacher learning emphasizes practices that build on participant insights instead of focusing on predetermined content, we hold insight-driven PD models are especially suited to responsive needs of developing learning-for-teaching. By centering this PD on the practices and processes of inquiry in addition to the content addressed, teachers were positioned to engage in the generative process of building on the insights they developed based on their own understanding and experiences. This characteristic makes insight-driven PD responsive to teachers' learning trajectories, thereby supporting the development of their learning-for-teaching practices through a different process than would be afforded by one-size-fits-all content (Kennedy, 2016). While many of the patterns we describe here align with the theories and conjectures that informed the design of the program, some aspects stood out as unexpected, participant-directed elements. For instance, the noticing interviews were initially conceived as an instrument for data collection, but participants found them to be impactful for their own learning and development. Consequently, we reconceptualized the noticing interview as a central learning activity in the PD and are planning to include it as a pedagogical structure in future PD and teacher preparation programs. Moving into the third stage, learning through design, was similarly participant-directed. The original plan involved the participants collaborating with researchers on data analysis in

a more typical "academic" fashion. Upon reaching that point, however, participants voiced a strong desire to design PD for pre-service and early career teachers and had comparatively little interest in data analysis or academic writing. As a result, the research team chose to follow participants' energy and pursue the design phase as a set of practices that the *participants* expected to be generative. These changes in emphasis and direction on the basis of participants' engagement highlight the opportunities for reciprocal learning afforded by an adaptive, insight-based approach to professional development.

As an effort to map a fluid and dynamic process of learning, the process model we provide appears more static and straightforward than the network of practices it represents; recall the comparison above to a map of ocean currents. Consistent with the processual lens of our analysis, our model represents the evolving practices of the PD in phases to render the *patterns* and *trajectories* of participants' activity visible (Gherardi, 2009; Langley, 1999). The challenge in applying this model, therefore, is to design with the "current" of insight-driven learning in mind without forcing participants to follow a particular course. Our findings suggest that beginning with building awareness, providing opportunities for multiple forms of collaboration, and applying insights through co-design work can together encourage practices of inquiry that at the same time prioritize participants' insights and preserve their agency. We recognize, however, the limitations of investigating this process on the basis of a single case. Future work could improve and complicate our understanding of insight-driven PD by modeling the emergence of practices in additional cases and contexts of teacher learning (Langley, 1999; Saldaña, 2011). With a clearer picture of designing for and facilitating the process of insight-driven learning, PD stands to support teachers in cultivating a deep, personal, and lasting orientation to reflective, responsive, and equitable teaching practices.

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Introducing Authentic Datasets into the Biology Classroom: Teachers' Considerations when Designing Digital Instruction Units

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Abstract: Introducing datasets into the science classroom may facilitate developing scientific practices and epistemic thinking. However, authentic datasets are rarely used in high school, and little is known about biology teachers' knowledge considerations regarding dataset-driven instruction. Here we investigated these knowledge considerations in high-school biology teachers. Forty teachers designed dataset-driven instruction units and completed open-ended questionnaires during a professional development workshop. Our analysis, based on the PISA framework of scientific literacy, indicated that although epistemic considerations were the most prominent of teachers' perceived benefits of dataset-driven instruction, they were less pronounced than content and procedural considerations in the instruction units that they designed. This suggests that although teachers recognize the value of epistemic thinking and see authentic datasets as a means to facilitate scientific literacy, further effort is needed to assist teachers in designing instruction units which better reflect these goals.

Introduction

Biology as a discipline has a long history of engaging with large datasets (Leonelli, 2014). Using authentic datasets in the science classroom enables students and teachers to engage in, and assist in developing scientific practices (Kjelvik & Schultheis, 2019; Wyner, 2013). However, most current use of data in the biology classroom is highly simplified, as authentic datasets are messy and complicated. Indeed, selection and curation of datasets require expertise and application of domain knowledge (Duncan et al., 2018). This notable gap between biology as a data-based science and high-school biology could be mediated by the biology teacher. However, little is known about teachers' perceptions of the challenges and benefits of data-driven instruction, or their design considerations, in general and in biology in particular. Therefore, we examined the knowledge considerations expressed in biology teachers' views of data-driven instruction, and in the goals that they set when designing data-driven activities tailored to their students. Our research focuses on teachers' epistemic considerations in using and designing data-driven instruction, and offers insights that can be further used to design better learning materials, teachers' professional development (PD) programs and teacher education. This may be a step toward promoting the use of authentic datasets in the high-school biology classroom, thus contributing to students' scientific data literacy.

Theoretical framework

Promoting scientific data literacy by using authentic data and the teacher's role

To gain scientific literacy, one should understand not only basic scientific information, but also the process by which science is carried out, and its epistemic backbone (NRC, 2012). Here we followed the OECD PISA framework (OECD, 2019), which defines scientific literacy as the ability to participate in science-related issues. This framework defines three components of scientific literacy: (a) content knowledge – knowledge of the theoretical concepts and ideas of the discipline; (b) procedural knowledge – knowledge of the standard procedures that underlie the methods and practices used to establish scientific knowledge; and (c) epistemic knowledge – understanding the rationale of scientific inquiry, and how scientific knowledge is derived; and the degree to which such knowledge is justified by evidence or theoretical explanations. The competency-based perspective described in the PISA framework also recognizes an affective element in the student's display of these competencies (OECD, 2019).

The recent strategic vision proposal for the PISA 2024 framework anchors the importance of data literacy, and states that understanding global challenges, such as pandemics, requires evaluating statistical data and probabilistic thinking (OECD, 2020). Data literacy can be developed by asking students to use authentic datasets, establish and justify interpretations, and consider potential sources of error, such as limited data (Osborne, 2014). Use of authentic datasets in the science classroom provides a broader range of science practices in which students and teachers can engage, and assists in developing these competencies (Kjelvik & Schultheis, 2019; Wyner, 2013), while applying biological knowledge (Yarden & Levkovich, 2021, p. 72). Although datasets do not permit the full scope of scientific inquiry, because students do not collect the data first-hand, datasets can provide a rich,

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multifaceted set of information that requires highly complex reasoning (Chinn & Malhotra, 2002), various research questions, and data-analysis approaches (Wyner, 2013). To support data literacy among students, teachers must first be aware of its importance, gain familiarity with data-rich environments and be able to mediate these practices to their students. Previous research has shown that curriculum materials alone, without teacher-mediated norms that enable scientific sense-making and epistemic talk, are not sufficient to promote students' understanding of scientific knowledge (e.g., Berland et al., 2016). Thus, effectively teaching scientific reasoning requires holding a body of epistemic knowledge (Kind & Osborne, 2017) and applying epistemic considerations (Ke & Schwarz, 2019). When designing data-rich activities for their students, teachers use a variety of goals and considerations. Understanding teachers' considerations in general, and epistemic considerations in particular, is important because they shed light on what teachers notice, value, and see as important for students to learn (Ariely et al., 2021). Therefore, here we focus on teachers' epistemic considerations regarding the use and design of data-driven activities for their students.

Science teachers' PD

Implementing instructional approaches that involve authentic scientific practices and technologies requires first introducing them to the teachers. Providing teachers with opportunities to experience the technology first-hand, to observe its pedagogical benefits and gain an awareness of its associated challenges may affect their approach to applying the technology in their classroom (Dorfman et al., 2019; Mishra et al., 2019). Referring specifically to working with authentic data, research has shown that following PD courses, teachers changed their views toward using authentic data and toward the way they use data in their classes. For example, following a PD course which included the implementation of a data-rich ecology curriculum, ninth-grade biology teachers were more positively disposed to including authentic scientific data in their lesson plans (Wyner, 2013). Another recent study showed that at the end of a PD course, teachers were able to integrate computational thinking into their teaching, emphasizing the important role of teachers as co-designers of activities for their students (Wu et al., 2020).

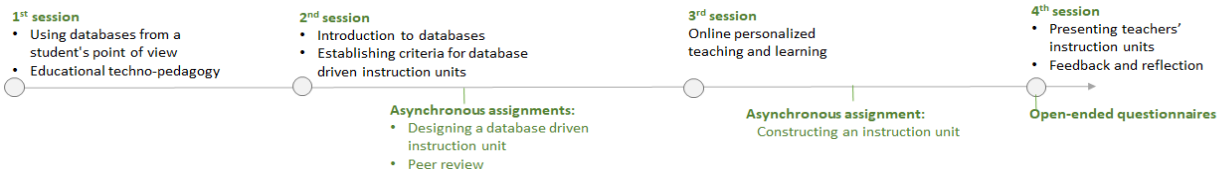
PD courses in which teachers design and adapt instructional units can support different modes of use by the teachers, while meeting their instructional goals and their students' needs (Brown, 2011). Supporting teachers' design process in the form of co-design can enhance teacher understanding of the technology being used, foster professional growth and improve outcomes in the classroom (Peel et al., 2020). Even in the context of integrating advanced educational technology, co-design processes that involve teachers have been shown to be a useful approach to designing solutions that address teachers' needs, and to gaining the teachers' trust (Holstein et al., 2019).

The context of the study

Description of PD workshop

In light of the above, a PD workshop was designed to help high-school biology teachers incorporate authentic digital datasets into their instruction, and to identify their knowledge considerations toward using datasets and while designing digital instruction units. We followed the Eylon and Bagno (2006) three-stage model of teachers' PD. In the first stage—*teachers as learners*, they experience data-driven instruction units as students. In the second stage—*teachers as curriculum developers*, they design an instruction unit based on their own pedagogical expertise, consultations with experts and critique by their peers. In the third stage—*reflection*, teachers report on their designed units and reflect on their design process (Eylon & Bagno, 2006). Similarly, in the current workshop, teachers first experienced an online data-driven activity as students. Then they were presented with authentic taxonomy datasets. Based on those datasets, while relying on their pedagogical expertise, the teachers developed different instruction units. Following the workshop, teachers' views and considerations of data-driven instruction were assessed through an open-ended questionnaire and their written instruction units (Figure 1). The workshop was designed and taught by the researchers and took place during the summer break (July–August 2020), in the context of the activities carried out by the National Center for High-School Biology Teachers in Israel. Due to the restrictions following the COVID-19 outbreak, the PD workshop was designed and carried out as a 30-hour online workshop, using the Personalized Teaching and Learning (PeTeL) platform. As a result, the rate of registration and participation was higher than expected (n = 52), and participants included teachers who do not usually participate in the face-to-face activities of the National Center for High-School Biology Teachers in Israel due to distance and time considerations. In addition, the COVID-19 restrictions created a need for teachers to access online activities for their students, which may also have contributed to the relatively high number of participants (Sun et al., 2020).

Figure 1
Professional development timeline



The datasets used in the activities

The teachers were presented with several authentic taxonomic datasets of various species that were curated in natural history museums, with different contents and volumes. The following datasets were available to the teachers: (a) mammal dataset (16,139 cases over 17 measurements); (b) gazelle dataset (1,175 cases over 14 measurements)—this was a subset of the bigger mammalian dataset; (c) bird dataset (5,653 cases over 19 measurements), and (d) brown bear dataset (1,339 cases over 13 measurements).

The first three datasets (a–c) were constructed in collaboration with the Steinhardt Museum of Natural History (https://smnh.tau.ac.il/en/); the fourth dataset (d) was based on the Arctos museum collectors' database (https://arctos.database.museum/home.cfm). All datasets were cleaned to remove duplicates and irrelevant data, and formats and units were standardized. Variability and biological outliers were maintained. Each dataset included variables such as weight, body length, and time of collection. The datasets were introduced to the teachers using the Common Online Data Analysis Platform – CODAP (Finzer, 2016). In addition, the teachers were told that they could use other public or personal datasets. However, 85% of the teachers who completed all of the assignments (n = 34/40) chose to use one of the four ready-made datasets (or subsets of those datasets) for their instruction units.

Research questions

Teachers have a key role in promoting data literacy and epistemic thinking in the biology classroom. Since little is known about high-school biology teachers' views regarding dataset-driven instruction, we sought to answer the following research questions: (1) How are high-school biology teachers' knowledge considerations expressed in their perceptions of the challenges and benefits of using authentic datasets in their classroom? (2) How are knowledge considerations in general, and epistemic considerations in particular, expressed in teachers' data-driven instruction units?

Methods

Participants

Participants were high-school biology teachers in the above-described PD workshop focusing on dataset-driven instruction. Of the 52 teachers who started the workshop, 40 completed all of the assignments. Herein, we present the findings based on those 40 teachers. All of the teachers teach biology in high schools across Israel, and have teaching experience ranging from 1–44 years (avg 13.7 ± 9). Only eight teachers had previous experience working or teaching with datasets. The teachers voluntarily chose to participate in the PD workshop and in the accompanying research.

Data collection and analysis

Teachers' views and considerations regarding the use of authentic datasets in the classroom were assessed by:

a) An open-ended questionnaire, which asked the teachers to "describe the challenges and benefits of dataset-driven instruction (i) for you as a teacher and (ii) for your students." The questionnaires were voluntarily filled at the closing session on the last day of the workshop. Each participant wrote freely, with a total of 66 benefits and 58 challenges.

b) Written instruction units: during the workshop, the teachers designed dataset-driven digital instruction units, and documented their design considerations. Due to space limitations, in the current paper we focus on the design considerations expressed in their teaching goals (a total of 140 considerations).

The data from the questionnaires and instruction units were analyzed according to the PISA framework (2019). In addition to these predetermined categories, we identified subcategories using the deductive–inductive procedure approach (Srnka & Koeszegi, 2007). Two science-education researchers independently analyzed the

data, and the categorization was discussed until an acceptance rate of 100% between researchers was reached. Pearson's chi-square test was performed to assess whether the distribution of the teachers' perceived benefits and design considerations were consistent. A case study was chosen from the instruction units. A comprehensive analysis of that case study is beyond the scope of the current paper and therefore, it is presented here only to demonstrate the translation of epistemic considerations into an instructional sequence. To provide a rich illustration, we chose the instruction units with the most detailed epistemic considerations.

Results

The challenges of using authentic datasets in the biology classroom

In the open-ended questionnaire, teachers related to different challenges of data-driven instruction, with a total of 58 references. The knowledge considerations expressed in their answers are summarized in Table 1, in the order of their appearance in the PISA framework (OECD, 2019). Teachers' responses included considerations along the four dimensions: teaching content, procedural knowledge, epistemic knowledge, and affective aspects (coherent with the PISA framework—OECD, 2019). Eight teachers related to conflicts between teaching the required *content* knowledge and teaching with datasets, as the latter is often time-consuming. Some mentioned that contemplating the datasets may distract the students from the content knowledge. Most of the answers (n = 28/58, 48%) related to *procedural* challenges. They referred to difficulties derived from working with technology, which are not specific to working with datasets (n = 11, 19%), such as getting used to a new platform, user interface of the website, remembering a new password, etc. The rest of the procedural considerations (n = 17, 29%) related to data-driven instruction, such as the size of the databases potentially hindering students' orientation or operation throughout the activity. Some teachers stated the need for a lot of preparation work on their part, i.e., finding a quality dataset, editing, and cleaning it for their students.

Ten teachers (17%) related to the *epistemic* challenges of dataset-driven instruction, such as its "messy" nature, and questioned the reliability of authentic data, as well as of detaching the database from the way in which the data were collected, making the data meaningless for the students. Finally, twelve teachers also stated the affective influences of the large datasets, as being intimidating and/or frustrating, and potentially hindering students' approaching or completing their tasks (Table 1).

Table 1

Teachers' knowledge considerations expressed in the challenges of using dataset-driven instruction

Knowledge considerations	Challenges	Examples and number of references	
Content knowledge	Data-driven instruction conflicts with the curriculum	"Not part of the curriculum" "The main disadvantage is the time that such an activity takes, and which in the meantime can divert attention from the logical sequence of content teaching"	8
Procedural knowledge	Challenges specific to data-driven instruction (e.g., orientation difficulties, need for adaptations)	"The databases are too overloaded with data. They sometimes need adaptations to be made accessible to students"	17
	General technological challenges (e.g., the website, the platform, the user interface)	"The work on the website is not simple" "Students will have difficulty using the dataset because the environment is new, it will take them time to get used to it"	11
Epistemic knowledge	Messy and unreliable data	"The dataset is not 'clean' and sometimes includes incorrect or inaccurate information. There is educational value in seeing that in science, there are sometimes strange results, but from a teaching point of view, it also creates challenges"	10
Affect and engagement	Dataset sizes may be intimidating	"At first it can seem scary and intimidating" "The students will see the large dataset and will despair, without trying to use it"	12

The benefits of using authentic datasets in the biology classroom

In the open-ended questionnaire, teachers related to different benefits of data-driven instruction, with a total of 66 responses. The knowledge considerations expressed in their answers are summarized in Table 2, in the order of

their appearance in the PISA framework (OECD, 2019). Teachers' responses included considerations along the four dimensions: teaching content, procedural knowledge, epistemic knowledge, and affective aspects (coherent with the PISA framework—OECD, 2019). Nine answers (14%) related to the benefits of using datasets for teaching and learning *content* knowledge, to authentically exemplify phenomena instead of teaching them in theory. Seventeen teachers (26%) addressed *procedural* knowledge and stated that datasets can enable the development and practice of inquiry skills, such as constructing graphs and other means of data visualization. It can allow students to explore first-hand the connection between variables, and distinguish between correlation and causality. The most popular answer (n = 24/66, 36%, Table 2) referred to the advantage of using datasets for teaching *epistemic* knowledge. The teachers wrote that using authentic datasets provides an opportunity to expose their students to an authentic scientific practice as it is done in the real world. The encounter with authentic data evokes critical thinking (for example, regarding inconsistent results) and enables discussions about the nature of science. Furthermore, the teachers stated that using datasets in the classroom can improve students' interest and curiosity and contribute to diverse teaching methods (n = 16/66, 24%).

Table 2
Teachers' knowledge considerations expressed in the benefits of using dataset-driven instruction

Knowledge considerations	Benefits	Examples and number of references	
Content knowledge	Enables learning biological content knowledge	"A lot of information can be extracted and taught based on datasets" "Gives a lot of knowledge...allows thinking about various factors"	9
Procedural knowledge	Enables developing and practicing inquiry skills	"Students learn to build graphs themselves, and experience the difference between dependent and independent variables, etc."	17
Epistemic knowledge	Using authentic data	"The most important benefit is exposure to how research is really done, where the graphs are imperfect and require critical thinking"	9
	Nature of science	"Opportunity to discuss views based on data from different periods"	7
	Higher-order thinking	"Teaches critical thinking"	8
Affect and engagement	Affective aspects – interest and curiosity	"It's really interesting"	8
	Diverse teaching methods	"A new learning environment that is different from what the students are used to"	8

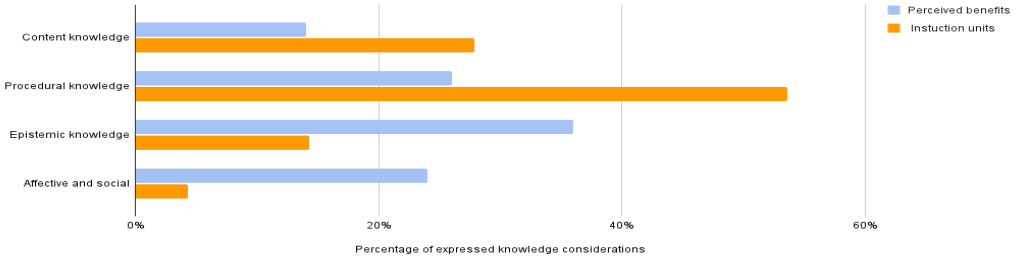
Teachers' knowledge considerations expressed in their instruction units

To answer the second research question, how knowledge considerations in general, and epistemic considerations in particular, are expressed in teachers' data-driven instruction units, we analyzed the instruction units according to the PISA framework (OECD, 2019). In the current paper, we focus on the considerations expressed in their stated teaching goals. Out of a total of 140 considerations, 31 focused on biological *content* knowledge, such as "The students will learn about the characteristics and risks of radon gas." The majority focused on *procedural* knowledge (n = 75/140). The teachers' aim was for their students to "identify the scientific inquiry components" or "identify measurements that deviate from the trend of most of the data and will explain the anomalies and how to analyze general trends despite the anomalous examples." *Epistemic* considerations (n = 20/140) included references such as "the students will gain knowledge regarding science and scientific research: critical thinking, research planning, problem definition and using suitable graphs" or "Students will recognize and understand the issue of dataset reliability." All but one of the teachers who highlighted epistemic design considerations also addressed procedural knowledge. Only six design considerations took into account affect and engagement aspects ("Creating a 'sense of discovery' of ecological rules," "Emphasize the individual's commitment to the population in following the rules"). To further investigate how knowledge considerations are expressed in teachers' data-driven instruction units (research question 2), we explored the extent to which the knowledge considerations stated

by teachers as benefits of data-driven instruction were manifested in their units. Although all knowledge components were expressed as considerations in both the perceived benefits and the instruction units, there was a significant difference ($p < .001$) between the distribution of those knowledge considerations in each case. Pearson chi-square test revealed a significant difference between knowledge considerations in teachers' perceived benefits and instruction units ($X^2(4, n = 206) = 38.63, p < .001$). Figure 2 illustrates 40 teachers' general considerations (blue) and their actual designing considerations (orange) as expressed in the dataset-driven instruction units. When generally discussing data-driven instruction, the most prominent consideration was epistemic knowledge (36% of considerations, Figure 2). However, when designing units in practice, 54% of the considerations related to procedural knowledge, 28% to content knowledge, and epistemic considerations dropped to 14%.

Figure 2

Knowledge considerations expressed in teachers' instruction units (n = 140) and perceived benefits (n = 66)



The case of teacher AS: students as inquirers

The following case study was chosen to depict teachers' epistemic considerations when designing data-driven instruction units in biology (italics have been added to emphasize epistemic considerations). Teacher AS has 20 years of teaching experience. She teaches biology in a Jewish religious school in the central part of Israel. Her instructional unit made use of the brown bear dataset, aimed at students' "acquaintance with the term dataset; *understanding that in order to understand and evaluate the data*, a way must be found to categorize the vast amount of data in the dataset; and carrying out a data-driven investigation – from 'dry' data we can draw conclusions and *support or refute our assumptions*" (AS written instruction unit). Note that content knowledge, although popular among other participants, was not one of her explicit goals. Her unit starts by showing a video of bears, and then the bear dataset is introduced to students accompanied by a series of questions aimed at "familiarizing the students with the dataset and the *investigation possibilities on the one hand, and its limitations on the other*." She asks her students "*What questions arise around the dataset? Which information is lacking?*" The activity includes questions referring to the *data source and data collection*, taking into account ethical considerations, "to evoke curiosity, thinking and interest...Were the data collected from bears that were hunted and killed? Or captured, fitted with a transmitter and re-released?" AS proposes scaffolding for her students and her instruction unit includes an in-class demonstration of visualizations and written instructions for independent work. In the last part of the instruction unit, the *students choose their own research question*, define variables, create graphs and draw conclusions. AS states that "*there is an immense amount of data and the students as inquirers should decide what is relevant and right for them.*" The AS case study demonstrates how this teacher's instruction unit highlights epistemic thinking through authentic dataset inquiry, from thinking about the way in which the data were obtained, to considering the dataset's limitations and merits.

Discussion and implications

In this study, we provide an analysis of knowledge considerations expressed in biology teachers' perceptions of the challenges and benefits of dataset-driven instruction, as well as of their considerations when deciding on their design of a dataset-driven instruction unit. The conclusions of this study leverage the PISA framework for scientific literacy, and further refine it by identifying subcategories, in the context of scientific data literacy. Our conclusions have implications for the use of datasets for biology teaching and for science teacher education, particularly as science teachers face the challenge of engaging in debates around the epistemic nature of science, for which dataset instruction can serve as one of many possible instructional strategies.

Our analysis shows that although some teachers perceived dataset-driven instruction as a possible way of teaching content knowledge, content considerations were the least pronounced of the knowledge components when they considered the benefits and challenges of dataset-driven instruction. This may be because the teachers perceive dataset-driven instruction as conflicting with the curriculum. Indeed, it has been shown that when designing non-mandatory curriculum instruction units, most science teachers' decisions are related to contextual

factors, such as work overload (Kaplan Mintz et al., 2021). However, when designing their instruction units, content considerations were expressed significantly more often in the teachers' goals. The teachers found ways to connect the databases to the curriculum, possibly minimizing the aforementioned conflict.

Procedural considerations made up a major fraction of the perceived benefits and challenges. Teachers often related to dataset-driven instruction as beneficial for teaching and practicing scientific practices and inquiry (both guided and open), which are a part of the mandatory Israeli biology curriculum. Perhaps that contributed to procedural considerations being the most pronounced component in the instruction units, considering the influence of their connection to the curriculum on teachers' practice (Kaplan Mintz et al., 2021). Chinn and Malhotra (2002) stated that database tasks have the potential to simulate most features of authentic reasoning in the context of interpreting existing data. They studied database-driven activities in which students conducted investigations using a database containing information about dozens of birds (Reiser et al., 2001). However, they concluded that those database tasks do not allow students to design and carry out their own studies and do not permit new investigations. Our results indicated that our much larger datasets (thousands of cases) may allow teachers to prompt their students to ask novel research questions, and seek answers in the dataset. As teacher AS explained, the volume of the data enables the students to become "inquirers, [who] should decide what is relevant and right for them." The procedural challenges were both dataset-specific and related to technology in general, and were attributed similarly to students and teachers. The teachers addressed these in their instruction units, providing scaffolds and leading their students step by step through the datasets, as demonstrated in the case study.

As for epistemic considerations, the most popular benefit of authentic dataset-driven instruction referred to the opportunity afforded to teach epistemic knowledge, exposing students "to how research is really done, when the graphs are imperfect and require critical thinking." The epistemic considerations were also demonstrated through the case study. Teachers' epistemic considerations while designing dataset-driven instruction indicated that they: (a) recognize the value of epistemic thinking for students' scientific literacy and (b) see authentic datasets as means of teaching epistemic thinking.

However, in the instruction units, the fraction of epistemic considerations decreased significantly, becoming the least pronounced amongst the knowledge components. One possible explanation for this gap is that epistemic knowledge (although declared as important) is not expressed in practice, in the biology curriculum. As discussed above, the curriculum affects teachers' practices. Another possible explanation lies in the challenges. As teachers noted, there are epistemic-related challenges in dataset-driven instruction, such as explaining the messy nature and reliability of the data, and data-collection procedures (which are not always available to teachers). Overcoming these challenges is even harder when procedural-related challenges are still very pronounced, as our analysis revealed. Research has suggested that there is a hierarchy for the use of knowledge components during learning, according to which procedural knowledge is needed to promote epistemic knowledge (Levkovich & Yarden, 2021). Therefore, it is possible that because the teachers are new to dataset-driven instruction, they still struggle with the procedural knowledge involved in engaging with datasets; although they did see authentic datasets as a means of teaching epistemic thinking, they are still limited in their ability to incorporate these ideas into practice. The gap between teachers' knowledge considerations in the perceived benefits and in the units they designed is not surprising. Research has shown the difficulty in inducing in-service teachers to change, and in their translating new approaches and ideas into practice (reviewed in Luft & Hewson, 2014). The PD workshop presented here was only 30 hours long, and although the participating teachers already deemed dataset instruction as valuable (as they chose to participate in the workshop), it could only have a limited effect on teacher change. Nevertheless, increasing instructors' access to high-quality, data-intensive resources, alongside the necessary training to effectively implement them, might increase the use of authentic data in the science classroom (Kjelvik & Schultheis, 2019). Further effort is needed to assist teachers in designing instruction units that better represent these goals. For example, future PD courses might explicitly discuss the way epistemic knowledge and considerations can be expressed in dataset-driven instruction.

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Learning in Practice Space Games

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Abstract: Classroom-based assessment is essential to good teaching and learning. Nevertheless, pre-service and in-service teacher's assessment professional development (PD) has been slow to change and the research supporting good assessment PD is still nascent. In this paper, we report the investigation of a relatively new approach to assessment PD, a game-based intervention, *MetaRubric*, a game designed to provide teachers with a playful experience that supports critical examination of rubrics, including their design and use. Games - and in particular practice space games - have been suggested to be potentially useful for teacher professional development, however little has been written about their design, practical application to teacher professional development, especially in the context of assessment, or mechanisms of action. The data presented here provide preliminary empirical support for and detail the design of one such intervention.

Rubrics for Improving Teacher Assessment Literacy

Teacher's assessment practices are widely acknowledged to be an important influence on student learning. Black and Wiliam (1998), for example, in their widely circulated meta-analysis, reported that classroom assessment can improve student performance on large-scale assessments with effect sizes between 0.4 and 0.7, which are "amongst the largest ever reported for educational interventions" (p.61). Despite its importance in education, assessment has a decades-long history of being a challenging area of teacher preparation (Pastore & Andrade, 2019). In the early 1990s, top education associations in the U.S. collaborated to publish the Standards for Teacher Competence in the Educational Assessment of Students (American Federation of Teachers et al., 1990). A decade after the Standards publication, assessment continued to be a critical issue, with authors citing "unacceptably low levels of assessment literacy among practicing teachers and administrators in our schools" (Stiggins, 1991) and surveys suggesting that pre-service and in-service teachers held inadequate levels of assessment literacy across the same period (Campbell et al., 2002; Plake, 1993). Despite the longstanding support of classroom assessment for improving learning, professional development programs have not significantly improved in preparing teachers to practice in-class assessment (DeLuca et al., 2016).

Rubrics, or scoring tools typically presented as a matrix split into levels that describe expectations for an assignment's evaluation, are one type of in-class assessment tool that may be useful for addressing this need; they are a tool that is both effective and that can be reasonably introduced through typical teacher professional development. Research supporting classroom-based rubric use has grown massively over the past two decades - from 100 papers in 1997 to 1000 in 2005, to 5000 in 2013 (Dawson, 2015) - making a review of rubrics literature beyond the scope of this paper. Two points are worth noting from other reviews of the literature, however. First, empirical evidence supporting the benefits of rubric use has grown while evidence showing negative effects of their use is not supported (Brookhart & Chen, 2015; Dawson, 2015; Jonsson & Svingby, 2007; Panadero & Jonsson, 2013, 2020). Such studies have shown that rubrics can be useful in assessing higher order cognitive skills, performance skills and complex skills (Arter & Chappuis, 2006; Mertler, 2004), in supporting student self- and peer-assessment, and for communicating with learners how they can improve their work (Andrade, 2005). In addition to improving assessment and learning, rubrics are used by teachers to communicate expectations for an assignment, provide focused feedback on works in progress, and grade final products (Andrade, 1997, 2000; Popham, 1997).

Second, because effective rubric design and use is a professional, on-going process, training for both students and teachers is recommended (Brookhart & Chen, 2015; Reddy & Andrade, 2010). Rubrics by themselves are not entirely self-explanatory (e.g. Andrade, 2005) and require interpretation by the students in order to be used effectively, particularly with open-ended authentic tasks. Additionally, while there is strong evidence that rubrics can be used as a regulatory device that ensures consistency, rubrics alone do not necessarily lead to better assessment validity (Jonsson & Svingby, 2007). Thus, how a rubric is designed and used matters, and to be effective, professional development programs may need to help teachers shift rubrics away from a focus on products or content and toward what rubrics do best - make expectations and criteria explicit (Jonsson & Svingby, 2007). This paper and project focused on this latter point of professional

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development. Specifically, it explored the design and use of a game intended to improve how teachers thought about and used rubrics in their classrooms. Based on teachers' use of the game, *MetaRubric*, we suggest that one way to create games for teacher professional development is to create artifacts that support 1) in-game, playful opportunities for players to connect prior professional experience and knowledge with local practices, problems, and solutions, and that 2) encourage opportunities for reflection and sharing amongst their colleagues.

Games for Teacher Professional Development

Games have been seen as a useful means of professional development (PD) in diverse domains, such as architecture (Agapiou, 2006), engineering (Baker et al., 2005; Deshpande & Huang, 2011), construction management (Pariafsai, 2016), entrepreneurship (Kriz & Auchter, 2016), nursing (Tan et al., 2017), medical surgery (Sabri et al., 2010), and journalism (Hatfield & Shaffer, 2006). However, game-based learning applications are still nascent for teacher PD (Pozzi et al., 2016). More attention devoted toward teacher professional development for effective game use (e.g., Annetta & Shapiro, 2019; Foster & Shah, 2020; Stieler-Hunt & Jones, 2019) than toward using games as tools for teacher professional development (Meredith, 2016; though see Markauskaite & Goodyear, 2017; Vrasidas & Solomou, 2013). This new field of games for teacher professional development has only recently begun to organize and theorize how such games should be designed, how their designs tend to lead to particular learning outcomes, and how such games should best be used.

Given the variety of contexts and learning goals of teacher professional development, an educational PD game's design could vary widely, making it paramount at the outset to be clear about the game's intended effects, its relationship to other aspects of PD, and theorized mechanisms for learning (Gaydos, 2015). For example, a teacher PD game may be designed to provide a context in which players may develop an improved understanding of subject matter content (e.g., statistics; Dayal & Sharma, 2020) or more directly to help players understand and practice particular ways of *knowing* and *being* that are based on teacher professional standards and practices (e.g. lesson design; Markauskaite & Goodyear, 2017). In this paper, we detail the game *MetaRubric's* design and intended learning goals, present data from its use, and then situate our findings and the game in the context of epistemic games in order to theorize the role of games in teacher PD.

MetaRubric, a Teacher Professional Development Game-Based Activity

MetaRubric is a card game-based activity designed to be played by groups of 3 - 5 players in education professional development settings. The game consists of a set of numbered cards, each containing instructions for the players to follow. To play *MetaRubric,* one player flips through the deck of cards, reading aloud the instructions on each card for all of the players to complete. Cards are flipped over and read until the deck is complete. The game is divided into two rounds. Cards #1-12 are around 1, and cards #13-20 are round two. There is a recommended break in between the rounds, which are expected to take about one hour each. During the first round, players are instructed to create a movie poster based on a film all players are familiar with, create a rubric to evaluate that poster, and then evaluate one another's' posters using the rubric. During the second phase, players are instructed to create a rubric to evaluate the rubrics that they created during the first phase - a "*meta-rubric*". The players then evaluate each other's rubrics using the *meta-rubric.*

The broad aim of the activity is to provide players with a playful, creative experience that they can evaluate with a rubric and a *meta-rubric* that they use to evaluate the rubric they just created. In this completing the *meta-rubric* creation process, the hope is that participants will reflect on the advantages and disadvantages of rubrics, especially for open-ended, creative activities like the one they just completed. The activity is creative and game-like (e.g., it includes scoring) though it may not be a "game" per se, as it does not tend to support typical game activities. For example, the design relies on the emotional affordances that are provoked by the purposeful ordering of activities –the movie poster is deliberately created before the rubric used to evaluate it. Re-doing the activity or doing the events out of order would presumably provoke different reflections from the players, making *MetaRubric's* re-playability more like narrative-based games that are typically played only once, and less like games that support strategizing and replayability. Given the familial nature of games and difficulty in clearly defined borders (e.g., Gee, 2011)

MetaRubric's design sought to integrate design principles from previous research on teacher professional development. In particular, three design principles that were primary in this work were:

1) Teacher professional learning as social - Research on teacher professional development has demonstrated the value of teachers learning from each other as they take on new instructional reforms (e.g. Grossman, Wineburg & Woolworth, 2001). *MetaRubric* is played in a group of colleagues or other professionals (e.g., rather than as a single player game at a PC).

2) Teacher professional learning should de-privatize practice - In general, this collective work of teacher learning serves to de-privatize the teachers' practice (Bryk et al, 2001; Wardrip & Herman, 2018). Too often, teachers' work has been characterized as isolated without allowing colleagues to see each other's work (Lortie, 2002). In *MetaRubric*, rubric creation and interpretation – an often-isolated activity – is carried out in real-time and discussed in groups.
3) Teacher professional development should supports sense making - *MetaRubric* creates opportunities for teachers' sense-making of what new forms of instruction might look like, particularly through providing a concrete example (the rubric creation process) (Rosebery & Puttick, 1998). Teachers can observe other professionals' sense-making processes and through the guided discussion, share with others what they're thinking (e.g., their justifications and rationale). These discussions create opportunities for teachers to learn new practices (Horn et al, 2015)

Prior to this study, *MetaRubric* had been used as an educational experience at conferences and as a part of teacher PD workshops. Participants, through self-report, were generally positive about the game experience reporting a range of educational take-aways (Kim & Rosenheck, 2020). *MetaRubric* is a teacher professional practice space game (Reich et al., 2018), meaning that it is designed to provide an opportunity for teachers to rehearse and reflect on their instructional practices, particularly through playful activities that help to surface problems they might encounter during design and enactment. Teacher professional practice space games are theorized to compel teachers to change their use of rubrics due to greater empathy with how students experience the rubrics and a deeper recognition of the tensions faced during rubric design and use (Reich et al., 2018). This study sought to gather more direct data supporting this theorized process, connecting the particularities of its design to teacher learning and professional development. To do so, this study focused on educators' meaning making through examining their discussion before, during, and after game play (Horn & Kane, 2015), seeking to draw connections between how it is that teachers talked about the game and their teaching practices.

Methods

Eight high school teachers were recruited to participate in this study. All were from the same high school where one of the author's worked as a principal. The recruited teachers had been teaching for 2 - 12 years, taught at least one English class in general, advanced, or special education classes for students from 9 - 12 grade. The teachers were asked to bring rubric materials that they currently or previously used in their classes for discussion. At the start of the first session, all of the teachers were briefly told about the game, its design, and the structure of the research. Then, they were split into two groups of four based on their professional learning community and colleagues they work with on a regular basis. In these groups, they were 1) interviewed, 2) played *MetaRubric,* and 3) were interviewed again, with each group led by one of the paper authors. The following prompts were used to guide the interviews, which lasted between 30 minutes and 1 hour: What kinds of formative assessments do you currently use in your teaching? What are your views on rubrics and how have you used them? How do you think about designing assessments to support student-centered learning? Can you share some examples of assessment tools that you use? Researchers were present in each group during game play to answer questions and provide additional moderation, such as keeping track of time and explaining unclear instructions. Teachers' interviews and their discussions during game play were audio recorded and transcribed. Additional researcher field notes from the observations were also included in the corpus of data.

Analysis

To understand teachers' views of rubrics going into game play, two researchers independently reviewed the pre-interview, game, and post-interview transcripts, and created descriptive codes to answer the following research questions: 1) "How do teachers view rubrics?" 2) "How do teachers talk about the game?" and 3) "How do teachers talk about rubrics relative to the game experience?" Working independently, the descriptive codes were then grouped into themes. To maximize coverage and coherence of the research question results, the researchers then shared their generated themes in order to create a combined theme set. They then reviewed their descriptive codes to either combine codes, generate new themes, or to reassess whether a new code might need to be applied to the original data.

Utterances used to answer the first two research questions were found by looking for explicit references to the game or to rubrics in the transcripts. Utterances used to answer the third question (making sense of the game in terms of their professional experience related to rubrics) were inherently less clear, as such reasoning would likely be internal rather than explicit. For example, ideal data would include a teacher saying something like, "Based on the game, I think that rubrics..." or "Based on my experience using rubrics, I think that the game..."

Therefore, in order to answer this question, we looked for utterances about rubrics that occurred *during* game play. This data allows us to characterize the game-based, rubric-oriented discussion.

We sought credibility in our analysis through several means (Lincoln & Guba, 1985). Specifically, we sought to maintain methodological consistency through our data collection and analysis (Morse et al., 2002). By this, we mean that our data and analysis were aligned with our research questions and the theoretical framework guiding the study. This was not meant to constrain our process of analysis. Rather, this alignment was intended to ensure "trustworthiness" (Lincoln, 1995) in that our point of inquiry, our analytic approach and our analyses were carried out systematically and as we designed. Also, we conducted regular critical discussions of our analysis among the research team. This permitted us to compare each other's interpretations, challenge one another's analyses and refine our own coding definitions to maintain a common understanding among the group. When consensus was not reached, additional examples from the data were brought to the discussion and the coding definitions were refined until consensus was reached. Finally, having a principal as part of the research team allowed the team a built-in way for the researchers to check interpretations.

Results

How did the teachers view rubrics?

With regards to student learning, the teachers described rubrics as providing a backdrop against which they and their students could evaluate work, "setting the tone" for feedback on how the student could improve. For example, one teacher described rubrics as a tool that provides a space within which students' work could fall (e.g., a 3 out of 4 for clarity), and teachers, students themselves, or peers could perform such an assessment. In addition to being used by students for formatively evaluating their work, the teachers saw rubrics as a means for communicating with students, helping them students to internalize the values along which their work is judged (e.g., good papers are clearly written). Ideally, the teachers expressed, rubrics provided both a scale and descriptive text that students would use repeatedly as they edited and improved their work.

Another function of rubrics the teachers discussed was as tools to communicate their evaluations to students, to other teachers, to parents, and to administrators. Two communication examples were emphasized, communication with colleagues, so that different teachers within department were "on the same page" with regards to evaluation, and communication with administration and parents, so that teachers could explain (e.g., during parent-teacher conferences) why a student paper received a particular score. The rubric, in this way, served as both a means for professional communication amongst teachers, and as an assessment tool that provided transparent and justifiable rationale for student grades.

The teachers also cited challenges to using rubrics to help students learn. They expressed concerns that the students might not understand what a rubric's component means (e.g., what does it mean for a paper to show originality?), what the difference between rubric scores means (a 3 or a 4 on clarity), or how a student might change their work, given the feedback they get through the rubric (e.g., how can a sentence be changed to become clearer?). They pointed out that creating longer, more verbose versions of rubrics could provide more examples, hopefully communicating the evaluation metric in more detail, but were concerned about students not reading the rubrics, especially if the rubric was long or had a lot of dense text. Applying a rubric can also be difficult because interpreting student work relative to a rubric is inherently subjective, and different teachers within the department can use the same rubric but end up with a different score for the student's work, a problem that is amplified the more diverse or creative student submissions are. Additionally, different parts of student writing may fall into different levels of quality, leading to problems like "circling between the [levels]" for an overall evaluation. Finally, teachers noted that rubrics are not often used in real-world settings, and so while students may find them useful during school, the skill needed to use a rubric well might not have application once students graduate.

How did teachers talk about the game?

During the post interview, teachers described positive and problematic aspects of the game, *MetaRubric*. They pointed out that the game highlighted the way that rubrics don't always support a level of creativity in student work, rather, rubrics can limit what students create from the onset. *MetaRubric*, they said, helped to highlight this difference - between trying to come up with creative solutions versus more narrowly aiming to fulfill assignment criteria.

Reflecting on *MetaRubric* as a professional development tool, the teachers pointed out that the game very quickly helped them to talk about professional practices while also avoiding personal aspects of professional work that can get "dicey," such as when two teachers might critically discuss the merits of a rubric that one of them had developed. By providing a playful, neutral activity, *MetaRubric* provided an experience where teachers

felt they could more easily talk amongst one another about the professional challenges of rubric use, "getting on the same page" especially with colleagues who don't normally work closely together.

With regards to drawbacks to *MetaRubric*, they pointed out that the game did not seem to teach them anything particular (e.g., a significantly new way to view rubrics, a new method for rubric creation or use). This was especially notable for these teachers when they encountered and reflected on the parting words of the game, which states that players should have gained "a new perspective on what is and isn't helpful in evaluating students' open-ended work."

How do teachers talk about rubrics in terms of the game experience?

We categorized how teachers talked about rubrics in terms of the rubrics generated through the game as well as how teachers talked about rubrics relative to the game and in their professional work. With regards to the game-based rubrics, the teachers' discussions were based around the use of the rubrics, such as "what [score] did you give that? I gave that an 8." As they used the rubrics in the game to grade one another's movie posters, they also asked one another for clarifications (e.g., "What did you mean by that?").

With regards to talking about the game-based rubrics and their own rubrics, the teachers pointed out that they had a different definition of "rubric" than the game seemed to use. Three of the teachers said that, within the past year they had taken a professional development course that was explicitly oriented toward creating good rubrics, and that based on that course, they understood rubrics to be different from what the game was focused on. As a result of that prior PD, they'd consider the game-generated rubric to be more akin to a checklist than a rubric, as it did not go into sufficient detail regarding the assignment's grading criteria.

Prior to this study, informal observations of how *MetaRubric* was played suggested that the target experience was being achieved, with participants making and thinking about rubrics more deeply, reflecting on their own prior understanding of rubrics, and their use of rubrics in classrooms. Results from this study support that, showing first-hand how *MetaRubric* provokes rich discussion around the problems that teachers face, including their understanding of what rubrics are and what role rubrics play within their profession. These discussions, including the teachers views and the problems they face with rubrics, were extremely context-dependent, relating to both the teachers' personal experiences and training with rubrics, the goals for teaching and learning they have in their classrooms, and the school environment in which they work.

Discussion

Design and Use of *MetaRubric* – Is surfacing problems enough?

MetaRubric was originally designed as a professional practice space game that could provide a play-based experience through which teachers create rubrics, and then reflect on the rubrics and their own rubric-based practices (Kim & Rosenheck, 2020; Reich et al., 2018). Observations from this study suggests that *MetaRubric* was successful in this regard – it created a collaborative playful experience that was a short enough to play during an hours-long PD workshops, it simplified rubric creation, and it served as a shared experience that was reflected on relative to professional notions of rubric design and use.

MetaRubric and other similar professional practice space games, by design, use the games' rules and mechanics to allow for teachers to playfully engage with these professional practices, surfacing problems rather scaffolding particular teaching practices (Reich et al., 2018). That is, the game does not embed, for example, "how to make rubrics better" in its core design or in the post-game reflection. Instead, the game's intended experience ends once an issue is raised, and at this point, relies on teachers' prior professional knowledge and experience to make the experience educational and beneficial moving forward. As a result, players may walk away from a game play session not necessarily knowing how to improve their own rubrics. In this study, for example, teachers raised the challenge of creating rubrics that provide verbose descriptions that attempt to provide students with clarity against the risk of creating rubrics that were too long and that students did not read at all. The problem was one that many had struggled with and none new how to resolve effectively. So, while the teachers were generally positive about the PD experience and the way that the game created a space where they could quickly and easily discuss rubric-related issues, they also expressed that the artifacts generated through game play were neither rubrics (by their understanding) nor did the experience significantly change their view of rubric design and use. Further design work is therefore needed if the game experience is to achieve its intended goal of helping participants impact their own rubric design and use.

Learning in a practice space game

The work of teaching has long been characterized as taking place in isolation (Lortie, 2002), however educational reformers have begun to emphasize the importance of professional practice learning opportunities that

intentionally bring teachers together to reflect upon and shift teaching practice (Wardrip et al., 2015). As the data from this study suggests, PD games like *MetaRubric* may be particularly useful tools for this community-oriented reflection, as the game tends to achieve its intended design goal of helping participant raise issues of practice that they faced. In order to move forward with *MetaRubric's* design and differentiate between individual and community-oriented learning that can occur beyond raising issues of practice, we believe it's necessary to further specify what and how learning might occur, especially relative to the particularities of the game's design.

To do, we turn to Markauskaite, Goodyear, and Bachfischer (2014)'s typology of epistemic games, which differentiates between epistemic games that are *formal*, in which disciplinary epistemologies are conveyed to the player and those that are *functional*, pertaining to the epistemic knowledge used to make sense of the world, especially in professional contexts. In formal epistemic games, the epistemologies adopted by players are new and knowledge is associated with a particular discipline. In functional epistemic games, players are concerned with determining how disciplinary knowledge is situated and applied to their professional actions. Markauskaite, Goodyear, and Bachfischer (2014) go on to categorize different epistemic game types based on 1) their review of five different fields' professional development course material and 2) interviews with relevant faculty. The game types they describe are: propositional games, situated problem-solving games, meta-professional games and trans-professional games, translational public discourse games, and weaving games. *MetaRubric,* though it was not intended to be designed with the taxonomy in mind, can be interpreted as a *(functional) meta-professional game,* or a game that does not aim to convey *new* disciplinary knowledge to the players, rather is designed with the intention to "*enhance joint knowledgeable action"* (p. 1291) especially through re-describing the activity from a shared professional view with intentions of applying disciplinary knowledge to local professional contexts. Identifying *MetaRubric* as a functional meta-professional game is helpful for specifying design aims, identifying shortcomings in achieving those aims, and for guiding the development of supplementary and supporting learning activities to address such shortcomings.

For example, teacher professional development practice space games like *MetaRubric* are characterized by at least two parts, a playful experience that models a component of teaching and the post-game reflection activity (Reich et al., 2018). The playful experience is used as a foil for reflection; the reflection is presumably to help teachers relate their game experience to their own actual professional practices (though its role is not clearly specified in prior literature). In *MetaRubric,* in particular, five reflection questions are provided: Did this activity make you think differently about rubrics? Next time you make a rubric for a class, what will you keep in mind? How did you feel about the format of this rubric? Did it work well or was it constraining? How would you modify it to better meet your needs? Revisiting the design intention of the game, we can see how these questions might change – from questions that are intended to provoke individual conceptual and practical change, toward a change in the local professional community through sharing of expertise, connecting with one another, and finding local solutions.

Advancing Games for Teacher Professional Development

Practice space games are a relatively new approach to teacher PD, and more work is needed to both understand how such games can be designed and used effectively, especially across different audiences and environments. Given the complex landscape of teacher PD, different models of game and play-based learning will need to be explored. For example, games designed for professional environments with participating experts might be designed with less focus less on directly affecting individuals' practice through novel understanding and more on helping teachers sharing expertise with one another. Such games could better support players through dialog - talking about current practices, the professional problems the face, and then coming up with solutions to solve these problems. Learning in such a game activity is less like knowledge acquisition from game play, and more like participation in a professional learning community; the role of the game is to support professional community development. Nevertheless, given the rapidly changing landscape of education technology and the way that in-class assessment skills and associated professional development have long been critiqued (e.g., Brookhart, 2001; Campbell et al. 2002), practice space PD games research is especially timely (Timmis et al., 2016; Will et al., 2019).

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International Society of the Learning Sciences

How the Shape of the Earth is Argued into Being

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Abstract: Claims that depart from Western scientific consensus, such as the relationship between vaccines and autism or the flat shape of the earth are often disparaged. We aim to cultivate greater convergence with scientific consensus, from a stance that rejects attributing alternative explanations to heedless partisanship or emotional susceptibility. We focus on the 'flat earth' explanation, and examine argumentative moves, attention to evidence and knowledge co-construction in YouTube discussions between supporters and critics of 'flat earth.' We found that Flat Earth supporters engage in argumentation and meta-talk about evidence, even at least as frequently as the critics. These findings suggest that cultivating greater convergence on scientific consensus requires deep and nuanced approaches, because alternative explanations can be couched in scientific, deliberative, and argumentative structures.

Introduction

"We're not just fighting an epidemic; we're fighting an infodemic" said the WHO Director at a conference on the COVID-19 outbreak (WHO, 2020). Indeed, scientific misinformation and disinformation on well established scientific topics such as climate change, vaccinations, and the shape of earth are being challenged and disputed. Specifically, in contrast to Western scientific canon, the Flat Earth movement argues that the earth's shape is planar, doubting government agencies' evidence that the earth is spherical (Garwood, 2008). In light of declining trust in science and institutional providers of information (Barzilai & Chinn, 2020), the proliferation of alternative theories (Landrum & Olshansky, 2019), such flat earth, foretell increasing divergence from scientific consensus, some to detrimental effects (Sinatra & Lombardi, 2020). Although ultimately our aim is to encourage public engagement with science, and to support greater convergence with scientific convention, we reject approaches that attribute the adoption of alternative explanations to deficit, heedless partisanship or emotional susceptibility. Instead, we contend that a deeper understanding of the internal logic of such theories can provide more productive avenues for deepening belief and trust in Western science (Kienhues et al., 2020), and increasing the convergence between publicly held beliefs and scientific convention. Therefore, the current study proposes to elucidate how alternative theories are communicated and maintained by discourse practices on social media.

We focus on discourse in post-video comments on YouTube that appear following videos in support of Flat Earth. Unlike other alternative theories, such as concerns over specific vaccines or schedules of vaccinations, where there is controversy within the scientific community, there is a strong consensus over the spherical shape of the Earth, and the idea that the Earth is flat is a radical departure from scientific canon. We chose YouTube as the medium for our analysis due to its key role in the Flat Earth movement. A Flat Earth Conference in Raleigh, North Carolina, November 2017, revealed that many of the participants came to accept the alternative theory of Flat Earth after watching videos about it on YouTube (Olshansky et al., 2020).

Theoretical background

Discursive approaches to knowledge

A discursive approach to knowledge and knowing assumes that social groups and cultures develop shared meanings that are ascribed to practices, artifacts, and systems of signs (Gee, 1990; Kelly & Green, 1998) and that these shared meanings are reflected in interaction and communication. Argumentation is a specific form of discourse in which participants make claims, support these claims with evidence, or try to refute or discount claims raised by others (van Eemeren et al., 2015). Argumentation can be disputational in which participants have persuasion goals, or it can be a form of knowledge construction, referred to as deliberative argumentation (Asterhan & Schwarz, 2016) or collaborative argumentation (Chinn & Clark, 2013) in which participants are mainly driven to understand an issue. In this study, we focus on scientific knowledge and understanding from a community and discursive perspective (Mason, 2007). That is, rather than examine the declarative conceptions of specific individuals through interviews, written tests or tasks, the study examines naturalistic discussions concerning the shape of the earth as these discussions occur spontaneously in the comments section of YouTube videos. This approach may limit our ability to understand individual cognition, but it provides insight into the ways in which knowledge is used in practice in the world. Specifically, by examining arguments between those

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that advocate that the earth is flat and those that advocate that the earth is round, we can examine the ways in which each of these groups engages with the practices and theories of formal western science.

Alternative conceptions and public engagement with science

Science education has a long history of examining learners' conceptions and the ways in which they align with or depart from scientific conventions, variably referred to as misconceptions or alternative conceptions (Chi et al., 1994; DiSessa, 2014; Duschl & Jiménez-Aleixandre, 2012; Linn & Eylon, 2006; Linn, 2008). Examining public engagement with science, there are increasing concerns over the proliferation of alternative conceptions that depart from canonical scientific explanations of natural phenomena or that cast doubt over scientific innovations such as vaccines (Sinatra et al., 2014; Sinatra & Lombardi, 2020). The advent of the Internet and social media has brought about greater access to both conventional science information as well as to alternative positions, and people struggle with reconciling these conflicting resources (Tabak, 2016). One approach to alternative conceptions sees these alternative conceptions as a deficit on the part of those who hold these alternative conceptions (Brossard & Lewenstein, 2010; Seakin & Hobson, 2017; Stocklmayer & Bryant, 2012), implying that if the public were less ignorant of science they would not maintain such conceptions. These approaches may be more pronounced as research on post-truth suggests that people are highly susceptible to adopting misinformation online, and that they tend to engage in immediate surface processing of information (Barzilai & Chinn, 2020; Brashier & Marsh, 2020; Kahan et al., 2017) rather than engage in deeper deliberation (Bago et al., 2020; Sinatra & Lombardi, 2020; Tabak, 2020). In recent years, the deficit model has been critized as an inaccurate and denegrating protrayal of public understanding of science (Brossard & Lewenstein, 2010; Sturgis & Allum, 2004), and there are increasing calls for gaining a better understanding of the nature of the public's scientific knowledge and skills and of how they are used in everyday contexts.

The Flat Earth community

In contrast to current scientific convention that the Earth is spherical, there are those that maintain that the earth is flat (Olshansky et al., 2020). Within the community that adopts a flat earth position, referred to by some as Flat Earthers', there are different perspectives over how gravity works, whether the earth is surrounded by a sheet of ice, and other ideas concerning celestial bodies beyond the earth (Garwood, 2008; York, 2017). Although Flat Earthers have existed for at least as long as spherical earth theories emerged, there has been a resurgence and expansion of this community in the last few decades, considerably influenced by videos posted on YouTube promoting the flat earth perspective (Brazil, 2020; Olshansky et al., 2020). Dating back to at least the 1970's and continuing today, members of the flat earth community offer justifications for their position that include references to religious scripture as well as those that are based on observation, measurement and experimentation (Vogt, 1979; York, 2017). The relationship between conventional Western science views and religious views and their role in adopting flat earth perspectives is an area of study and of mixed results, where religiosity, sensitivity to conspiracy ideology and science literacy were all implicated in a tendency to adopt alternative theories, and a flat earth perspective (Landrum & Olshansky, 2019). In this study, we seek to better understand the foundation of flat earth perspectives by focusing on how flat earth ideas are constituted through the discourse and argumentation that takes place within the flat earth community and between Flat Earthers' and their critics in post-video comments on YouTube.

Methods

We used several search and filtering strategies in order to obtain the YouTube videos that were used in our analysis of post-video comments on videos advocating a flat earth approach. We initially searched for "flat earth" on YouTube and selected the top 20 by number of views. Afterwards, we extended our search using information we obtained from other sources such as documentaries about the Flat Earth community, search trends and popular sites as shown on Google Trends. We searched YouTube for videos based on names of leaders in the community, and on the use of experimentation in support of the flat earth theory. We collected a database of 20-30 videos. Our first filter criteria was videos that advocate for the flat earth theory, next we eliminated videos that had comments that consisted mostly of derogatory interchange. Finally, we selected 4 videos published on the "YouTube" platform that advocated for flat earth, had extensive comments and "likes," and that represented two types of videos typically found in the database we collected, as described below.

We sampled 1278 post-video comments out of these 4 videos. Each video represents a stance supporting the Flat Earth theory, from a different perspective: two videos explain and discuss common questions regarding the theory, and two videos present experiments. We assessed each comment as a unit of analysis using a four-fold coding system:

1. Supporters vs. critics. We coded statements for being expressed to support or to oppose to Flat Earth theory.
2. *Argumentative Discourse Moves.* A coding system was developed based on Lu, Chiu, and Law (2011). Comments were coded along three main dimensions for argumentative discourse moves. The first dimension of the code considered how the present comment evaluates previous comments; namely, whether it expresses disagreement, a counter claim, agreement, or a question. The second, classified each comment as having grounds to warrant their comments. Third, classified each ground for its type (e.g., religious, or scientific).
3. *Meta-talk about evidence*. A coding scheme developed by Shi (2020) to examine changes in use of evidence-based claims during argumentative discourse. This scheme conceptualizes three categories: solicit evidence (e.g., "what is your evidence?"), evaluate source of evidence (e.g., "tell us where you get that evidence", and evaluate content of evidence (e.g., judgment of evidence quality and evidence comparison).
4. *Collaborative knowledge construction (CKC).* We used Gunawardena, Lowe, and Anderson's (1997) coding scheme which assesses the process of knowledge construction in a series of successive (though not necessarily strictly sequential) phases that are viewed as moving from lower to higher levels of group collaborative interaction: (1) Sharing/Adding (e.g., a statement of observation or opinion; definition, description, identification of a problem); (2) Negotiating meaning (agreement or disagreement by providing restatements, by identifying inconsistencies, or by asking for clarification); (3) Elaborating (building on and expanding previous statements and meanings); (4) Proposing synthesis (synthesis of the discussion with the prospect of testing it and finalizing it); and (5) Consensus/Applying constructed knowledge (stating a summary of agreements, application of new knowledge, metacognitive statements of changes in knowledge or ways of thinking).

Findings

From the resulting data, one detail that stood out was that even though the videos support the Flat Earth theory, most of the comments were made by those opposing it 679 (60.2%).

Argumentative Discourse moves. Overall, the most common discourse move was expression of disagreement (630; 61%). As apparent from Table 1, critics expressed significantly more statements of disagreement than Flat Earth supporters (76.2 % versus 38.8%, accordingly; $X_2 = 146.798$, $p<.001$); in contrast, Flat Earth supporters expressed significantly more statements of agreement than critics (39.2% versus 7.2%, accordingly; $X_2 = 158.923$, $p<.001$). Posting direct disagreements was also more prominent at experiment-based videos discussions than discussions that followed theory only based videos (72.8% versus 48.9%, accordingly; $X_2 = 62.115$, $p<.001$).

Overall, 31.7% of *argumentative discourse moves* also included grounds. While there was no significant difference in number of grounds incorporated by supporters compared to critics ($X_2 = 0.435$, $p=.510$), there was a significant difference in type of grounds that were used. Particularly, Flat Earth critics grounded their claims using science-based information significantly more than Flat Earth supporters (98.6% versus 56.0%); while Flat Earth supporters tended to warrant their claims using religious based evidence (44% versus 3.2%, accordingly; $X_2 = 101.134$, $p<.001$).

There was also a significant difference between videos that only discussed the Flat Earth theory and videos that incorporated experiments (Table 1). Particularly, videos with experiments tended to incorporate more grounds in their comments than theory only videos (34.7% versus 28.5%, accordingly, Table 1).

TABLE 1.
Argumentative Discourse Moves count and percentage by participant position or type of videos

		Participants position		Video type	
	Subtypes	Supporters	Critics	Theory only	Experiment
Evaluation:					
	Claim	54 (12.9%)	45 (7.3%)	79 (15.5%)	20 (3.8%)
	Agree	164 (39.2%)	44 (7.2%)	110 (21.6%)	98 (18.7%)
	Disagree	162 (38.8%)	468 (76.2%)	249 (48.9%)	381 (72.8%)
	Question	38 (9.1%)	57 (9.3%)	71 (13.9%)	24 (4.6%)

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Statistics (X_2)	$X_2 = 192.185$, $p < 0.001$		$X_2 = 86.590$, $p < 0.001$	
Grounds:	137 (30.6%)	220 (32.4%)	157 (28.5%)	200 (34.7%)
Statistics (X_2)	$X_2 = 0.435$, $p = 0.510$		$X_2 = 4.957$, $p < 0.05$	

Meta-talk about evidence took place in about 24.1 % of comments. Meta-talk analysis revealed a significant difference between supporters and critics (Table 2). A post-hoc analysis showed that Flat Earth supporters tended to evaluate source of evidence significantly more than critics (12.8% versus 4.5%, accordingly; $X_2 = 6.178$, $p<.05$); while Flat Earth critics tended to judge the quality of evidence significantly more than supporters (36% versus 19.1%; $X_2 = 8.251$, $p<.01$).

Meta-talk about evidence also evolved differently throughout the different types of videos (Table 2). Videos that involved experiments tended to raise more judgment of evidence quality comments (41.8% versus 18.8%, accordingly, $X_2 = 17.005$, $p<.001$); and evidence comprehension (37.3% versus 21.7%, accordingly; $X_2 = 7.943$, $p<.01$). Discussions following videos that only involved theory tended to incorporate more source of evidence evaluation comments than videos with experiments (11.6 % versus 3%, accordingly; $X_2 = 7.397$, $p<.01$).

TABLE 2.
Meta-talk evidence analysis by participant position or type of videos

	Participants' position		Type of videos	
Meta-talk about evidence	Supporters	Critics	Theory only	Experiment
Solicit evidence	7 (7.4%)	21 (11.8%)	20.3%	0%
Evaluate source of evidence	12 (12.8%)	8 (4.5%)	11.6%	3.0%
Evaluate content of evidence:				
Comprehension	20 (21.3%)	60 (33.7%)	30 (21.7%)	50 (37.3%)
Judgment of Evidence Quality	18 (19.1%)	64 (36.0%)	26 (18.8%)	56 (41.8%)
Multiple Interpretation	14 (14.9%)	6 (3.4%)	18 (13%)	2 (1.5%)
Evidence Comparison	23 (24.5%)	19 (10.7%)	20 (14.5%)	22 (16.4%)
Statistics (X_2)	$X_2 = 34.539$, $p < 0.001$		$X_2 = 64.026$, $p < 0.001$	

Finally, *Collaborative knowledge construction (CKC)* analysis revealed that a bigger proportion of comments posted by Flat Earth supporters achieved higher levels of group collaborative knowledge co-construction (level 3 of elaborating; Table 3) than critics (18% versus 10.1% accordingly, $X_2 = 15.191$, $p<.001$). Interestingly, there were no significant differences at the CKC higher levels (level 3 to level 5) that were achieved by the theory videos and experimental videos (Table 3).

TABLE 3.
Collaborative knowledge construction (CKC) analysis by participant position or type of videos

	Level 1	Level 2	Level 3	Level 4	Level 5
CKC levels:	Sharing/ Adding	Negotiating meaning	Elaborating	Proposing synthesis	Consensus/ Applying
Participants' position:					
Supporters	182 (41 %)	172 (38.7%)	80 (18%)	6 (1.4%)	4 (0.9%)
Critics	304 (45.6%)	282 (42.3%)	67 (10.1%)	11 (1.7%)	2 (0.3%)
Type of videos:					
Theory only	279 (51.4%)	183 (33.7%)	69 (12.7%)	10 (1.8%)	2 (0.4%)
Experiment	207 (36.5%)	271 (47.8%)	78 (13.8%)	7 (1.2%)	4 (0.7%)

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Discussion

The broader research program in which this study is embedded aims to understand how people reason about science in everyday contexts to inform formal and community-oriented science education. We further aim to advance greater trust in, and alignment with formal (Western) scientific practices and knowledge. However, we work from a grounding assumption that alternative perspectives arise from a conceptual ecology and reflect an internal logic (Chinn et al., 2020; Demastes et al., 1995; diSessa, 2018). Therefore, we aim to uncover and understand the internal logic underlying alternative theories, as they are "talked into being" (Caronia & Chieregato, 2016) and constituted through naturalistic discourse (Kelly & Chen, 1999). In the present study, we examined the Flat Earth community as a test case, analyzing and characterizing the discourse moves of YouTube post-video comments.

Our findings reveal that in open public discussion venues, theoretical and ideological commitments are shaped and sustained not only through supportive and co-constructed discussion within the community but also through defense of these ideas against critics. The YouTube information ecosystem attracted and gave voice to Flat Earth theory supporters and to its critics. Ironically, critics, who seem to have the goal of eradicating flat earth ideas, may in fact contribute to perpetuating these ideas by providing supporters a need to "close ranks" and defend their perspective (White et al., 2018). In our analysis, Flat Earth supporters achieved higher collaborative knowledge construction levels than critics.

Moreover, the patterns that we found in these pro/con flat earth debates in YouTube post-video comments differed from patterns we found in other, less charged, science-related post-video discussions. The Flat Earth debates included (among supporters) higher levels of collaborative knowledge construction and of expressions of disagreement than those found in less charged discussions, which were predominantly characterized by neutral claims (Dubovi & Tabak, 2020). This supports the notion that Flat Earth supporters are driven toward Flat Earth preserving argumentative moves. In addition, it suggests that research examining scientific discussions on social media should pay closer attention to the social-emotional weight of the issues that are discussed (Dubovi & Tabak, 2021), because differences along these dimensions could affect argumentative patterns.

If we consider the flat earth critic participants as reflecting a stance more aligned with formal science, then we see that Flat Earth'ers are more similar than different, discursively, to "scientifically aligned" speakers. Both Flat Earth supporters and critics engaged in argumentative discourse and meta-talk dialogue about evidence. However, there were two main patterns that distinguished supporters from critics, which could inform education. Flat Earth critics and supporters incorporated warrants for their claims with similar frequency, but they based these claims on different grounds. Flat Earth supporters tended to call on religious evidence, while critics relied more on scientific warrants.

The similarities in argumentative moves between supporters and critics point to the difficulty in resisting alternative scientific explanations. Prior research demonstrates that people are sensitive to texts and discourse that connote "scientificality," and consider the more scientific-seeming texts to be more reliable (Bromme et al., 2015; Thomm & Bromme, 2012). The discussions following videos that presented experiments in support of a flat earth are especially pertinent, because of the combined effect of the use of experiments and the higher proportion of argumentative moves. Therefore, through their "scientificality," alternative theory presentations on social media may seem reliable and convincing. The similarities in argumentative structures and moves between supporters and critics suggests that extending experiences with scientific argumentation may not be sufficient for supporting greater alignment with scientific consensus. The differences in warrants suggest that developing a deeper understanding of the nature of evidence and what constitutes scientific evidence versus other forms of evidence (Chinn et al., 2020; Duncan et al., 2018) may be a step in the right direction.

Conclusion

People who maintain alternative scientific beliefs are often cast as adopting these positions from unreasoned responses to emotional manipulation or to group affiliations. The Flat Earth discussions that we analyze suggest that at least those members of the Flath Earth community who participated in the discussion were reasoned and deliberative, and that much of their argumentative moves were aligned with scientific moves. These findings suggest that cultivating greater convergence on scientific consensus requires deep and nuanced approaches, because alternative explanations can be couched in scientific, deliberative, and argumentative structures.

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Mapping Visual Marginalia in Educational Contexts: A Model for New Types of Self-Regulation of Learning

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Abstract: Visual Marginalia (VM) are a common phenomenon in school, but they hold untapped potentials. We aim to understand their nature and role in learning and thinking. Marginalia are described as making annotations in book margins. In this paper, we extend this concept to include visual self-expressions such as para-writings and para-drawings, creative drawings and writings at the margin of books or notebooks, modification of book pictures, titles or texts, squiggling and doodling. VM are part of students' self-regulatory processes but are frowned upon by teachers. Thus, VM are *marginal* but also *marginalized*. We present a theoretical discussion of the topic, a new semiotic methodology that maps visual marginalia in a real classroom, and a model that reveals unstudied ways that students self-regulate.

Visual Marginalia, visible thought in the margins

Marginalia are the production of graphical and textual elements in the margins of written texts. The Latin term "*marginalia"*, meaning "on the margin", refers to a praxis as old as books themselves and a way to overcome physical and temporal borders. Notes and drawings written in a book or manuscript (Jackson, 2001), allow authors and readers to challenge the text. Jackson (2001; 2010) and Golick (2004) identified two aims of marginalia. The first is a public use where authors of marginalia respond to significant works or to a historical accounting of social and cultural rituals by leaving messages for posterity. The second holds a private function where authors use marginalia to create self-awareness, "tracing the development of reader self-definition in and by relation to the text" (Jackson, 2010, p.10; McHatton & May, 2013). Our work led us to extend marginalia to visual marginalia (VM) in order to study their impact on cognition, motivation, emotions, and regulation of learning.

Marginalia in the educational field: Visual Marginalia

According to social and cognitive constructivism, learners' thoughts and actions are influenced by external elements and by context (Hadwin & Oshige, 2011), but teachers tend to consider external elements in ontological isolation from context and culture. Science teachers typically downplay students' personal experience, artifacts and practices, positioning schooling as potentially disconnected from and not necessarily relevant to students' everyday lives and interests (Darling-Hammond et al. 2020). Yet, individual goals and self-efficacy influence motivation (Bandura,1999) and motivation and goals are expressed in collateral processes and productions (1). According to Reid (2018) marginalia are studied in the development of reading and writing skills with adults where a reader or student, relates to a written text to be understood, modified, or reflected on (Jackson, 2001; Stoddard, 2005). However, we are not aware of studies that consider marginalia as an expression of students' experience and emotional world while they are reading, listening and participating *in class*.

If Schott (2011) claims that marginalia are related to the prevailing state of mind of the author (2), VM 's definition (Dario & Tateo, in press) include the marginalia's author who is interacting in the educational context. Furthermore, VM include all collateral productions such as para-writings and para-drawings, creative drawings and writings at the margin of books or notebooks, modifications of book pictures, titles or texts, squiggling and doodling (the former being less organized and more unconscious), made by students in interaction with the lesson and *not* directly requested by the teacher. Thus, such products are both marginal and marginalized by teachers who may neglect their educational value. VM's main characteristics are as follows (Dario & Tateo, in press):

- They are collateral, literally "located at the margin of the lesson", of the printed book or hand-written notes. Depending on the type of cognitive-emotional involvement stemming from the context or from the lesson, VM assume different positions, locations and forms. First, they may have no relationship to the lesson. Second, they may relate both to the lesson text and the context of the lesson. Third, they may not be related to the lesson context, but reveal the cognitive-emotional state of the student. Thus, writing on the margins is a cognitive-emotional dialogue with the lesson text and context, in which internalization (e.g. thinking and memorizing) and externalization (structuring and expressing cognitive and emotional states) feed into one another (Vygotsky, 1997). VM play a role in structuring,

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understanding, articulating and extending individual experiences because these signs are manifestations of people's uniqueness in relation to socio-cultural context (Vygotsky, 1997).

- They are carried out on support using an exosomatic tool such as a pencil, a pen, or mouse on a screen. Tools change the nature and value of marginalia and Visual Marginalia.
- Marginalia embody affects, meaning they capture how a body acts when it is embedded in a collective that encompasses not just other individuals, but entangled material and discursive elements that constantly co-produce each other (Barad, 2007; MacLure, 2013). In addition, they can reduce tensions generated by negative emotions and be a relaxation strategy to foster learning, a tool for emotion awareness and emotion regulation (Polo, Lund, Platin & Niccolai, 2016).

In summary, marginalia have been studied in contexts where individuals read and annotate material on their own. Based on their marginalia, connections have been made to these readers' learning and thinking. However, in educational contexts where students are interacting in class with their peers and a teacher, there is a significant potential in developing more comprehensive theoretical and empirical approaches to grasp the role of Visual Marginalia in the teaching/learning process. We use a semiotic cultural psychology approach to study Visual Marginalia, to create a qualitative methodology to explore their phenomenology, and to propose a descriptive model that places VM within a two-axis space, from spontaneous to deliberate and from marginalized to normative, allowing us to discuss their impact in self-regulation (Järvelä, Hadwin, Malmberg, & Miller, 2018).

A semiotic approach to marginalia

Educational phenomena are complex and a classroom is a sociocultural environment, providing meanings and resources for human beings to act and stabilize the world they experience through the semiotic mediation of sign-systems and systems of activity (Valsiner, 2007). Visual Marginalia are particular types of signs that play a role both in the internalization and in the externalization of meanings at school. Once meanings are internalized and the developing person has learned to master signs, they will be able to use them to externalize meanings back into social relationships. This process occurs through an active production of meanings by the developing person, in a constant negotiation between social interpretations and personal meaning-making.

Furthermore, the scaffolding role of drawing in the ontogenetic development of sign-mediated higher psychological functions is clearly acknowledged (Papandreou, 2014). It is thus reasonable that Visual Marginalia continue to play a role of external mediator in the elaboration of meaning in the course of development. The marginal spaces become the arena where students can elaborate meaning through the production of particular signs. However, in accordance with the developmental approach of cultural psychology of education, we must observe the process *in its making, in its historical unfolding*, in order to really grasp the developmental role of Visual Marginalia. Thus, Visual Marginalia are studied in their development and the methodology used allows us to "specify precisely both where the development happens and where interventions into development are located" (Valsiner & van der Veer, 2017, p. 152). This requires being able to capture the moving horizon of the developmental process, thus observing the production of Visual Marginalia in the classroom's ecological context.

Accordingly, we present our innovative methodology used to map Visual Marginalia in an authentic school context. Through interviews, we co-construct with the participants the development of their VM and the links with the lesson and the written or printed page. Our aim was to access the first-person subjective experience of students inside the classroom context. This gave us a window into how their emotions led to self-regulation.

A qualitative methodology to study Visual Marginalia

Study Design

To our knowledge, no study exists on VM in the classroom. We approach VM as a developmental process, through the perspectives of semiotic cultural psychology (Anderson & Larson, 2013) that respects phenomenological and interpretive epistemology (Giorgi et al., 1975). In other words, we aimed to describe the who, what, why, when and where of Visual Marginalia. We were also sensitive to personal meaning-making, considering the different voices involved in the process (e.g. students, teachers, and researchers). The protocol is based on a design that employs a teachers' questionnaire, video-recorded lessons (two for each class) and "auto-confrontation" interviews (Theureau, 2003; Clot, 2005). Due to the pandemic, the lesson was conducted at a distance for secondary schools, but face-to-face for primary schools.

Participants

Data came from three classes (42 students, 6-12 years; from primary (15 students, 7 males, 2nd grade; 12 students, 6 males, 5th grade) and secondary school (15 students, 7 males, 6th grade). All three teachers were female. Lessons

took place at *Istituto Comprensivo* in Northern Italy during the 2021 lockdown. Not all participants were Italian native speakers but all had been schooled in Italy for 4 years. No one had behavioral or learning difficulties. Each teacher and student participated voluntarily and parents authorized their children. Three students opted out.

Materials/Tools

The tools used were the:

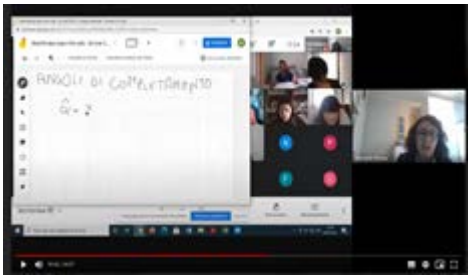
- Google Meet Platform where teachers and students interact, video-record lessons and conduct interviews;
- Interactive Whiteboard (IWB), where researchers interact with Primary School Students via the above;
- Wide-angle lens camera on the IWB to video-record face to face lessons at Primary School;
- Google Jamboard where students move a pointer on Visual Marginalia to explain how they made them.

Procedure

- Phase 0: The researcher established a collaboration with the school and kick-off meetings were organized with the principal and the teachers who participated. Classes were identified and parental assent acquired.
- Phase 1: The teachers filled in a questionnaire on lesson organization: time, activities, task. A researcher gave teachers instructions on how to activate Google Meet and record the lesson. Primary school teachers activated Google Meet so a researcher could participate (cf. Figure1a). Classes in secondary school were virtual and the teacher, students, and researchers were connected through Google Meet (cf. Figure1b).
- Phase 2: The researcher re-informed students that their work would be recorded due to interest in their activities. No further information was provided. The video-recording was set for 40 minutes. Students were trained for 10 minutes on the presence of the camera. At the end, we asked the children to hand in any Visual Marginalia. Some VM were collected by screenshot within Google Meet by photo. Other students sent in photos of their VM with a smartphone. One author viewed all three classroom videos.

Figure 1 (a,b)

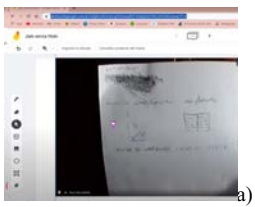
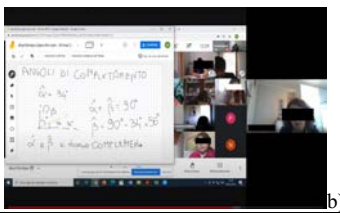
The video-recorded lesson in the primary school is on the left (2a) and the secondary school lesson in the Google Meet Platform is on the right (2b).

a)

b)

- Phase 3: Researchers carried out auto-confrontation interviews (15-20 minutes in Google Meet) where students revealed how they produced Visual Marginalia from start to finish. Interviews took place within two hours from the end of the recorded lesson and were conducted in parallel by a researcher and by two Master Degree students. The interviewer shared two screens. The first contained the student's marginalia (first column) and the second contained the lesson (third column). The student could move a pointer and explain the different phases of her elaboration (Table 1). Students are designated by "P" for pupil; "T" is for teacher, and "I" is for interviewer. Participants are numbered.

Table 1

Example of Mapping the developmental Visual Marginalia productions during a lesson

 a)	P.1: "I meant to take notes and so, as instructed by the teacher, I made a complementary angle".	 b)	T1: "You have to write that alpha and beta are complementary".

Results and Interpretation

We give six canonical examples of Visual Marginalia (scribbling, ornaments, modifications of images, doodling, and drawing). Due to space and interest, we do not present labels or annotations. Interviews reveal how students produced VM. They all appear in Dario & Tateo (in press) and we discovered no new forms of VM. We illustrate how particular instances of Visual Marginalia have an impact on cognition, emotion, and self-regulation in the classroom. This allows us to propose an initial model that reveals unstudied ways that students self-regulate.

Scribbling

This type of VM consists of lines and scrawls. It is positioned at the margin and it corresponds to a rapid movement of the student's hand and often only makes sense to the student at the end of the action. In Figure 2, the student says he is bored and unmotivated in math class and so continues to work on the art concept of *chiaroscuro*. In Figure 3, the student also recounts how she gradually attributed meaning to her scribble while doing it.

Figure 2

A student during math class uses a scribble to reflect upon an art concept studied in the previous period

1: How did you feel before you started scribbling?
P.31: Bored, I had finished the exercise and did not know what to do
I1: and how did scribbling make you feel?
P.31: less bored
I1: Do you also remember what you were thinking?
P.31: About the art lesson I had done earlier
I1: And why?
P.31: Because we had done the chiaroscuro and I wanted to see if I could do it
I1: So it is not connected to the arithmetic lesson but to that of art?
P.31: Yes
[…]
F: Was it born spontaneously or did you decide to make it with intention?
P.31: Spontaneously
I1: That is, did you find yourself doing it without thinking about it?
P.31 Yes

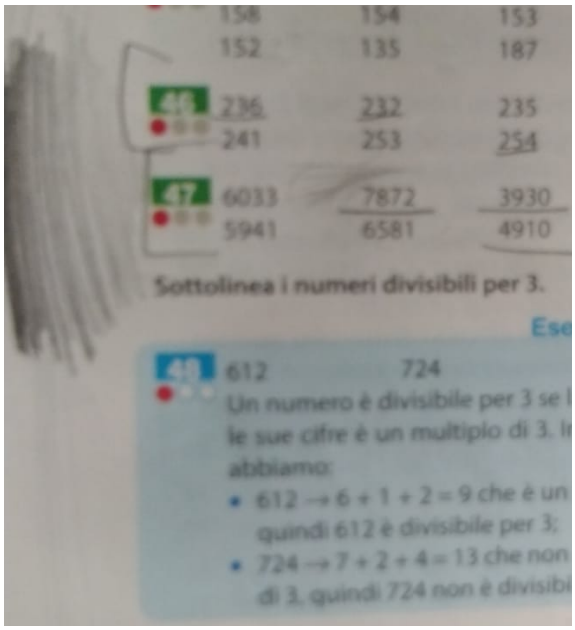
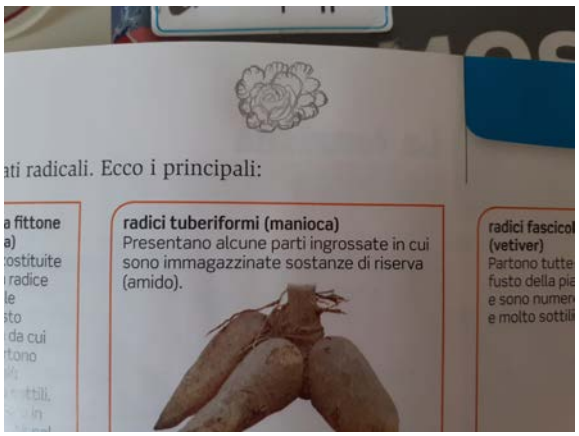


Figure 3

In science class, a student uses a scribble of a flower to conceptualize a metaphor for inner and outer beauty

I: Can you explain it to me?
P.40: There are two flowers, on the outside it is an ugly flower, while on the inside it is a rose that I tried to make look real
I: and what does it mean for you?
P.40: its meaning is not to judge from appearances but to see what that person is like from within, a butterfly is first a caterpillar and then becomes a butterfly
[…]
P.40: We were talking about plants
[…]
P.40: First, I did a scrawl then I realized that…It was a science lesson. I wanted to simply draw a flower because it was science time but then I thought I could draw a rose with a message of inner beauty

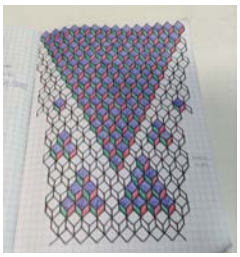


Ornaments

In this VM (cf. Figure 4) students repetitively produce the same simple form (e.g. flower, cube...) but there is a pattern. The student is concentrated on the lesson in the same way as for labels, and reproduces the same element. This particular example is from Dario & Tateo (in press).

Figure 4
In middle school art class, this student produced this detailed ornament that helped her to concentrate

I1 Then when you did this, did your emotion change?
P.2: Yes, I became calm. Let's say that I'm myself again...not because I have many other thoughts but boredom simply disappears and becomes concentration!
I1: Were you getting bored when you made it?
P.2: Yes, a little but it helped me reason and eliminate boredom.



Modifications of images

In this VM, the student modifies the pictures that are printed in the book, for example by inserting decorative/drawn elements (e.g. moustaches, new clothes, noses, etc). In **Figure 5**, the student expresses a state of being connected with the context; he was laughing with his peers during the English lesson on actions. When a scene of happiness appears in a cartoon in the book page, he produces the marginalia, retracing the main characters' mouth and putting crosses on their eyes. In this manner, he creates his prevailing emotion: happiness.

Figure 5
Pupil 25 modified the image on the right during an English lesson on actions to express his emotion

P.25: Yes, the things done with the red pen (.) I made the outlines of the mouths
I1: the crosses on the eyes
P.25: ((chuckle))
I1: I wanted to ask you why did you decide to do this?
P.25: Ehh ... because maybe I had seen some things in cartoons or things came to mind and made me laugh

A student may also use modification of images when he is angry and unmotivated. In **Figure 6**, the student had failed in the first class, and considered that his history teacher was responsible. Thus, during the lesson he often emphasizes his state of being.

Figure 6
Participant 25 modified the picture during an English lesson on actions

P.25 It depends if we are talking about history, in this case it is like if a war was taking place in my head and many times, I draw war pictures on the school images.
I1. What happens in the image?
P.25 "Well, if it is already in the book…maybe I change the character's eyes. I make him meaner. If he has a gun, I add a sword, so I give him a fighting spirit

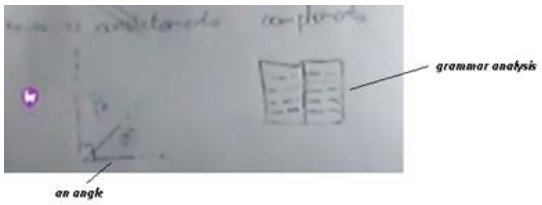
A Doodling Medley

In a doodling medley, the student produces elements that do not have a meaning individually, but have a student-constructed collective meaning (cf. Figure 7). Here, the student thinks of the word "complement" in its mathematical context because two angles that add up to 90° are complementary angles. In addition, the dots on the end of the angle rays represent infinity. But, he also relates these two concepts (complement and dots) to Italian grammar. A sentence with a subject, verb, and complement, is complete, in a similar sense to completing

a 90° angle. Secondly, this student's grammar teacher also always forgot to dot the "i's" and the student was reminded of this when his math teacher said "Please, put the dots that I have forgotten on the sides of the angles".

Figure 7
The student shares the value of marginalia as a tool to reflect on the language of math and grammar.

P1: Here I thought of 'complement', a term used in the grammar analysis that I did with my primary school teacher
I2. "So, is there a relationship with what is happening here"?
P1. "Yup…the connection here is that the teacher said: "Remember to put the dots at the end of the sides of the angles" and so I remembered that my primary school teacher never dotted the "i's" and we used to say: "Teacher, the dots! "



Drawing

Figure 8 shows realistic representations of a scene that condenses the teacher's lecture and page content. The drawing is done at the margin of a hand-written story. The student draws a picture as the teacher reads.

Figure 8
The drawing done by a primary school student to sustain her comprehension and memory during the lesson.

I1: Why did you choose to draw it?
P.8: because it was like the story the teacher read to us
I1: Did it help you understand the story better?
P.8: yes
I1: and what does it represent?
P.8: A little dog and a little girl playing together.
I1: Did the teacher ask you to draw it?
P.8: No, I felt like doing it

A model for new types of self-regulation of learning

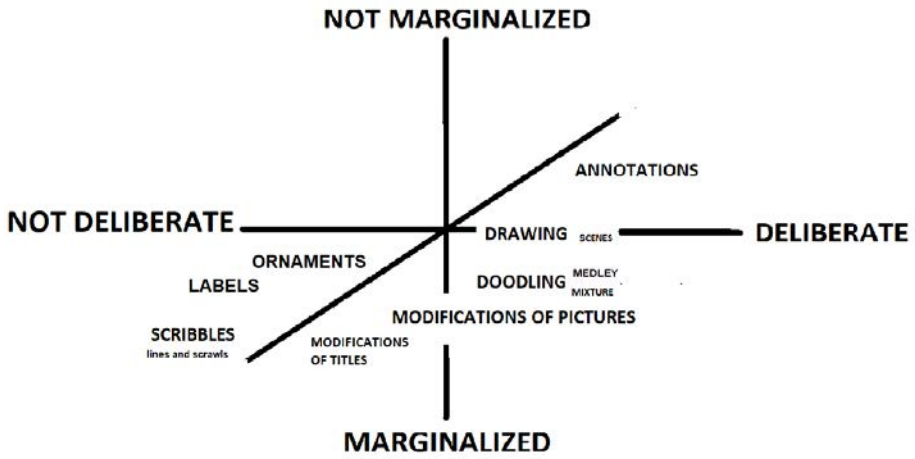
Our analysis allows us to generate an initial model that reveals unstudied ways of how students self-regulate in the classroom (cf. Figure 9). The correlation between the lesson and Visual Marginalia functions as an intermediate space of signification where the student relates his VM to the lesson and enhances the value of both. VM acquire value as they move from being spontaneous to deliberate. Specifically, if the students in our corpus find parts of the lesson boring, their Visual Marginalia are spontaneous products that take the form of scribbles, labels or ornaments, corresponding to automatic writings that the student produces when she has a pen in her hand. They help her to maintain attention during the lesson and awareness of the classroom around her, and limit inappropriate body movements (P.11 "At school I often end up drawing when theoretical subjects are being discussed and teachers could be distracted by my movements). VM can also be deliberate. Modifications of images, doodles and drawings are more deliberate forms and they sustain students' ability to explain, recall prior knowledge, information and experiences about a lesson (Andrade, 2010; Brown, 2014) as well as remember a printed text or their notes, and as we have seen, help students recognize their self-facilitation of understanding.

Often, students' VM change from a spontaneous, repetitive and hardly understandable form (squiggling, labels and ornaments) to a deliberate and meaningful one (drawing and annotations). That said, the entire trial and error process remains mainly marginalized (e.g. generally thought by teachers to be childish) and we argue that this is a missed opportunity. We present the diagonal line moving up to the right as a potential for creative productions. We have observed that students' unstructured drawing and writing (e.g. scribbles, loops or curls) has accompanied the generation of new concepts or creative productions. There is support for this idea from Winnicott (Berger, 1980) who discovered that when children play the squiggle Game, they manifest the necessity to start with a circular line before producing a new drawing.

Certain types of VM (scribbles, labels and ornaments) can also be an escape from stressful situations or they can contain the expression of feelings connected with the ongoing lesson. Thus, Visual Marginalia could reinforce an internal feeling or repress it. VM increase students' self-awareness of their feelings and their state of

being (See P.25 in Figure 5 and Figure 6) and their skill in recognizing and manifesting them. VM are an emotional regulator. When students feel unmotivated or disengaged, they draw and consequently they reduce their tendency to mind-wander while increasing their concentration.

Figure 9
Visual Marginalia occur along two continua: spontaneous to deliberate and marginalized to not marginalized.



In the case of doodling (mixture and medley), Visual Marginalia becomes a powerful tool in elaborating the learning experience when there is high-level content-based interaction (cf. Figure 9). Through the connections between elements, we can reconstruct the elaboration of student thought. When retrieving information immediately after the teacher's talk or reading, a student may have access to a highly active mental network and, according to Fletcher, van den Broek, & Arthur, (1996) meta-comprehension can be facilitated (Thiede et al., 2018). Doodles are multimodal summaries of knowledge at the margin without being time consuming practices.

Conclusions

We illustrated the concept of Visual Marginalia, a ubiquitous phenomenon, to which little attention is paid in the educational field. We presented a qualitative methodology, implemented at two school levels in order to explore VM in an authentic teaching-learning context. We showed how video-recorded lessons and "*auto-confrontation*" interviews with students *revealed* how and why VM were produced during class, giving the interviewer insight into the reasons for emotions it produced, or what emotions caused it, and how these emotions were linked to the lesson. We then proposed a model illustrating heretofore unstudied ways in which students self-regulate.

In this sense, VM are not regressive and childish, but can be a valuable visual support for teachers to understand how students self-regulate their socio-cognitive-emotional processes. Given the visual nature of VM, our perspectives for teacher training modules include 1) STEAM (Science, Technologies, Engineering, Art and Mathematics), where art can be used to express scientific concepts and 2) collaborative settings, where students can use marginalia to engage in transactive discourses such as critique, challenges, and synthesis.

Endnotes

(1) We use the term collateral to indicate all the processes at the margin or marginalized by teachers and students and that are considered to have little or no educational value.
(2) According to Schott (2011) doodles provide a window into the personality and the psychology of authors. They can be a symbol of mental disorders such as schizophrenia and they recall surrealist automatic drawings.

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International Society of the Learning Sciences

Actor-Network Theory as a New Direction in Research on Educational Dialogues

Abstract: The analysis of educational dialogues has been traditionally undertaken according to pre-given coding schemes, which are often teacher-centered, and in which multiple time scales are not considered. In this paper, we consider the use of Actor-Network Theory (ANT) methodology. While ANT has already been used in education, its application for analyzing the deployment of educational dialogues over time is novel. We analyze some educational dialogues in a program dedicated to dialogic pedagogy. We show that ANT enables us to consider the observation of educational dialogues as the formation and dissolution of networks between humans and non-humans, where roles are not pre-determined but translated in interactions, and the educational design of instructions is black-boxed.

The gaps between dialogism and dialogic teaching

Dialogism is a vast domain that has inspired scholars from various traditions (Marxism, semiotics, structuralism, religious criticism) and disciplines such as history, philosophy, sociology, anthropology, and psychology. It has also revolutionized the world of education. This revolution is firstly linked to Bakhtin's communication legacy. According to Bakhtin, every utterance is related to another utterance, true to turn-taking. The conversational norms are followed for a discourse to have a cohesive flow in which individuals respond to one another (Bakhtin, 1935). Bakhtin's enterprise critiques the monologization of the human experience that he perceived in the dominant linguistic, literary, philosophical, and political theories of his time (Baxter, 2006).

While dialogism breaks the monology of humanism, it is still bound by its Humanist threads: it focuses on the human as the instrument of knowledge-making. Dialogists focus on 'culture', sociolinguistics, classroom interactions, and communication patterns, which are all human-centered. This is evidenced, for example, by take-up 'the utterance' as the basic unit of analysis in dialogical research (Bakhtin, 1935). Davies and Renshaw (2019) stretch the notion of human beyond the unfinalisability of dialogism and its humanist legacies; they adopt a *posthumanist* political approach that 'dislocates the foundations of the humanist worldview' (Braidotti, 2006, p. 203). For them, human is neither a biological nor sociological category, but an interface, a field of intersecting material and symbolic forces; a surface where multiple codes (sex, class, age, race, etc.) are inscribed'.

Dialogic education is a pedagogical movement based on dialogism. Its implementation is constrained by the educational structures, practices, and norms in place in schools, though. Consequently, the major ideas of dialogism – the interrelation of voices and their uniqueness and the polyglossy of communication – do not fit classroom talk ruled by traditional pedagogies. The fact that voices should be aligned to what is recognized as correct, the centrality of the teacher as the authority of official knowledge, the attainment of clear learning outcomes, are few phenomena that make it difficult to implement dialogic education. The term Educational Dialogues points at a change, which envisions classroom talk as more fit to dialogism. The recent volume Research Methods for Educational Dialogues (Kershner et al., 2020), which is aimed at presenting various methodologies for observing the quality of educational dialogues, stresses in fact the passage from old to new practices. In the

volume, the Scheme for Educational Dialogue Analysis or SEDA elaborated by Sara Hennessy and her colleagues is presented. It transcribes the dialogue, divides and classifies it according to pre-given code schemes (Hennessy et al. 2016). SEDA served as a tool for showing that Dialogic Teaching improves learning outcomes (Howe et al., 2019) which provides an important answer to the detractors of Dialogic Education. However, SEDA does not enable us to look at the development of dialogues over time. Also, it is anthropocentric and does not relate to non-human actors and how they shape classroom dialogue.

Actor Network-Theory

Actor-Network-Theory (ANT) seeks to give an account of how the social world endlessly disassembles and reassembles itself through the complex interactions of its actors, which may be animate or inanimate. ANT spurns traditional social 'forces' as determinate of actions, seeking to account for social structure by analyzing the processes and connections through which networks are assembled. Latour and Woolgar's (1979) ethnography of a biomedical laboratory draws on citational data, and research reports from the lab supplemented with fieldwork and interviews. They turned the lab into a place where facts are 'secreted' through processes that involve researchers as actors assemble and interpret data.

A key assumption in ANT is *symmetry* (Latour &Woolgar, 1979). ANT researchers oppose approaches that concentrate only on humans, while objects, machines, and materials remain often overlooked. According to the ANT approach, all things, human and non-human, can assemble, exert force, change, and be changed. According to ANT researchers, nothing is given or *a priori* defined. Entities, human and non-human, are transformed through to process of becoming part of a collective network (Fenwick & Edwards 2010). The title of an actor does not convey a pre-given role; it is translated by his/her/its actions, connections, and the change he makes in a specific network. Agency, power, identity, and knowledge are relational effects of a certain network and not pre-given attributes. For example, McGregor (2004) shows how a science teacher becomes a knowing location through the interaction of materials, routines, texts, and people. She describes how laboratory artifacts, instructional practices, and teacher traits are assembled into a network and create knowledge and agency.

Certain assemblages stabilize and move about from one network to another network and extend its original network's power. When these assemblages move to new networks, they can be taken for granted. Fenwick and Edwards (2010) bring an example of the Black Boxing in education and describe how curricula become Black Boxes. A curriculum is an effect of a heterogeneous network of people and things, and historical and political networks, which often solidify and become durable. Then it spreads and shapes the learning in classes. The teachers (and the students) might take the curriculum for granted, leaving behind the ongoing discussion and interaction that led to its creation.

In this paper, we exemplify the use of Actor-Network Theory (ANT), a methodology that has not been used to analyze educational dialogues. Educational dialogues are viewed through networks of teachers, students, and actants that exert power on each other. The roles in the networks are not pre-determined but translated in interactions (e.g., the teacher may become a discussant whose status is comparable to that of the students). Educational activities designed to promote dialogue are often black-boxed, and the original process and circumstances of their creation might be ignored. Still, this black-boxing is possibly reversed in further educational

dialogues. We show then that the adoption of ANT for analyzing educational dialogues uncovers the shifts from less dialogic to more dialogic and explains the mechanisms that lead to these shifts. Shifts from one network to other convey the change of power relations between the different actors and the determining role of non-human actors (instructions, pictures, etc.). ANT emphasizes how these actants shape the dynamics of networks in which educational dialogues lay. We draw from ANT's analysis implications both for research and educational practice in dialogic education.

The educational context

In September 2019, we initiated a multidisciplinary, dialogic instruction program in four schools in a mid-size town in Israel. A school professional development (PD) program was implemented in which teachers that taught in Grade 7 in mathematics, humanities, and science. The school principals encouraged the teachers to participate in the program in order to enact dialogic practices in their classes. We negotiated the program with all the stakeholders involved. The teachers and superintendents responsible for schools pointed at the need for a program that would raise strong interest and engagement. We preconized the enactment of a dialogic pedagogy for enabling interdisciplinary processes among students. We and the stakeholders decided to instigate an out-of-school series of interdisciplinary activities to foster dialogic argumentation. 130 Grade 7 students participated in a series of activities organized in "climax days". Each climax day focused on a different societal issue, and included disciplinary sessions (in mathematics, science and philosophy) during which students learned about ideas relevant to the societal issue, preceded an interdisciplinary session in which a joint product (e.g. a presentation, a clip, a written story, a petition) was produced. Deliberations around texts that invited inquiry and dialogic argumentation were conducted in all disciplines and all sessions.

1st example: Revealing with ANT the complex role of design in educational dialogues

The teacher begins the lesson by giving explicit instructions for a small group activity: "This activity summarizes everything you have been through today... I will distribute a board with an axis to each group, representing the degree to which arguments support or oppose the issue we discuss today [Would it be right for the government to mandate parents to vaccinate their children?]. You will be provided the cards you already produced in the previous sessions in the different disciplines. We will discuss this question in this summary section using all the information you gathered along the different sections. You should already have two cards of reasons and arguments pro or against vaccination… so you should pinpoint your card somewhere on this axis. In addition, I will give you cards with new arguments, and you should decide as a group where to place them on the axis." The instructions conveyed a meticulous design. Then the teacher arranged the students into different groups. We present an excerpt from one group of five girls. After clarifying the instructions, the group discussed how to design the board:

Table 1

Excerpt 1

55	s1	Just one minute, so we need to [design the board] with one side opposing, and the other side supporting.

56	s4	Let's split it into halves, and then we will know.
58	s4	Right. It is [designed that way] so we can put [the cards] here and here in the plus-minus axis.
60	s3	Axis. Look, I and Yuval thought [abrupted].
61	s4	Don't make dots; make them lines. That way.
62	s2	Yuval, should I write it this way?

In this excerpt, the human actors are the teacher and the students. They explicitly refer to the Bristol board or point at it in all turns. It is a non-human actor; it is an actant. This reference to the Bristol board exemplifies the methodological concept of symmetry (Fenwick & Edwards 2010), in the interaction between human and non-human actors. In this example we can see how the Bristol exerts agency and shapes the interaction as an actant: The teacher's instructions referred to the board; the "we need to design the board" in turn 55 shows that the students interact with the instructions just given by the teacher. The Bristol board is translated to become a performing part of the network, which almost "gives orders" to the human actors, like in line 56 as if the board 'says' "split me in two halves and then you will know". In this interaction, the non-human actor, the Bristol board, becomes the center of the network instead of the group of students. It exerts force upon them and subordinates them. The students are busy with making a material product, which alienates their actions. We define such a network in which some human actors are subordinated as a non-dialogic network. After five minutes of designing the board, a student suddenly asked her friends' opinion on mandatory vaccination. This discussion went on for a few minutes only, as another student interrupted it to request the group to focus on an organizational task.

Table 2

Excerpt 2

76	s5	Girls, do you support mandatory vaccination?
77	s4	No
78	s1	No
79	s2	Yes
84	s5	I support vaccinations, but I don't think it should be mandatory.
85	s4	I don't think it should be mandatory because in the end, come on, someone that doesn't want to [be vaccinated] it is his problem.
86	s5	No, it is not only his problem.
87	s6	All the people with cancer and babies [that cannot get vaccinated]. **[88-146] the argumentative discussion continues**
147	s2	In the end, [he has a choice] about his health, and I understand that he can infect someone by accident. But the majority of the population, as Lea said, is vaccinated so [abrupted].
148	s1	As you said, who does not get vaccinated, it is his problem; he will get sick.
150	s5	If someone doesn't take care when he has lice, others get infected.

158	s3	First thing, I wanted to say that we have to start working as Rachel [the teacher] said. Stop! You wrinkle it!
181	s2	We should. Let's organize it [the cards on the board].
184	s4	I wanted to say we have to start working and don't say our opinions; otherwise, we will not work.
185	s5	Because our opinions do not matter, just joking.
186	s2	So, let's finish [with saying] the opinions
205	s2	First, we read [the card], and then we need to decide if it is supports or opposes.
206	s5	We don't care about your opinions. Read already!
209	s3	"The Israeli Ministry of Health. Vaccinations are considered a medical breakthrough. They defend against disease…"
210	s1	OK, we got the message. It's pro.

This excerpt demonstrates how easily a network can be dissolved. Students examine the issue and constitute the main actors of a dialogic network up to line 150 (and in fact to line 157, which is not displayed). In line 158, S3 calls her peers to "start working", namely classifying text cards on the axis on the board (158). The board, and the text cards exert their power upon the students, who decide to end their argumentative dialogue: In line 184, s4 suggests to "stop saying their opinions because otherwise, we will not work." In line 185, s5 sarcastically says that "our opinions do not matter." The students obediently read the reasons on text cards and decide if they support or oppose compulsory vaccination. Students' decisions are immediate and do not lead to further discussion. This exposes what Latour termed "a Black Box" - a process when dynamic events and negotiations freeze and become durable. Then it can extend itself to other networks and contexts where it conceals the dynamics and circumstances where it was produced. Paradoxically, when the researchers designed this activity, they intended to promote a dialogue. They assumed reading the text cards would enrich the students' dialogue and open it into new directions. However, this complex process was frozen into compliance to a set of instructions that dissolved the small group network. The classification of the text cards black-box the network, into a material product used in further activities without reference to the network that preceded its production. Therefore, instead of promoting a richer dialogue, the students' interpretation of instructions undermined it and replaced it with a different network where instructions and boards ruled interactions.

2nd example: The contextual character of the formation and dissolution of networks

Like in the first example, the teacher gives instructions in a small class before splitting it into two small groups. The teacher asks one of the students to read a text, which describes a futurist scenario about Genetically altered embryos and its possible consequences, and then says: "What I ask you right now is to split into two groups: supporting and opposing [genetically altered embryos]. You can use the futurist scenario [text to support your position]. Think about what kinds of reasons, supporting and opposing it provides. There are things here that can help you. What I ask you to do is to split into two different groups and write arguments supporting and opposing [genetically altered embryos]". The beginning of the discussion in the group assigned to support genetic

modifications deploys in a dialogic network, in which the students present different reasons, weigh them, and challenge each other.

Table 3

Excerpt 3

4	s1	So, let's think about the reasons. Wait, [are we] support or oppose?
5	s2	support.
15	s2	I have something really good. We can genetically modify children. I am talking about health here. They will not have diseases, so the government will not have to invest in vaccinations and have much more money. Think that one genetic modification [is needed] instead of eighty years of medical treatment.
17	s3	It is written here that it costs a few million dollars.
27	s3	On the one hand, it is good, but on the other hand [disrupted]
28	s4	Many people will lose their jobs.
30	s1	We don't know what will happen fifteen years from now. Maybe many other medications will be found, and perhaps the doctors' community will change. Perhaps we will not need so many doctors and robots will take their place.

The teacher functions as a facilitator of the dialogue (not shown in the protocol). After 15 minutes, a second teacher (T2) joins the conversation and changes its direction:

Table 4

Excerpt 4

130	t2	OK, I would like to ask you something: Who eats fruits? All the fruits we eat today, all food engineering is based on genetic modifications. Wild bananas don’t look like the ones you eat.
144	t2	So, I gave you a piece of information. How does it help you to argue in favor [of genetically altered embryos]?
145	s1	It does not.
146	s2	It really does. If genetically modified fruits come out so tasty. Why shouldn't we?
147	s4	They are so pretty and healthy and good - so we also want to be pretty and smart.
153	t2	You know that one of the opposers' arguments is the fear of technology. Their fear will affect other things. But we can say: it is not frightening; we use it and we even - (interrupted)
154	s1	But we never tried it on humans! Vegetables, fruits, and humans have different genetic structures.
155	t2	Noa, you support [your group is supposed to support genetically altered embryos].

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156 s1 I am against it!

157 t2 You should [interrupted].

158 s3 Noa, write that all fruits are [genetically] modified yet we eat them.

159 s1 I wrote [it].

This excerpt demonstrates the unexpectedness of a network in educational dialogues. T2's interventions in lines 130 and 144 were intended to refute critiques about genetic engineering based on a comparison of human and food genetic engineering, ineluctably leading the students to conclude that people should not fear genetic engineering. One might expect that this move would reduce student agency. However, S1's interventions in lines 145, 154 and 156 change power relations: In line 154, S1 challenges T2's position according to which genetic modifications were never experienced on humans' fetuses because humans have a different genetic code than vegetables. She put herself as an equal contributor as the teacher by doing so. Before the teacher joined the discussion, the students constantly examined and challenged each other ideas, and their agency was salient. The students' agency conveyed in their dialectical activity was not altered when T1 appeared (not shown in the excerpt): S1 criticized T1's statement the same way her other students challenged S1's position several minutes earlier. Nevertheless, despite her criticism of T1's statement, she eventually writes T1's challenge on the Bristol board. Her acceptance shows that agency and power should be seen as dynamic effects of relations.

This example shows that roles cannot be prescribed in advance in educational dialogues. Entities, human and non-human, are translated in specific contexts, e.g., changed through to the process of becoming part of a collective network (Latour & Wooglar 1979; Fenwick & Edwards 2010). The role of the teacher, of the students, and other objects emerge from their interactions and assemble in specific networks. The title 'teacher' or 'student' does not convey a pre-given role; it is translated by actions, connections, and changes in a specific network. The second example demonstrates the tension in the process of translation. The teacher acted as an authority that wished to transfer knowledge; however, as she joined an existing discussion where the agency was in the hands of students, S1 did not see her as a source of knowledge but as an interlocutor whose position could be challenged.

Discussion

The use of ANT is not new in educational research. ANT has been used for investigating curricula, policy analysis, and the relations between technology and education (Hamilton, 2012; Wright & Parchoma, 2011). Yet ANT has not been used for contexts of learning in social interaction. The present paper focuses on educational dialogues and capitalizes on ANT to consider dialogues as networks of human and non-human actors who constantly assemble, dissolve and reassemble, and exert force and agency on each other.

Although the analysis of several protocols is not sufficient to validate the usefulness of the ANT methodology in research on educational dialogues, it points at several phenomena that we recurred in further analyses. First, the maintenance of educational dialogues is fragile: They may assemble due to instructional designs and paradoxically dissolve because of these very designs. We showed that the documents, instructions, etc., that these designs generate might play as actors whose agency interrupts the deployment of educational dialogues. More generally, the ANT methodology stresses the central role of inanimate things – Bristol, instructions, texts, and various tools in inhibiting or catalyzing the deployment of dialogues. The ANT

methodology suggests that designers should plan meticulously settings to not impair the flow of educational dialogues. Moreover, we saw that ANT helps identifying black-boxed networks, that are solidify and exert power in further activities as the original process and circumstances of their creation might be ignored.

The use of the ANT methodology enabled us to exemplify how actors do not have fixed pre-determined roles. Instead, this role emerges in specific networks that assemble or dissolve: The role of the teacher or the students varied in the protocols we presented from a peremptory figure to a facilitator of dialogues; students alternatively complied with instructions or opposed the injections of the teacher. We claim that the context of educational dialogues, which is a context of educational change, is characterized by frequent passages, back and forth, between traditional and novel roles. The insights we reached should be backed up in further research, but the examples we presented point at an important role that ANT should play: when the term "dialogue" is overused, this methodology enables to distinguish between dialogic and the non-dialogic in the classroom discourse.

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Solidarity in Shifting Lines of Practice: Learning in the Weave of Social Movements

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Abstract: While learning sciences researchers have explored forms of solidarity underpinning learning and relations across powered forms of social difference, they have largely not integrated insights from social movements literature. Building with lines of practice theory (Azevedo, 2011, 2013), we analyze ethnographic interviews with animal rights activists to understand how power relations and the felt obligations of privilege shape how individual lines of practice develop within the collective pursuit of justice. We find that individual learners feel the implications of their place in the "weave," as one thread among many, shaping their practice in ways that are neither internal nor external, but fundamentally relational.

As the learning sciences have embraced questions of power, politics, and ethics in recent years, a theme around relationships of solidarity has organically emerged. In analysis of classrooms, of social movements, of extra-curricular activities, and other spaces, we have seen the significance of relationships of solidarity across diverse contexts. This is a promising field of analysis, with much to offer our understandings of who is learning, when, and how, and the emergent work actively addresses racialization and gender as significant relations that must be accounted for. However, across the different analyses, scholars have theorized the relations differently and inconsistently, generating descriptive terminologies steeped in specific contexts. As social movement-attentive/immersed researchers, we read all of these examples as residing under the umbrella of solidarity, yet without attending to the social movement usage or the academic treatments of solidarity that underpin their use.

This additional literature productively supplements learning sciences theorization of relational enactments of solidarity. The learning sciences have long been sensitive to accounts of learning as an interpersonal phenomenon (Vygotsky, 1978), but have often left power relations under-examined (Esmonde, 2017; The Politics of Learning Writing Collective, 2017). Learning research in movements helps correct this, enabling new analyses of collective learning in the form of larger transformation in social structures that movements effect. There is also value in examining how learning transforms individuals within movements and how power inflects that process.

Theories of learning in out-of-school spaces, such as "lines of practice" (Azevedo, 2011, 2013) and "cultural learning pathways" (Bell et al., 2012) can help us bridge these theoretical conversations. We revisit these ideas in the context of more recent work on relationships in politicized learning contexts to build on what they offer for our accounts of individual learning within solidary relations. We seek to orient learning sciences researchers to theories of solidarity in order to anchor the emergent work on relationality in the broader theory and praxis of social movements. We then use the conceptual tools from solidarity studies to analyze the relations of solidarity that show up in our own research in social movements to articulate the messiness of learning in and from relations of solidarity and the contradictions that are inherent to those relationships. We argue that when we examine the learning of individuals as they act on the basis of solidarity in social movements, we can see how their learning is constrained and opened up not only in relation to their own constraints and scopes of possibility, but in the deeply affective ways in which they understand the constraints and scopes of possibility of *others*.

In the sections that follow, we briefly highlight work in the learning sciences that fits under the umbrella of solidarity, and then review social movement theories of solidarity to ground learning sciences work in larger conversations around political organizing across difference. We also bring to bear insights from out-of-school learning and how people develop increasingly sophisticated practice. We then provide an overview of the animal rights activist group Direct Action Everywhere, our data collection, and our methods for analyzing these shifting pathways and possibilities as activists mobilized solidarity frames. We analyze the data from activists reflecting on the solidarity tactics they attempted, tying them to both the theories of solidarity we review, and reading them through the lens of lines of practice. We conclude by arguing that learning in solidarity reveals important insights about the relational and collective nature of individual development.

Solidarity in the learning sciences

Recent work in the learning sciences that has focused on relationships in explicitly politicized learning contexts demonstrates the value of shared experiences in developing solidarity relationships. The Politics of Learning Writing Collective (2017) call to action asked the learning sciences to be in solidarity with community, using research partnerships as an avenue for social change, and sharing the fight against nationalist racial capitalism.

As a call to action, the paper did not articulate what solidarity is or how it enables learning relations, but it emphasized solidarity as an emergent concept that can—and should—underlie learning sciences approaches.

We see evidence of solidarity across many examples of recent work. Uttamchandani's (2021) work on educational intimacy theorizes the relational practices of queer youth as they prefigure spaces of radical inclusion that embody queer politics. Using humor, teasing, self-deprecation, and other interactional practices, these young people focused on building relationships of care which both expressed and enabled their political work. Key to this perspective is the ability of LGBTQ+ youth with a shared basis of experience to prefigure together the relations of justice they wanted to see more broadly. Teeters and Jurow (2018) describe relations of confianza, signifying "commitment, trust, and reliability" forged in intimate spaces. In their work with promotoras in a mostly low-income and Mexican immigrant neighborhood, they examined how relations of confianza enabled expansive forms of learning by laying a relational foundation on which community change could be built. Vea (2020a) examined how friendship forged in shared experiences of community enjoyment in an animal rights collective helped make learning possible through emotional configurations that enabled and sustained new forms of politics. Curnow et al. (2020) argued that relationships based in shared experiences of gendered marginalization within a social movement organization created spaces where snarky critiques of masculinity and mainstream environmentalism led to stronger relationships and stronger political analysis through dialectical and iterative processes. In each of these cases, shared experience was a foundation for political learning and change.

The work of McKinney de Royston, Vakil, and colleagues (McKinney de Royston et al., 2017; Vakil & McKinney de Royston, 2019) both demonstrates the importance of explicitly race-conscious solidarity and the consequences of its absence. McKinney de Royston et al. (2017) found that in a program for Black middle school boys taught by Black men, educators developed an explicitly politicized notion of caring in which academic success and addressing systemic racial inequities was seen as preconditioned on the social-emotional wellbeing of the Black youth and the intentional cultivation of strong instructor-student relationships. Vakil and McKinney de Royston (2019) developed the idea of "politicized trust" as encompassing mutual understanding, respect, and solidarity. Focusing on solidarity as an interactional accomplishment, they found that a lack of politicized trust between a Black/Eritrean student and a white student ultimately limited the possibilities for equity-oriented learning in a multiracial classroom. While in one case, relationships based in shared racialized experience supported an explicitly politicized form of learning, in the other case, a lack of racial and political solidarity interrupted opportunities for learning.

These contributions demonstrate the significance of relationality for shaping learning, and they put politics at the center of those relationships. In attending to marginalized communities, they highlight learning that happens in and through struggle, along with the joy, intimacy, and trust that emerge from those spaces. But these analyses do not draw on the larger body of scholarship around solidarity and the complicated, and often contradictory, relations of power that emerge when people work and learn across difference, especially in cases where people in positions of relative power and privilege are working for and alongside those with less power, while contesting those very power relations they seek to leverage. These messy politics and relationships across difference push learning scientists to bring stronger theories of solidarity into focus alongside conceptual tools for understanding learning, finding new points of synthesis that can strengthen our understandings of both solidarity and learning. To do this, we now turn to the social movement and scholar activist literatures of solidarity to expand the discussion and anchor it in social movement praxis.

Social movement perspectives on solidarity

We focus on theories of solidarity rooted in social movement contexts, many of which are written by scholar-activists embedded in solidarity campaigns, and we note that these applications that stem from the ground are significantly different than the political theories that circulate (Curnow & Helferty 2017). Solidarity is defined as activism in one location—geographical, socio-economic, political—that works to "defend the interests, rights, and identities" of people in other locations (Olesen, 2005; Sundberg, 2007). The central premise of solidarity, from activist perspectives, is that solidarity is defined by its attention to work on behalf of others (Finley-Brook & Hoyt, 2009), though many stress that solidarity is not done on behalf of others—it is not charity. Koopman (2012) argues that the difference between charity and solidarity is foundational: where charity makes no effort to disrupt systems or imbalances of power (it is oriented to helping people navigate existing systems) solidarity is constructed as a process of amplifying voices of marginalized people (Koopman, 2012; Mahrouse, 2014) or standing alongside the oppressed (Brown & Yaffe, 2014; Shohat, 2001). These campaigns are based in shared vision of collective liberation (Finley-Brook & Hoyt, 2009; Hussey & Curnow, 2016; Mahrouse, 2014).

Across the strategies for solidarity, the distinguishing features are a recognition of inequitable power relations and an attempt to prefigure different kinds of relationships. This means that solidarity strategies explicitly attempt to use disparate access to power and privilege as part of their strategic interventions (Koopman 2012;

Mahrouse, 2014). Solidarity campaigns often rely on the participation of people who benefit from structural privilege in current systems working within their own communities to spread understanding of privilege and grow the base of people working to unmake systems of oppression (Finley-Brook & Hoyt, 2009; Hussey & Curnow, 2016; Koopman, 2012), or to strategically focus on advocacy work within their own countries in support of campaigns elsewhere in the world (Finley-Brook & Hoyt, 2009). The research and campaigns framed around solidarity stress that mutual solidarity is possible and is built on resisting systemic power imbalances (Sundberg, 2007). Reviewing this work on various theorizations of solidarity, Curnow and Helferty (2018) argue that the contradictions of solidarity are significant, and that the ideas about using racialized power and privilege to counteract it ultimately rely on and reinforce those very positions of power. They argue that ideas of solidarity are often incommensurable, and that the tensions embedded within solidarity relations, while not resolving anything in a tidy or satisfying way, do work to "remain unreconciled" (Whetung, 2017) and create opportunities for new political formations, both structurally and in practice and consciousness.

For a learning sciences perspective, this body of work demands attention to how individual learners within movements make sense of their own locations relative to power and relative to others alongside whom they are learning. It also suggests the importance of looking closely at how these personalized and other-oriented analyses of power are felt and translated into political and moral obligations to act in specific ways within the overall collective. In order to achieve group goals, individuals acting in solidarity must learn to interpret what the power arrangement means for how their own trajectories of learning *ought to* take shape.

Building on the navigation of "lines" and "pathways"

Learning scientists have demonstrated how power arrangements shape individual learning in out-of-school pursuits. For example, Azevedo's (2011, 2013) concept of "lines of practice" suggests how patterns of interest-driven activity cluster at intersections between individuals' "preferences" and "conditions of practice" in their environment. "Preferences" refer to the "variety of long-term goals, values, and beliefs" that shape a learner's pursuits (Azevedo, 2011, p. 162). They are conceived in individualized and interiorized ways, as "elements in a person's psychology" (p. 163). "Conditions of practice" involve constraints and affordances that shape practice:

> the material infrastructure available to the practitioner (e.g., rocket kits of varied assembly complexity), the immediate circumstances of the hobbyist's life (e.g., the person's socioeconomic status and whether or not he/she has easy access to practice sites), the larger social, cultural and institutional spaces in which the hobby exists (e.g., the availability of hobby stores), and so forth. (p. 163)

Azevedo's research revealed that preferences and conditions of practice were in dynamic interrelationship with one another. They seemed to "cluster" into particular expressions of activity, or "lines of practice" along which the constraints and affordances external to the learner could be attuned in ways that satisfied and extended their preferences. In this way, lines of practice represent "the deep patterns of engagement" of an individual learner's activity over time (p. 163). A line of practice is a particularized and developing form of life that an individual navigates in value-driven and pragmatic ways.

A second navigational metaphor from the literature is "cultural learning pathways," defined as "connected chains of personally consequential activity and sense-making" (Bell et al., 2012, p. 270). These pathways develop over the life course, span diverse settings, and reflect the values that guide the activity of individuals and social groups. Like lines of practice theory, Bell et al. specify that cultural learning pathways are a way to account for the "opportunities and impediments faced by learners" (p. 271). They draw attention to the ways that "individuals and groups arrange or transform the conditions of their own learning in relation to their expectations, interests, concerns, and available resources" (p. 271). Bell et al. focus on acts of coordination that people make between their concerns and the arrangements available to them. As acts of coordination accrete over time, analysis reveals how "people come to participate in specific forms of social practices in increasingly sophisticated and socially coordinated ways" (p. 274). The authors present the notion of "scopes of possibility" to describe the dynamic interplay between learner's actions, the social and material dimensions of place, and the social positions available within settings (p. 277).

In this paper, we build on these ideas by putting them into conversation with social movement theorizations of solidarity and learning sciences literature examining the politicized contexts in which relationships across difference shape the possibilities for learning and social transformation. Learning to be in solidarity entails undertaking personal and other-oriented analyses of power. Learners must conceptually understand how differential access to power, along racialized, class-based, or even species-based lines condition the practices they and others can engage in on the way to social transformation. This conceptual understanding

must be combined with an axiological commitment, involving an emotionally rooted regard for the other, to act in ways that others may not be able. In this way, an individual's line of practice or learning pathway in the context of solidarity, while individually articulated, is always perforated by social others—by what we know and feel of their positions in relations of power, and what we know and feel about how we ought to practice as a result. A solidarity relationship marks the connection between at least two lines of practice, and the ways in which ethical and political commitments shape their trajectories in tandem. Working together in solidarity may counterintuitively require lines of practice to diverge.

Context: Direct Action Everywhere

This research was conducted with Direct Action Everywhere's (DxE) San Francisco Bay Area chapter, the original chapter of an international animal rights network founded in 2012. Organizers reported that by 2017, the chapter had approximately 150 active members. Activists in DxE SF Bay Area were mostly White, though many Asian, Latinx, and Black activists also participated. The group aimed to shift social norms around the use of more-than-human animals through direct action, ultimately working to achieve "total animal liberation." For example, the activists held protests in restaurants and grocery stores. They also conducted "open rescues," using video to document conditions in farm facilities and leaving with sick and injured animals. For DxE, shifting social norms also required politicizing existing vegans within the organization so that they were prepared to take direct action.

While many social movement organizations use solidarity as a coordinating frame, animal rights activism attend to these ideas in a distinctive way. For many of the tactics, motivational frames, and emotional configurations (Vea, 2020b) deployed in animal rights, solidarity is mobilized unconventionally, in that it relies on ideas of cross-species help, rather than a collective liberation approach. However, there are places where mainstream solidarity discourses are visible, as we will explore in the data below. In these places we see solidarity emerge as a strategy and tactic between participants within the DxE community.

Methods

The larger study on which this analysis is based used participant observation and ethnographic interviews to understand how people learned to become animal rights activists and participate in the valued practices of the group. Vea engaged in participant observation with DxE SF Bay Area between December 2014 and May 2015 and between October 2016 and July 2017. Settings included protests, social events, trainings, outreach events, working meetings, and more. Vea wrote fieldnotes (Emerson et al., 2011) which became a primary data source. While analysis of fieldnotes inform the analytical claims, here we focus primarily on ethnographic interviews with current and former DxE activists. Interview participants included 10 women and 10 men, ranging from early-adulthood to middle-age and were majority White, with two identified as Latinx, one as Asian, and one as biracial. Vea asked about personal stories of changing involvement with respect to vegetarianism, veganism, animal rights, and activism activities. Interviews were audio-recorded and transcribed.

To analyze the data, Vea coded the transcripts for privilege, risk, danger, and other concepts that relate to the idea of speakers using their relative power and position to enact change. A parallel track of coding focused on emotion, and how emotion was articulated, made sense of, and cultivated (see Vea, 2020b). These parallel processes of coding help illuminate the ways in which individuals' developing lines of practice were shaped both by a political analysis of where vulnerability resides—and their own position relative to it—and by constructed emotional meanings that attached to their analysis. The coding was conducted iteratively, and the instances from the transcripts shared below are selected for their ability to illustrate the multiple ways solidarity showed up in the data, along with learning around power, emotion, and risk that supported those axiological and tactical choices.

Findings: Lines of practice as threads in the weave

Unlike some other forms of interest-driven learning in out-of-school settings, participation in the practices of DxE carried some embodied and legal risks. In preparation for protests, DxE organizers always reviewed the principles of nonviolence with activists. In addition to being sound strategy, they believed, nonviolence could also help prevent potential confrontations with bystanders from escalating to violence. DxE also assigned police liaisons at most actions. These people were trained to interface with law enforcement, if they were to show up, and all other activists were instructed not to speak with police under any circumstances. Other tactics, such as open rescue—a civil disobedience tactic that included breaking into farms to collect information, bear witness, and remove animals for placement at sanctuaries—involved even more risk. To be trained to take part in open rescue, activists needed to sign a non-disclosure agreement, a measure DxE used to prevent infiltrators from industry groups. Risks were also mitigated through workshops on digital security and how to handle potential police interrogation, for

example, and DxE had a Legal Working Group who examined legal issues behind upcoming actions and who could be called up in case of arrest.

Taking on these risky strategies was often framed through a lens of solidarity. Activists explained that the open rescues and confrontational tactics with people they assumed would not be supportive were a critical way for them to build awareness of the conditions facing more-than-human animals. As with the literature on solidarity, they believed that they had a responsibility to use their relative positions of power in service to the political struggle they engaged. Even as they contested the injustice of these systems (whether it be white supremacy or human supremacy), they intended to leverage those power imbalances strategically. This tension created opportunities to learn and shift their scopes of possibility that are not easily explained in terms of "preferences" and "conditions of practice."

In this section, we introduce excerpts from interviews with three White DxE activists, each of whom were grappling with what their privilege meant for how they should pursue their activist practice. Yet each of them articulated their understanding of privilege and solidarity in different ways. In our analysis, we attend to how each activist developed a line of activist practice in relation to other lines of existence—both human and more-than-human. If a movement was made up of many individuals' developing lines of practice, the movement itself can be seen as a woven fabric that uses all threads within it to reach toward justice.

Daniel: Practicing community protection

In some cases, DxE activists foregrounded human-human power relations in explaining why they were developing their activist practice in particular directions. For example, a young White woman named Daniel explained why she was training to be a police liaison:

> One of the reasons that I want to be a police liaison is to contribute to my community but also because I AM White. I have more privilege, and I feel like, okay, this is a way that I can really exercise my privilege in a way that is going to protect my community. I can physically put my body between police and demonstrators.

In her discussion, Daniel drew on the social-movement-rooted theories of solidarity that demand that people use relative racial privilege to provide safety to other people and to advance political goals through consciously using racial privilege to undermine white supremacy. She centers her racial position as the rationale for her tactical choice and her specific role as a police liaison—the rationale being that police are less likely to brutalize a White person than someone racialized as a person of color.

> It's very stressful, [laugh] and it's scary. It's not something that I ENJOY doing. I don't WANT to talk to police, but it's a role that's needed, and it's one that I can use my privilege to do.

Daniel's line of practice in the role of police liaison is shaped by a sense of duty that emerges from her concern for the conditions of precarity affecting others in her community. She was good friends with many other activists, some of whom were members of communities she understood to be marginalized, and those relationships meant that her understanding of privilege was not just intellectual but deeply felt in her day-to-day work with the group. Daniel acknowledged that emotion could have pushed her in ways that constrained her participation as a police liaison. She found it "stressful" and "scary," but it was nonetheless an obligation for her to take up the role and its practices. In this sense, Daniel's felt freedom, a recognition of her privilege as allowing her range of motion in her activist practice that was not afforded to others, also entailed its own feeling of constraint.

In this example, we see Daniel's "preferences" (Azevedo, 2011) come into direct conflict with other considerations that guide her line of practice as a developing activist. In particular, we see Daniel grappling with how her position within racialized power relations requires her morally and politically to step up to meet the overall needs of DxE's cause. Central to this reasoning is the fact that others in the community cannot practice in the ways she can, due to her privilege, so she feels an obligation to "protect [her] community." Daniel intentionally leveraged whiteness to insulate others from police violence—a strategy rooted in activist solidarity. In performing solidarity in this way, her ethical and tactical choices reflect an understanding of whiteness and white supremacy that is imbued with emotional meaning from her friendships and community ties. Her talk in the interview also demonstrates some of her mixed feelings about this ethical obligation. Her preference would clearly be *not* to develop a line of practice as police liaison. However, in the weave of the movement, some threads have to be on the outer edges. Taking up a position of vulnerability is something, she says, "I can use my privilege to do."

Tamar: Caring enough?

Questions of solidarity, privilege, and responsibility also shaped Tamar's involvement in the campaign, though they reoriented away from Daniel's focus on human-human solidarity across power difference to instead focus on human/more-than-human animal relations. Tamar reflected on her own choices around which tactics she had not engaged in. She focused in particular on open rescue, a tactic that was valued in the community, but which came at higher risk to participants because of the illegal activity. Tamar said:

> I would say I'm definitely still very uncomfortable with the idea of being arrested, for a lot of reasons... both short-term and long-term consequences. And I think there's a lot of pressure in spaces like this where ... I would say I'm probably—out of the most involved people in DxE, I would say I'm probably the only one who has never done an open rescue. I don't know if that's true or not, but—I can think of someone as involved as me who hasn't done open rescue. But in that core circle of people, I'm one of the few people who hasn't, and that's definitely made me feel a lot of pressure, not that anyone is putting on me specifically, but just like, does this mean I don't care about the issue as much as those people who are willing to risk their lives? Am I weak? *Am I not giving up some of my privilege that I should be*? I don't know. It just makes me think a lot of these questions, I guess.

In particular we note how the question of privilege (emphasis ours) animated Tamar's sense-making about what tactics she should be using. The suggestion that to be a good activist, to prove one's dedication, a person had to leverage their privilege and risk arrest on behalf of more-than-human animals is something that Tamar sensed was circulating in DxE, even though she specified that no one "is putting [this pressure] on me specifically." Still, she "fe[lt] a lot of pressure" to develop her line of practice to include open rescue as a moral duty and as a choice that said something about her character and strength of commitment to the cause of animal liberation ("does this mean I don't care about the issue as much as those people who were willing to risk their lives?"). She compared the thread of her practice to others in the weave "in that core circle of people" who were as active as her in DxE. In Tamar's case, we draw attention to the way an axiological commitment to the protection of more-than-human animals was "socially coordinated" (Bell et al., 2012). Tamar was acutely aware of the developing lines of practice of the activists around her in the fabric of DxE, and the normative pressure to use her privilege as human and as a White person served as a condition of practice shaping her development in strongly felt ways.

Tyler: Grateful to go into "hell"

In another interview, Tyler, a White man, also talked about his privilege, explaining how his status made it possible for him to adopt particular tactical repertoires that were considered higher risk, but also higher impact. Like Daniel, he stressed how his positionality made it possible for him to take on tactics with a higher risk of arrest, and he suggested that his privilege shaped his political choices. He said:

> For one it's like a really big privilege to just be able to go and see these places like firsthand? And like I can do it... because I'm a citizen you know, and able-bodied and all those other things that kind of give me this opportunity. And so I feel just like grateful for the chance to go, which it's kind of an odd thing to feel grateful for because it's hell, you know? It's horrible. And I personally don't feel like I've really suffered from what I've seen, you know? But some people have, so I've been lucky to not.

First, we see Tyler adopting the mainstream-in-movements ideas of solidarity, where power and privilege are considered a rationale for taking up specific actions in service to less-powerful others, and in the process implicitly troubling the power relationship even as he relies on it. In particular, he references his citizenship status and ability as factors that give him the "privilege" of seeing farming facilities firsthand. However, we also see Tyler mobilizing the discourse of solidarity in relation to other-than-human animals. It was a privilege in part because drawing close to the embodied site of suffering was valued in this group as a way to uncover and communicate the ethical truth of their cause (Vea, 2019). For Tyler and other DxE activists, farming facilities were "hell," which made the privilege to bear witness to them "an odd thing to feel grateful for." Tyler referenced another form of privilege as well, the privilege to witness and not to suffer "from what [he has] seen." He knew other people who had developed their lines of practice in similar ways to him, also participating in open rescue actions, but who experienced what they regarded as secondary trauma from what they had witnessed. Tyler was aware of how the thread of his practice stood out in relation to the threads of those others, and it allowed him to feel he could make a particularly important contribution to the movement.

There is a distinctive cross-species solidarity being articulated in emergent ways that are specific to animal rights activism, and that extend the frame, which we argue reflects a significant learning accomplishment. Later in the interview, Tyler again expressed his willingness to take on risks of violence and punishment in service to protecting more-than-human lives:

> After watching *Earthlings* [a documentary] and just getting involved I feel like I really appreciated the injustice that animals go through and would be willing to suffer whether that's like go to jail or whatever—risk my life? But— But— So I had that like in me, but I just didn't have an opportunity to like make those risks.

Tyler's politicization exemplifies learning around power and solidarity. In making his choices to engage in tactical repertoires that risk arrest (or even bodily harm), he explicitly troubled dominant power relations where human lives were valued more highly than more-than-human animal lives. He made an axiological commitment to solidarity, in which he used his positionality to work toward animal liberation—and he did this through potentially jeopardizing his privilege. Informing the development of Tyler's line of practice was a felt appreciation of "the injustice that animals go through," a moral and emotional impingement that helped thread his line of practice through the fibers of others in the movement, human and more-than-human.

Conclusions and significance

For members of DxE, practicing solidarity by using their privilege in service to the protection of less structurally-empowered others was an animating tactic and ethic. The idea of taking on risk to serve both human and more-than-human partners drove the tactical decisions, the motivational frames, the emotional configurations, and the ethical foundation of these activists. We see the social movement idea of solidarity extended across forms of human difference such as race and ability, and we can also see the activists grappling with what those forms of difference mean in relation to the species line as a powered form of social difference understudied in the solidarity literature. DxE members wrestled in multiple complex ways with the personal costs of solidarity and their theories of change as they related to power, privilege, and risk.

For the learning sciences, this analysis shifts the focus of solidarity work. Where others in the field have productively considered how relationships of trust, intimacy, and shared politics enable particular learning ecologies, this work elucidates learning processes that at once draw members' individual cognition toward power relations, while also shifting their collective lines of practice. Expanding the analytical power of lines of practice theory through solidarity highlights the ways that individual development of practice is shaped by complex awareness of collective goals for social change (the more just future toward which the collective weave of lines is reaching) and of what other lines of practice in the collective are best positioned to do, according to their place in powered relations such as race, gender, or ability. We see this theoretical intervention as an expansion of lines of practice theory, toward a more rigorous accounting of how individuals' lines of learning and development are always being navigated among the thickly woven lines of others. In our analysis, the understanding activists expressed about their place in the weave was more than a form of declarative knowledge. It was deeply felt as an emotional and axiological obligation to do right, according to the privilege one has. If "preferences" are seen as internal factors and "conditions of practice" are understood as external factors shaping an individual's developing line of practice, the notion of the weave draws our attention to the ultimate impossibility of separating what is internal and external in learning in solidarity. In fact, it is the powered relation between self and others that defined how these activists understood how and why to develop their practice in the ways they did.

There's a clear move from learning scientists to study the learning that is made possible in spaces shaped by solidarity. This move entails an interest in studying the solidarity made possible through learning as well as how people learn about and practice solidarity. Actualizing just social futures is not just about speculation or design work. It requires the right relations between people to carry out the work of acting in solidarity, even when it is difficult, long, and may conflict with some individuals' supposed self-interest. For learning settings beyond social movements, educators and designers should consider whether learning settings make space for relational accountability and solidarity to emerge, or whether they foreclose those possibilities. Researchers should consider whether and how the felt freedom of privilege or the moral impingement of obligation shape individuals' learning and participation. Though the embodied risks may be less severe, all learning is done with others. It matters whether our theorizations are sensitized to what it means to learn amid the weave, or whether they reify the supposedly stable boundaries between individuals. Combining social movement theorizations of solidarity with learning sciences theorizations of interest-driven practice in out-of-school settings helps reveal what people understand about how they are in relation with others in their learning activity, and how those understandings bear on what they can do together in the future. If the learning sciences want to concern themselves with the making

of more just social futures, then we need to understand how people know and feel the obligations of their practice according to their place in the weave of the collective.

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Effects of Uncertainty Markers on Metacognitive Group Awareness and Regulation

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Abstract: Social platforms provide a vast amount of resources for sharing, discussing, and searching for information. Thereby, learners need to monitor their understanding to metacognitively regulate their learning. Awareness of peers' metacognitions can affect individual regulation processes and such information may be communicated through language characteristics. Thus, in our experimental study (N = 214), we examined the effects of uncertainty markers in a social media forum setting on perceptions of uncertainty within the group as well as changes in learners' content-related assumptions, certainty, and learning intention. Results confirmed the influence of uncertainty markers on perceived uncertainty within the group, which in turn affected the learners' changes in assumptions and learning intention via changes in certainty. Further exploratory analyses showed that the effect of perceived group uncertainty on own certainty was stronger for men than for women. This study confirms the intricate nature of individual and social metacognitive processes in online learning.

Metacognitive awareness and learning regulation

Digital learning environments enable location- and time-independent accessibility as well as interactive, individualized, and adaptive learning. Online environments also provide a digital space for collaborative learning, in which learners can work collectively on authentic learning problems and their solutions (e.g., Mäkitalo et al., 2005). Additionally, social media platforms provide a vast amount of resources for sharing, discussing, and searching for information. This extends to wikis and discussion forums (e.g., Heimbuch et al., 2018) or social networking sites (e.g., Tsovaltzi et al., 2015), where users potentially interact with a large number of often unknown users. In these contexts, individual and collaborative learning activities alternate with some learners actively contributing and others mostly consuming the externalized learning processes of others. Thus, like in other individual learning contexts, learners need to make various relevant learning decisions and metacognitively regulate their learning. However, they are also influenced by their social context.

Metacognition is essential for regulating individual and collaborative learning processes (e.g., Salonen et al., 2005) and is understood as "knowledge and cognition about cognitive phenomena" (Flavell, 1979, p. 906). Metacognitive planning, monitoring, and regulation enable learners to productively and reflectively use adequate learning strategies to achieve learning goals. Thereby, metacognitive monitoring of own knowledge and learning plays a central role in metacognitive models of self-regulated learning (e.g., Winne & Hadwin, 1998), as it forms the basis for controlling learning activities (Nelson & Narens, 1990; Thiede et al., 2003) and thus study success (e.g., Thiede, 1999). A learner's assessment of how well they have understood a topic influences whether they consider further learning necessary and this thus may affect their intention to learn (Renner & Renner, 2001; Von der Linden & Roebers, 2006). Metacognitive monitoring of own knowledge may result in experiences of certainty or uncertainty with regard to specific assumptions. Uncertainty can have a motivational effect (Anselme, 2010) and leads to an increase in engagement in learning (Howard-Jones & Demetriou, 2009; Ozcelik et al., 2013). Uncertainty can further increase and guide information-seeking behavior and when learners close perceived gaps within their knowledge, uncertainty is reduced (e.g., Schnaubert & Bodemer, 2016, 2017). Additionally, uncertainty is related to a lack of supporting evidence for specific assumptions (e.g., Gigerenzer et al., 1991; McGarty et al., 1993) and has thus been linked to an increase in changes in assumptions (Schnaubert et al., 2021). From a metacognitive perspective, it thus seems logical that learners may use uncertainty as an indicator for gaps in knowledge and may thus increase their intention to seek further information and learn when uncertain, but that learners uncertain are also more prone to change their assumptions regarding the learning content.

While even in individual digital learning environments, social processes may play an important role for learning (see Schneider et al., 2022), social platforms additionally provide a context for learners to communicate and interact. Awareness information about the social context may severely affect individual learning and also metacognitive regulation (Schnaubert & Bodemer, 2016; Schnaubert et al., 2021). Thus, in addition to individual metacognitions formed through metacognitive monitoring, there are also social metacognitions, which are based on monitoring of knowledge, emotions, and actions of other learning group members (Chiu, 2008). Social metacognitions convey what beliefs the other learners have, what mental and emotional state they are in, and how they envision effective collaboration (Jost et al., 1998). Being aware of others' metacognitions can facilitate

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collaboration processes during collaborative learning (e.g., Dehler et al., 2011; Schnaubert & Bodemer, 2019). Active social metacognitive monitoring may additionally help learners to identify their own cognitive and metacognitive mistakes. By actively engaging with others' metacognitive views and strategies, learners get the opportunity to adjust their own metacognitions (Schnaubert et al., 2021). Because of this, own metacognitive experiences can also be strongly influenced by social processes (Carr & Jessup, 1997). For example, Karabenick (1996) found that the more questions peer-students ask about the learning material, the greater becomes the learners' reported confusion about the content of that material because of perceived uncertainty in a classroom. Thus, monitoring other learners' metacognitions may provide information relevant to judge other learners, their assumptions, or the task at hand and may thus lead to changes in own metacognitive judgments (e.g., Schnaubert et al., 2021). These adjusted judgments may then be used as a basis for metacognitive regulation as frequently observed in individual learning (e.g., Thiede et al., 2003).

To test how awareness of others' metacognitions influences individual metacognitive monitoring and self-regulation, Schnaubert and colleagues presented metacognitive group awareness information to learners in the form of uncertainty ratings of their peers and found learners to converge towards these peers and regulate their learning processes accordingly (Schnaubert & Bodemer, 2016; Schnaubert et al., 2021). While it seems reasonable that learners take their social context into account when regulating learning in digital and social learning environments, these studies presented peer awareness information explicitly and it remains unclear, if the results found may be transferred to learning scenarios void of group awareness tools. In real-life learning contexts, learners rarely judge their certainty and present the information to their peers, but metacognitive processes may be communicated through words, actions, or facial expressions. Thus, it is assumed that learners can build group awareness (i.e., the salient perception of group characteristics; Bodemer & Dehler, 2011) by monitoring social interaction and extracting partner- or group-related information (e.g., Engelmann et al., 2009).

In digital learning environments, uncertainty in own assumptions can be conveyed in textual messages through the use of the co-called uncertainty markers (e.g., Jordan & McDaniel, 2014). These include, for example, interjections used as fillers (e.g., "well…", "so…"), hedges (e.g., "somehow", "perhaps"), but also self-referential phrases (e.g., "as far as I know") and sentences that report mental states reflecting metacognitive awareness of uncertainty like "I am not quite sure" (e.g., Durik et al., 2008; Jordan & McDaniel, 2014). The use of uncertainty markers may thus convey a lack of internal uncertainty associated with lack of knowledge (e.g., Juanchich et al., 2017) and leads to a weakening of the persuasiveness of the presented assumption (e.g., Blankenship & Holtgraves, 2005; Hosman et al., 2002), as uncertainty affects how speakers as sources of information are perceived (e.g., Price & Stone, 2004; Tenney et al., 2011). According to Green (1984), the interlocutor's uncertainty can be identified by three categories of particular expressions: (1) certain frequency adverbs (e.g., "often" or "rarely"), (2) adverbs that convey the psychological uncertainty of the person speaking (e.g., "expected" or "desperate"), and (3) modal verbs and linguistic devices that represent ambiguous uncertainty (e.g., "could" or "maybe"). Further speech or text characteristics (e.g., ellipses ("...") at the end of a sentence) may indicate missing information and be associated with incomplete knowledge or uncertainty. Uncertainty markers that occur in both spoken and written language include also tag questions as well as hypotheticals (if-sentences; e.g., Bernstein, 1962). It can thus be concluded, that various language characteristics may be associated with uncertainty as metacognitive characteristic of the speaker and may influence metacognitive group awareness (i.e., the salient perception of metacognitions of other learners or the group; Schnaubert & Bodemer, 2019).

Based on the above described literature, we assume uncertainty markers in social media posts to affect metacognitive group awareness and thus increase the perceived uncertainty that learners attribute to the social group (H1). It was further established that uncertainty within a group may affect own metacognitive evaluations of certainty (see also Schnaubert et al., 2021) and we thus assume perceived uncertainty within social media posts to reduce the level of certainty of social media consumers (H2). As uncertain learners are more likely to change their assumptions about the learning content (e.g., Schnaubert et al., 2021), we assume perceived uncertainty within a social group to positively affect changes in assumptions via an increase in individual uncertainty (H3). Following the argumentation above, perceived uncertainty within social media posts is further assumed to positively affect the intention to learn by promoting individual uncertainty via an increase in perceived group uncertainty (H4).

While the assumed processes are based on theory and empirical findings concerning general mechanisms of metacognition, differential effects are largely unknown. One characteristic frequently associated with differences in certainty and social perception is gender. While there are several empirical findings that reveal gender-specific differences in metacognitive processes in learning and self-regulation (e.g., Bidjerano, 2005; Zimmerman & Martinez-Pons, 1990), how they are influenced by social aspects of metacognition is unclear. Thus, as a first step, we will additionally exploratively analyze if gender affects how perceptions of uncertainty within a social group affect own metacognitive assumptions (E1).

Methods

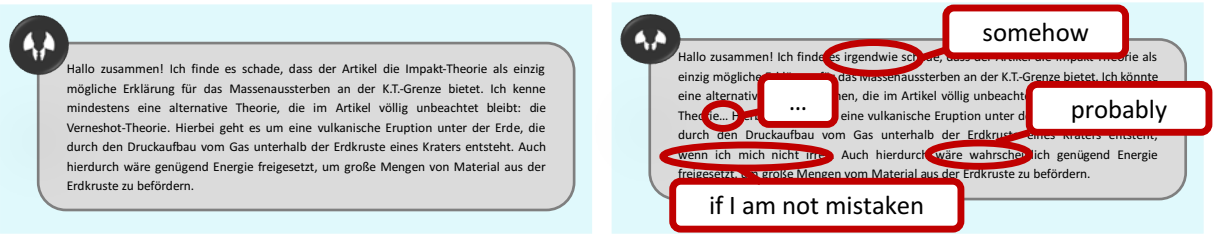
N = 220 participants initially completed the online study (ID: psychmeth_2020_MCSM_06), which was approved by the local ethics committee (vote: 2005PFSA4986). We excluded four participants with a reading speed above 600 words per minute as it can be assumed that they did not engage attentively and with full comprehension of the study content (e.g., Carver, 1990). We also excluded two participants who took a considerably long time to complete the study (> 1h) as this indicates interruptions or off-screen periods. The remaining sample thus consisted of *N* = 214 participants (*n* = 107 in each experimental group). The average completion time of these participants was 14 minutes and 37 seconds (*SD* = 7.35; range: 03:43–36:43 minutes). 133 of the remaining participants (62.1%) were women and 81 men (37.9%). Their age ranged from 18 to 68 years (*M* = 26.88, *SD* = 9.15), 104 had completed secondary school as their highest degree (high school or equivalent: 94 / 43.9%; lower secondary school: 10 / 4%) and 110 had an additional university degree (bachelor: 86 / 40.2%; master: 24 / 11.2%).

Design and procedure

At the beginning of the study, participants were randomly assigned to one of two experimental conditions. The conditions differed in the wording of the forum messages they received during the second reading phase, in which they read a discussion in a forum. One group received text messages with uncertainty markers during the study (UM+) and the other received text messages without markers (UM-) (cf. figure 1). Uncertainty markers were taken from the above described categories and we ensured that the text messages still read natural.

Figure 1

Examples for the uncertainty markers in text massages without UM (left) and with UM (right)



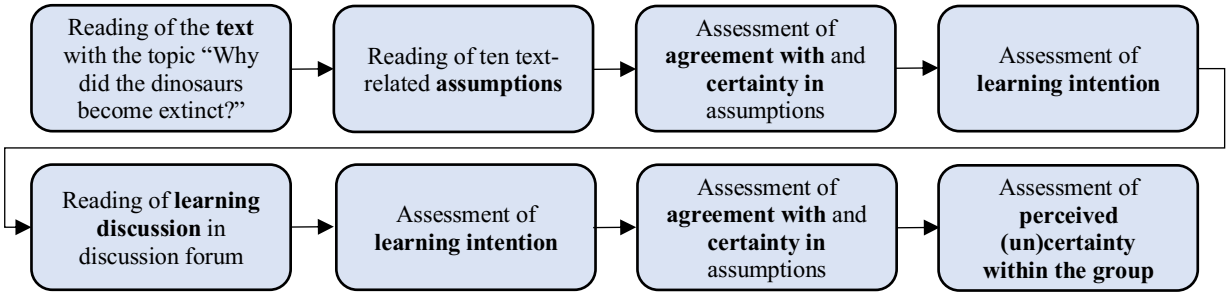
After giving informed consent and answering a number of questionnaires (e.g., self-efficacy, self-monitoring), all participants read a text with the topic "Why did the dinosaurs become extinct?". The text was based on materials from Heimbuch and Bodemer's (2017) adaptation of Buder and Bodemer's (2011) learning material on the extinction of dinosaurs, who used it to study group awareness in wiki-based learning. Subsequently, the participants read ten text-related assumptions (e.g., "The glass spherules around the Chicxulub crater are clear evidence that there was a meteorite impact 65 million years ago.") and expressed their agreement or disagreement with each assumption ("Do you agree with this assumption?"; *yes* vs. *no*). After each of the ten assumptions, the participants were asked about the certainty in their assessment ("How certain are you that your assumption is correct?") on six-point scale from 1 (*not certain at all*) to 6 (*completely certain*) (cf. Schnaubert & Bodemer, 2019). Afterwards, the participants' learning intention was recorded ("Would you like to look at further learning materials on this topic in the future?"). Participants were offered a six-point scale to answer, from 1 (*definitely not*) to 6 (*definitely*). Afterwards, the participants read the discussion in the online forum. The discussion threads each consisted of 14 posts with either 602 (UM-) or 719 (UM+) words. The content of the discussions between the experimental groups was identical, but the messages in the forum of UM+ contained uncertainty markers to convey uncertainty, while the messages in UM- did not (cf. figure 1). Subsequently, the participants were asked again whether they would look at further learning materials on this topic in the future to determine possible changes in their learning intention. Following, the participants had to express their (dis)agreement with the same ten text-related assumptions in the same order again and had to judge their certainty in their assessment. We further assessed the perceived (un)certainty within the learning group by having all participants rate the certainty of the contributors in the discussion forum on a scale from 1 (*not certain at all*) to 6 (*completely certain*) (this measure was later recoded; see below). The procedure is shown in figure 2.

Dependent variables

The dependent variables were calculated as follows: The number of *changes in learning assumptions* was determined by counting the number of assumptions (0 to 10) participants changed from "yes" to "no" or vice versa after reading the forum discussion. A higher value thus indicates more changes. *Changes in learning intention* was operationalized as the difference between learning intention before and after reading the discussion

(-5 to +5). A positive value indicates an increase in learning intention from pre to post while a negative value indicates a decrease. *Changes in own certainty* were calculated as the difference between the average certainty in own assumptions before and after reading the learning discussion (-5 to +5). Positive values indicate participants gaining certainty in their assumptions while negative values indicate losing certainty from pre to post. *Perceived uncertainty within the group* was determined by recoding the perceived certainty score (1 to 6) so that higher numbers indicate perceiving the group as more uncertain while lower numbers indicate perceiving it as certain.

Figure 2
Procedure



Results

Table 1 provides an overview over descriptive statistics of the dependent variables and their intercorrelations. We first tested if uncertainty markers in text messages caused learners to perceive their learning group as more uncertain (H1). A *t*-test for independent samples showed that there was a significant difference in the perceived certainty of the learning group between both experimental groups ($t(212) = 7.58$, $p < .001$, $d = 1.04$), with participants in UM- (without uncertainty markers) perceiving their learning group to be less uncertain and thus more certain ($M = 3.00$, $SD = 1.41$) than participants in UM+ ($M = 4.42$, $SD = 1.33$), supporting H1.

Using the SPSS software PROCESS macro (version 3.5) by Hayes (2017), we conducted simple mediation analyses (PROCESS model 4) to test the direct effect (H2) as well as the mediation hypotheses (H3 and H4). We found a significant total effect of *perceived uncertainty within the group* on *changes in learning assumptions* (ß = 0.22, $p < .001$, 95% CI [.09, .35]; cf. figure 3, left). We also found a significant negative effect of *perceived uncertainty within the group* on *changes in own certainty* (ß = -0.42, $p < .001$, 95% CI [-.55, -.30]), supporting hypothesis H2. Further, we founded a significant negative effect of *changes in own certainty* on *changes in learning assumptions* (ß = 0.32, $p < .001$, 95% CI [.46, .18]). As assumed in hypothesis H3, the analysis thereby revealed a significant indirect effect of *perceived uncertainty within the group* on *changes in learning assumptions* mediated by *changes in own certainty* (effect = 0.13, 95% CI [0.07, 0.22]). We founded no direct effect of *perceived uncertainty within the group* on *changes in learning assumptions* (ß = 0.08, $p = .235$, 95% CI [-.06, .22]) after controlling for the indirect effect. Taking together, the link between *perceived uncertainty within the group* and *changes in learning assumptions* is mediated by *changes in own certainty*.

In order to test the hypothesis H4, we calculated simple mediation analysis with *changes in learning intention* as dependent variable (cf. figure 3, right). We found a significant total effect of *perceived uncertainty within the group* on *changes in learning intention* (ß = 0.29, $p < .001$, 95% CI [.16, .42]). *Changes in own certainty* thereby significantly affected *changes in learning intention* (ß = -.43, $p <. 001$, 95% CI [-.56, -.30]) and there was a significant indirect effect of *perceived uncertainty within the group* on *changes in learning intention* mediated by *changes in own certainty* (effect = 0.18, 95% CI [0.09, 0.29]). *Perceived uncertainty within the group* had no direct effect on *changes in learning intention* after controlling for the indirect effect (ß = .11, $p = .114$, 95% CI [-.03, .24]). Thus, the effect of *perceived uncertainty within the group* on *changes in learning intention* is mediated by the participants' *changes in own certainty*, supporting H4.

Table 1
Means, standard deviations, and correlations with confidence intervals

Variable	*M*	*SD*	1	2	3
1. Perceived Uncertainty within the Group	3.71	1.54			
2. Changes in own Certainty	-0.03	0.66	-.423** [-.52, -.31]	(−)	
3. Changes in Learning Assumptions	2.14	1.79	.219** [.08, .36]	-.353** [-.47, -.21]	(−)
4. Changes in Learning Intention	-0.11	1.11	.288** [.13, .43]	-.476** [-.62, -.32]	.325** [.18, .46]

Note. $N = 214$; values in square brackets indicate the 95% confidence interval for each coefficient. Two-tailed significance: ** $p < .01$

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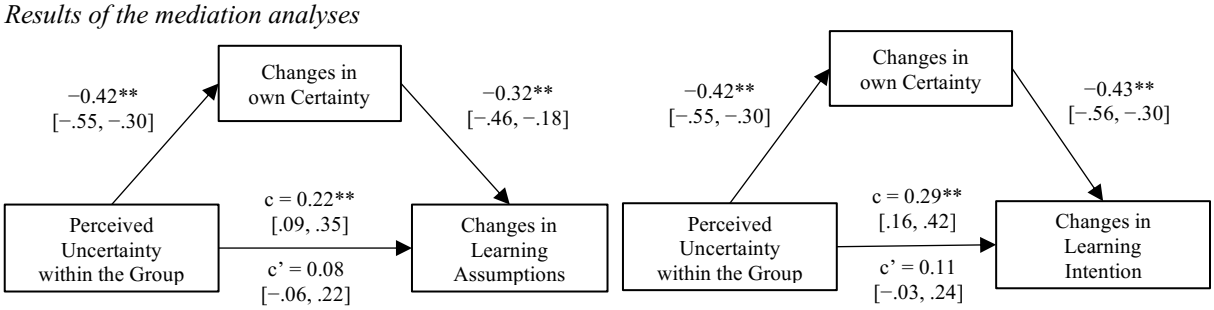
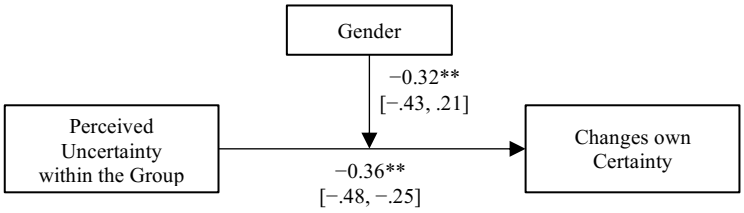
Figure 3
Results of the mediation analyses



Note. c = total effect; c' = direct effect; values in square brackets indicate the 95% confidence interval. Two-tailed significance: ** $p < .01$

Exploratively, the moderating effect of gender on the relationship between the *perceived uncertainty within the group* and *changes in own certainty* was investigated (E1). The moderation analysis showed a significant moderation effect: ß = -0.32, $p < .001$, 95% CI [-.43, -.21] (cf. figure 4). This means that *perceived uncertainty within the group* leads to significantly greater reductions in the men's certainty compared to women's.

Figure 4
Results of the moderation analysis of gender effect



Note. values in square brackets indicate 95% confidence interval. Two-tailed significance: ** $p < .01$.

Table 2 shows gender-specific differences in the *changes in own certainty* depending on different levels of *perceived uncertainty in the group*. For men, being confronted with uncertainty in the group led to a rapid decrease in own certainty, whereas women's certainty remained relatively stable even when perceiving high uncertainty in the group. It thus seems that the dampening effect of uncertainty in a learning group is stronger for men, leading to an overall decrease in certainty when perceiving the group to be uncertain only for men.

Table 2
Gender-specific changes in own certainty depending on perceived uncertainty within the group

perceived uncertainty within the group	changes in own certainty	
	female	male
low	0.281	0.528
neutral	0.166	-0.244
high	0.052	-1.016

Discussion

Taken together, we found uncertainty markers in social media posts to affect how learners perceive the certainty within the learning group. While this seems not surprising, it does mean learners are aware of the textual features and sensitive towards these markers. Further, it seems to have clear implications for the self-regulation of learning as perceived uncertainty within the social group seems to "rub off" on learners. While one would assume learners to become more confident during learning due to actual knowledge gained, overall, confidence seemed to be rather stable overall. However, the higher the perceived uncertainty, the lower this gain was. Furthermore, while women seemed to rather gain confidence under all conditions of perceived uncertainty within the group and rather less affected by the latter, men gained confidence when group uncertainty was judged low, but severely lost confidence in their assumptions when they perceived high uncertainty within the group. Thus, men seem to react stronger to social stimuli than women. This is surprising, as women are traditionally assumed to be more susceptible to social influence (Eagly & Carli, 1981) and better to perceive social stimuli (e.g., Bai et al., 2015), although scientific

results paint a much more pronounced picture. For example, there are indications that men may be more susceptible to social learning (Abdullahi et al., 2019) while other studies found not such effect but personality traits to be the important determinants (Oyibo & Vassileva, 2019). As sample characteristics may be one influencing factor and sample sized did vary between both gender groups in our study, further research needs to replicate found effects to unveil the mechanisms leading to these differences.

As expected, perceived uncertainty within the group also led to more changes in own assumptions and an increase in learning intention. Both effects were mediated by changes in own certainty. The results show that effects found regarding explicitly presented metacognitive awareness information (e.g., Schnaubert & Bodemer, 2016; Schnaubert et al., 2021) are transferable to more implicit markers in communication. This stresses the relevance of understanding the effects social contexts have on metacognitive self-regulation in digital and social learning environments. Further, it shows that language characteristics affect metacognitive group awareness. Linguistic markers are important to understand online communication and knowledge exchange even in anonymous online groups as communication not only contains content-information, but contextual cues used to generate group awareness (see Engelmann et al., 2009), which is also relevant for individual learning processes in digital and social learning environments (e.g., Heimbuch & Bodemer, 2017). While we focused our study on individual effects in social contexts, a logical next step seems to be the transfer to collaborative interaction processes. Apart from effects on metacognitive self-regulation and usage of the information about social metacognition for evaluating and regulating own learning processes, linguistic markers may provide valuable awareness information to appropriately interact with learning partners, for example by focusing on uncertain content (Schnaubert & Bodemer, 2019) or providing explanations to peers (Dehler et al., 2011). The correct interpretation of the metacognitive messages is crucial, as an incorrect interpretation may lead to misunderstandings and emotional conflicts, which could have a counterproductive effect on the learning process (Chiu & Kuo, 2008). Especially on large online learning platforms, when learners often do not know their peers and many communication-related aspects relevant to building group awareness may be unavailable, group awareness tools may be used to support collaboration and knowledge exchange (e.g., Janssen & Bodemer, 2013). However, without such tools, learners need to look for other cues to judge their social context and it is vital to understand how learners gain group awareness in unsupported learning settings (Schnaubert & Bodemer, 2022).

As we used a number of uncertainty markers, further research should look into more subtle differences in linguistic or speech characteristics and may use real online communication to determine the effects of uncertainty markers on metacognitive group awareness and subsequent effects on metacognitive monitoring and learning regulation in real online learning scenarios. Integrating this research with language technology to detect further uncertainty markers and estimate their effect on uncertainty perception (e.g., Pon-Barry & Shieber, 2011) would provide further insights into (social) metacognitive processes in digital and social learning environments.

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The Way to Better Learning Online: Using Online Discussions in College Classes During COVID-19

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Abstract: In recent years, a large body of evidence demonstrates that active learning through engaging college students in a discussion leads to increased learning outcomes. However, more empirical studies are needed to understand its effectiveness in online classes. In Experiment 1, students majoring in veterinary medicine were randomly assigned to three conditions: Lecture and Review, Lecture and Discussion, and Self-study and Discussion. Post-test results showed that the two discussion groups achieved significantly higher scores than the review group. Moreover, among the two discussion groups, the self-study group performed better than the lecture group. To reconsider the reliability and generalizability of our study we conducted Experiment 2 in which, we compared the performance of the two discussion conditions again for students majoring in social science. Our findings indicate that not only online discussions but active learning activities such as self-studying before the discussion is also crucial for students' learning.

Introduction

COVID-19 caused substantial confusion around the world, and education was no exception. As a result, educational institutions and schools in many countries have opted for online education (Rose, 2020; Kogan et al., 2020; Daniel, 2020). While the concept of online learning differs within researchers, it exists in various formats, such as, e-learning, web-based learning, cyber learning, distance learning, or mobile learning (Jacobson, 2004; Khan, 2005). Nevertheless, most online education consists of pre-recorded one-way style lectures shared by the instructors.

Growing bodies of studies show that the benefits of active learning move beyond those of one-way traditional lectures (Yannier et al., 2021). In particular, interacting with peers through discussions facilitates students' learning. According to the ICAP theory of cognitive engagement, collaborative dialogue through discussions often promotes greater learning than studying alone (Chi, 2009, 2021). However, although there is ample evidence that discussion facilitates students' learning, giving a lecture is a commonly used instructional method throughout the undergraduate curriculum (Lim et al., 2018; Stains et al., 2018). It is also difficult to find research comparing activities that come before and after the discussion, and even, the effect of active online learning activities has not been examined enough.

The present study compared the learning effects of reviewing study materials with those of discussions. We also compared two different pre-discussion activities, watching a lecture and self-studying. Additionally, through two experiments from two different majors, we can also pave the way for instructors who practice online discussions to promote better active learning online during and after COVID-19.

Literature Review

Pedagogical framework

Passive learning often refers to a teacher-centered instructional method. An example of passive learning is where students listen and watch teachers' didactic lectures. Chi (2009) posits that when students watch a lecture without any manipulation of the learning material, this is regarded passive (learning). Traditional lectures are lectures that are not effective in encouraging learners' discussions and acquiring deeper comprehension (Bligh, 1998). Therefore, it is possible that teachers wrongly believe that their lectures can draw students' attention, promote their motivation, and increase learning outcomes.

Although there is ample research on the limitation of passive learning, most classes are still composed of didactic lecturing (Stains et al., 2018). Wieman and Perkins (2005) emphasize that lectures deliver too much information and knowledge to students, while they do not understand much of it. In particular, STEM subjects still seem to be predominated by lectures (Stains et al., 2018). Stains and colleagues analyzed observation data

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from about 2,000 classes taught by more than 500 STEM faculty members. Their findings indicate that lecturing (i.e., teacher-centered learning) is pervasive in STEM courses. Likewise, Freeman et al. (2014) conducted a meta-analysis comparing students' academic performances in traditional lecture-centered classes to those who took active learning classes in the field of STEM. The results showed that active classes bring about higher scores and lower drop and failure rates compared to traditional lectures.

In accordance with previous studies indicating the limitations of lectures and passive learning, various alternative instructional methods have been explored (Mayer & Alexander, 2017; Chi & Wyle, 2014). Among the various definitions of active learning, Chi and Wyle (2014) classified active learning using Interactive-Constructive-Active-Passive (ICAP) modes. The ICAP framework is based on students' behaviors of engagement. Not surprisingly, the order of the modes (I > C > A > P) matches the order of students' learning outcomes. In detail, the *P mode* includes learning that happens when students sit in traditional lectures. The *A mode* involve activities in which students physically manipulate learning materials such as highlighting. The *C mode* refers to situations where students add new information to the given learning materials on their own, such as drawing a concept-map, or asking a question. Lastly, the *I mode* occurs when two or more students in *C mode* collaborate with each other. A representative example would be discussions that occur among students in class.

Schwartz and Bransford (1998) focused on preliminary activities that comes before lectures. Schwartz and Bransford showed that the learning effect of lectures differs depending on what learning activities were conducted in advance. They experimented three groups to prove their point. Group 1 simply summarized the learning materials and then listened to the lectures; group 2 analyzed the learning materials twice; finally, group 3 analyzed the learning materials and listened to the lectures. As a result, there were no significant differences in the recognition test, but group 3 had the highest score on the transfer test. Thus, even if instructors give a lecture, the learning effect varies depending on what and how students do before and after learning.

Therefore, we adopted the framework of Schwartz and Bransford (1999) and Chi and Wyle (2014). We conducted an experiment to compare the learning outcomes between a group that simply reviews the material after a lecture, a group that discusses the material with each other after the lecture, and a group that discusses after self-studying.

Peer discussions in classes

As an alternative to traditional lectures, researchers have claimed discussion as a promising instructional method (Almasi & Garas-York, 2014). Although students learn better or best when they are active, and engaged (Yannier et al., 2021), discussions are still rarely used in most classes (Walsh & Sattes, 2015). Specifically, even though students who participated in the discussion recognize that it helps themlearn and understand, discussions are rarely used in educational settings (Alvermann et al., 1996; Almasi et al., 2001). What is worse, discussion occurs as merely a post-reading event in which the teacher assists and intervenes students' interactions. This type of discussion is referred to as a teacher-led discussion or structured discussion. In a teacher-led discussion, teachers play a central role by starting the discussion, by asking a question and putting their opinions forward. In other words, the Initiate-Response-Evaluate (IRE) structure of discourse is dominantly used by the teacher in a teacher-led classroom (Cazden, 1986; Mehan 1979). Many teachers in teacher-led discussions wait less for students to respond and provide feedback authoritatively. Thus, students in teacher-led discussions often choose to remain passive (Good et al., 1987).

However, not all teacher-led discussions have only negative effects. Wolf et al. (2005) investigated the relationship between the quality of talk and reading comprehension. Twenty-one reading comprehension lessons in ten schools were examined. Results showed that student talk was predictors of knowledge sharing during the lessons. Also, the type of teacher's question was important for students' learning, where open-ended questions and follow-up probes were most effective.

McIntyre et al. (2006) also investigated the effect of teacher's scaffolding during students' discussions. They analyzed data from classroom observations, videos, and interviews. Their results indicated that teacher discourse can lead to students' engagement in interaction, facilitate students' participation and help bring them into the discussions.

Even still many researchers posit that student-centered discussion (i.e., peer discussion or unstructured discussion) are more effective than teacher-led discussion (Almasi, 1995; Hogan et al. 1999; Many & Wisman, 1992). Wilson et al. (1984) contended that discussions occur when a student deliberately initiate a talk with peers with a definite topic or goal in mind. For example, Almasi (1995) compared the effects of teacher-led discussions and those of student-led discussions. As a result, students in peer discussion were able to internalize their ability to recognize and resolve conflicts better than students in teacher-led discussions. Students in students-led discussion were also able to learn to think critically and retrieve argument-relevant information as they learn the principles of argumentative reasoning during peer discussions.

However, related research above has mainly focused on young children's literacy skills generalized in expository text. In the present study, we expanded on previous works and observed various aspects of unstructured discussions in college students. In particular, we investigated college students' academic achievements when they learned the contents of the textbook through discussions in actual classroom settings.

We conducted our research in online classes. With the demands of the times due to COVID-19 and the advent of online learning methodologies and technologies, educational stakeholders are actively utilizing effective e-learning methods. In this study, we investigated whether online discussion has a greater learning effect than other traditional instructions, and what pre-discussion activities maximize the effect of peer discussions. All in all, we compared the learning effects of three learning (experimental) conditions: Lecture Review (LR); Lecture Discussion (LD); and Self-study Discussion (SD), representing the combination of learning activities conducted by students, respectively. Based on the ICAP framework, we predicted that students in the two discussion groups would show greater learning achievement than those in the review group (LD, and SD > LR). In addition, compared to those who listened to a lecture, which is a relatively passive learning activity, we expected that the students who self-studied prior to the discussion would also show higher learning gains (SD > LD).

Experiment 1

Experiment 1 investigated the learning effect of the peer discussion activity itself, and the effect of different prior learning activities before the discussion. In this experiment, veterinary medical students were randomly assigned to three groups: LR, LD, and SD conditions.

Participants

All experiments were reviewed and approved by the university Institutional Review Board. Eighty-five undergraduate students majoring in veterinary medicine participated in this experiment (N = 85, female = 39). Students were randomly assigned to three groups: LR (n = 7), LD (n = 20), and SD (n = 18) conditions. There were no significant differences in age and gender between groups.

Materials

A monologue-style video clip was used as the lecture video in this experiment. The lecture video was from an actual lecture clip uploaded on the Internet for open use. The learning topic covered in this experiment was chemistry, specifically sections concerning covalent bonds. The topic was basic knowledge for veterinary medical students. We tried to secure the ecological validity of the learning material and made sure all veterinary students learned chemistry in their undergraduate curricula. A six-page lecture note was written based on the video clip which was used for self-study during the experiment.

The final test was comprised of transfer type items. Transfer type items were designed to test participants' improvement in transfer of learning which refers to applying learned knowledge from the materials (i.e., lectures and textbooks) to new situations. A total of 12 transfer type items worth 33 points were used.

Procedure

Students filled out a consent form and were given an explanation regarding the procedures. The LR group watched the lecture video for 20 minutes and then studied the six-paged text for 15 minutes. The text was not provided when watching the lecture. The LD group watched the lecture for 20 minutes, and then discussed about what they learned in groups of three for 15 minutes. The SD group studied the text by themselves for 20 minutes, and then had a group discussion of three for 15 minutes. All three groups had the same total amount of learning time. After completing the entire learning process, a 20-minute test was taken.

Results and discussions

The mean values and standard deviations of test scores for transfer type items (i.e., total score) are presented in **Table 1**. We conducted an analysis of covariates (ANCOVA) to examine the difference among the three groups. Age and gender were controlled as covariates. Significant differences were found between the three groups, $F(2, 40) = 7.72$, $P = .001$, partial eta-squared = .279. There were no significant effects of gender and age.

In detail, the LR group (M = 13.86, SD = 4.22) had the lowest score, Ps <.05, but the LD group (M = 18.90, SD = 4.33) and the SD group (M = 20.83, SD = 3.85) showed no significant difference, P = .317.

Table 1

Descriptive statistics of Experiment 1

	LR group (n = 7)	LD group (n = 20)	SD group (n = 18)
Transfer type items	13.86 (4.22)	18.90 (4.33)	20.83 (3.85)

Note. Data are shown as values of mean (standard deviation). LR refers to lecture and review; LD refers to lecture and discussion; and SD refers to self-study and discussion.

In line with our prediction that discussions would enhance students' learning, the results showed the LD group scored significantly higher than the LR group. Therefore, our findings supported the findings from the ICAP framework by Chi and Wylie (2014).

However, although there was a trend between the scores, there was no significant difference between the two discussion groups as expected. The result may be due to a small number of participants. Moreover, the results may be due to the topic of learning which was too familiar to veterinary medical students. Therefore, in Experiment 2, participants were recruited from the college of social sciences who were not familiar to, and had no prior knowledge on the learning contents. We conducted Experiment 2 with only the LD group and the SD group, which did not show a significant difference in Experiment 1.

Experiment 2

Experiment 2 examined the learning effects of having a discussion after different prior learning activities. In this experiment, students from the college of social sciences were recruited and randomly assigned to different two discussion groups (i.e., LD and SD groups).

Participants, learning materials, and procedure

Undergraduate students from the college of social sciences participated in this experiment for course credits. A total of sixty-two students were randomly assigned to two different groups: LD (n = 30) and SD (n = 32) conditions (N = 62, female = 32). There were no significant differences in age and gender between the groups.

Learning materials and experimental procedures were identical to Experiment 1.

Results and discussions

The mean values and standard deviations of final test scores for transfer type items are presented in **Table 2**. We conducted orthogonal planned comparison to examine the difference between the two discussion groups. The results showed that the SD group (M = 17.03, SD = 3.09) scored significantly higher than the LD group (M = 10.67, SD = 3.40), $t(60) = 7.731$, $P < .001$.

Table 2

Descriptive statistics of Experiment 2

	LD group (n = 30)	SD group (n = 32)
Transfer type items	10.67 (3.40)	17.03 (3.09)
Comparison	*t*	*P*
	7.731	< .001

Note. Data are shown as values of mean (standard deviation). LD refers to lecture and discussion; and SD refers to self-study and discussion.

In line with our prediction, the results showed that the SD group outperformed the LD group. Therefore, students' learning achievements varied depending on the type of learning activities before the discussion. The more active the learning activities before the discussion, the greater the outcome students gain through the discussion.

Comparison of Experiment 1 and Experiment 2

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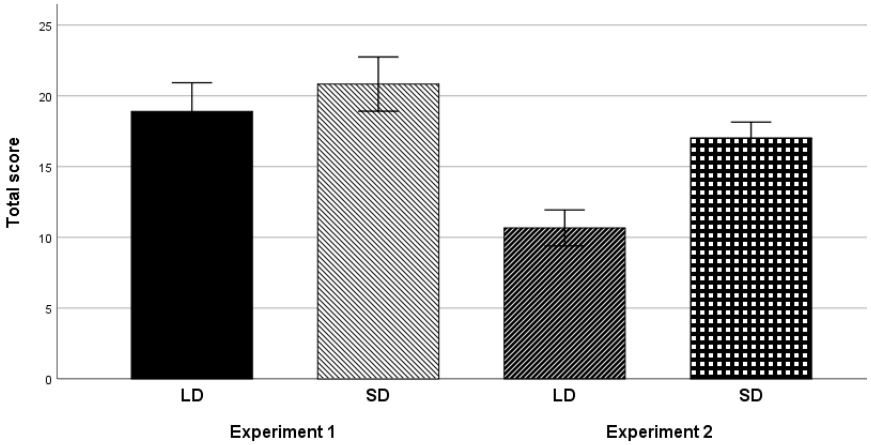
A summary of the results of both experiments is presented in **Figure 1**. In Experiment 1, there was no significant difference between the LD group and the SD group. On the other hand, in Experiment 2, the two discussion groups showed a significant difference.

Specifically, scores of the LD group of Experiment 1 had no significant difference with those of the SD group of Experiment 2, $P = .426$, while the scores were higher than those of the LD group of Experiment 2, $P < .001$. The SD group of Experiment 1 scored significantly higher than the SD group of Experiment 2, $P = .003$. Finally, the LD group of Experiment 2 scored significantly lower than the other three groups, Ps $< .001$.

Therefore, considering that there was no significant difference between the two SD groups across the two experiments, while no significant difference was also observed between the two discussion groups (i.e. LD and SD groups) in Experiment 1, the results may have been affected by the topic of the learning material. Participants in Experiment 1 already had basic understanding in chemistry, a fundamental subject needed to learn veterinary medicine, resulting in no significant difference between the two discussion conditions. However, with participants in Experiment 2 all majoring in social science with no background knowledge on the given topic, experimental results better revealed the effects of different prior activities each conducted by the two discussion groups.

Figure 1

Summary of Experiment 1 and Experiment 2



Note. Data are shown as values of mean (standard deviation). LD refers to lecture and discussion; and SD refers to self-study and discussion. The total score corresponds to scores for transfer type items. Error bars show +/- 2 standard error.

General discussion

The present study investigated whether discussions could be used as an effective instructional method in online learning. Our predictionswere that discussions would promote students' learning than reviewing, which is a more familiar and traditional learning method. Based on Chi and Wyle (2014)'s ICAP framework that showed active learning activities enhanced students' learning outcomes over passive learning, we predicted that self-studying before the discussion would be more effective than listening to a lecture. In other words, we expected that self-study, a relatively more active activity, would increase students' engagement in discussion and its learning effects.

In Experiment 1, we compared students' learning gains between the three learning conditions: Lecture Review (LR), Lecture Discussion (LD), and Self-study Discussion (SD). In line with our prediction based on the proposal by Chi and Wylie and other theoretical frameworks on active learning, discussions increased students' learning gains. The LD group had significantly higher scores than the LR group. However, unlike our initial prediction, there was no significant difference between the two discussion groups, the LD group and the SD group. This result was probably because veterinary medical students had prior knowledge of the contents related to the learning materials. Therefore, in order to increase the reliability and validity of the experiment, we conducted Experiment 2 with students majoring in social science.

In Experiment 2, the LD group and the SD group were compared with other participants majoring in social science. The learning materials and experimental procedures were the same as Experiment 1. The results showed that the scores of the SD group were significantly higher than those of the LD group. Thus, students' learning gains varied depending on the type of learning activities before the discussion. The SD group who self-studied the material before the discussion were involved in a more active learning activity than listening to a lecture as the LD group did, leading to greater achievements.

Our findings denote that discussions indeed enhance students' learning. In addition, its effect on learning varies depending on the type of activities before the discussion. Therefore, educational stakeholders, including teachers, should actively use discussion as a learning tool and provide opportunities and time for students to fully explore the learning materials before the discussion.

Finally, the result of this study suggests that effective online discussions are also possible. As Daniel (2020) suggested, we need to prepare for the upcoming disaster by applying the existing instrumental method to various types of classes (e.g., from offline discussion to online discussion). Now as we reconsider the effectiveness of online education due to COVID-19, our results show the potential and applicability of online discussions in student learning.

Limitations and suggestions

This study is early research for verifying the effect of online discussions, and more research is required in the future. First, the discussions in this study are unstructured, whereas our experiment can be repeated for structured discussions that involve teachers' interventions or for other semi-structured discussions. For example, Lim et al. (2019) used students' questions and summary notes of learning materials during the discussion that(and) added more structure. Therefore, future research should validate the effect of various forms of discussions used for learning.

Second, it is necessary to analyze the contents of the discussion. Future studies need to check how students changed their discussion patterns and contents according to their pre-discussion learning activities. Through more sophisticated dialogue analysis and topic modeling, researchers should be able to find additional evidence on the effectiveness of discussions that differs by what learning activity comes in advance.

Lastly, the long-term effects of discussions must be investigated. This study was conducted as a one-time study, and ended in an hour, but future studies may consider changes and trajectories of learning during discussions through a longer study up to one week or one semester.

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How Higher Education Instructors Conceptualize Diversity: A Phenomenographic Study

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Abstract: Higher education institutions around the globe have increasingly made the commitment to diversity. Instructors play an integral role in creating inclusive learning environments. Guided by sociopolitical perspectives on learning, we ask: How do higher education instructors conceptualize diversity? How do these conceptions inform curriculum and instruction? Interview data from 30 instructors teaching at minority-serving institutions in the United States revealed three distinct conceptions of diversity defined by variations in five aspects: student identities, intelligence mindset, pedagogical motivation, learning environment, and legitimized membership. The essentialist conception is based on students having inherently determinate traits described by preexisting universal categories. The functionalist conception differentiates students by academic performance. The existentialist conception acknowledges that students have unique experiences that impact the learning process. Our results indicate that while instructors acknowledge different student features and have varying understanding for why diversity is important, some conceptions of diversity do not necessarily suggest an inclusive culture.

Introduction

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has called for higher education institutions around the world to make the commitment to diversity. In an effort to promote inclusion and equity within education systems around the world, UNESCO (2020) called for the recognition and support of all learners who are diverse in "race, social class, ethnicity, religion, gender, sexual orientation, migrant status, and ability" (p. 24). Instructors serve an important role in the diffusion of diversity efforts through their design and implementation of transformed curriculum and cultivation of equitable teaching and learning environments (Kezar et al, 2008). Building the capabilities of and commitment from instructors to do this work often comes in the form of professional development (PD) (Macdonald et al., 2019). Though positive outcomes from such initiatives have been observed (Booker et al., 2016; Dewsbury & Brame, 2019), research continues to document chilly classroom climates and students' negative experiences (Harrison & Tanner, 2018; Súarez-Orozco et al., 2015). A reason for such inconsistencies may be the assumption that instructor participation in PD programs is the solution to improving classroom climate. Professional learning does not take place in a vacuum, and the usual focus of PD programs on instructor teaching practices overlooks the importance of the meaning instructors ascribe to student diversity (Amundsen & Wilson, 2012).

The need to investigate how instructors conceptualize diversity rests on the assumption that how one conceives of the world informs the approaches they take and the practices they employ (Pratt, 1992). Previous literature has demonstrated that instructors' conceptions of teaching are likely aligned with the approaches they adopt and the practices they implement; thus, any changes in conceptions will lead to observable changes in approaches and practice (Ho et al., 2001). Empirical research spanning decades has reported on different approaches and practices instructors have used in response to student diversity. Three pedagogical approaches have been broadly described: (a) the *ignore* approach, where instructors do not respond to student diversity; (b) the *compensate* approach, where instructors accommodate for students' diversity; and (c) the *utilize* approach, where instructors recognize student diversity as an enhancement to the learning environment (Boelens, 2018; Gordon et al., 2010). The most notable practice described in the literature is microaggressions (e.g. derogatory statements and invalidations (Sue et al., 2007)) perpetrated by instructors towards students. These often racial and gendered comments are a main contributing factor to the unwelcoming climate experienced by students in higher education (Harrison & Tanner, 2018). There still remains a dearth of literature on how instructors conceptualize diversity. Previous publications have discussed diversity as conceptualized through group and individual differences (Gordon, 2010; Jokikokko, 2005) or through external attributes and invisible characteristics (Jokikokko, 2005). Yet, there is also a lack of studies who attempt to connect conceptions of diversity and instructor approaches and practices. Leveraging the newfound traction and discourse surrounding critical consciousness (Freire, 1970) and the social and political ways of understanding education, teaching, and learning

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(Barton & Tan, 2020; González & Moll, 2002; Gutiérrez, 2013; Yosso, 2005), we sought to answer the following research questions: (a) how do instructors conceptualize diversity in higher education? and (b) how do these conceptions inform curriculum and instruction?

Conceptual framework

Phenomenography focuses on the qualitatively different ways that individuals experience, understand, and think about the same phenomenon (Marton, 1981). It is a common theoretical orientation used when examining conceptions (Åkerlind, 2005). The aim of phenomenography is to identify a range of conceptions, rather than describe correct or incorrect ways of thinking (Marton, 1981). Because conceptions are internal constructs, a phenomenon is assumed to be inseparable from an individual's experience. Therefore, phenomenography adopts a subjectivist and relative view of the nature of knowledge, where internal knowledge such as conceptions is dependent on the external reality and ultimately created through human thinking and activity (Svennson, 1997).

This relational nature between conceptions and reality means that a conception, when expressed, emphasizes parts of reality that have been more deeply experienced and thought about by an individual (Lamb et al., 2011). A fundamental assumption of phenomenography is that while conceptions holistically represent characteristics of a phenomenon, they can also be described compartmentally in terms of their reduced parts (Svennson, 1997). These reduced parts represent specific features of the phenomenon and are known as aspects (Marton & Booth, 1997). Variation theory within phenomenography further formalizes such awareness and relationship into an outcome space, which organizes the set of descriptions that are logically related to one another and reveals the distinctive ways in which individuals conceptualize a phenomenon (Marton et al., 2004).

Methods

Participants

Our study was conducted across multiple two-year and four-year minority-serving institutions (MSI) in California, United States. The instructors who served as participants were recruited from three PD programs. All instructors in our study engaged in their respective PD programs for at least one year. While this convenience sample through the PD programs was likely not representative of faculty at large in higher education, the sampling was also purposeful for the following reasons (Patton, 1990). Instructors who teach at MSIs are more likely to have interacted extensively with students from diverse backgrounds in their classrooms. The instructors also sought support and resources to develop pedagogical knowledge and improve their instructional practices. These specific contextual factors potentially provide information-rich experiences in relation to the phenomenon of diversity.

The sample included 30 instructors: 16 were full-time faculty at four-year MSIs, eight were part-time faculty at four-year MSIs, and six were full-time faculty at two-year MSIs. In terms of racial and ethnic backgrounds,19 instructors identified as White or Caucasian; five as Hispanic, Latina/o/x, or Chicana/o/x; two as Asian or Asian American; two with multiple racial and ethnic identities; and two unknown. In terms of gender, 17 instructors identified as women, 12 as men, and one unknown. In terms of disciplines, 19 instructors were in the natural sciences, eight in the humanities, and three in the social sciences. Each instructor taught a range of courses with a variety in class size and subject matter within their respective disciplines. The inclusion of instructors from different institution types and disciplines provides a more complete sample to draw from in making the outcome space, leading to informative and robust findings.

Data collection and analysis

Instructors were interviewed using a semi-structured protocol designed to explore their conceptions of diversity in relation to teaching and learning in the classroom. The semi-structured interview format allowed instructors the freedom to expand their views while maintaining a focus (Bernard, 1988). Interviews lasted approximately 60 minutes each, and the protocol consisted of six main questions: (1) When you hear the word diversity in relation to higher education, what comes to mind? (2) Was there ever a time in your academic career when you thought about diversity in a different way? How did you think about diversity then? (3) Are there other words that your campus or department use to describe ideas related to diversity? (4) Does student diversity influence how you teach? (5) Does student diversity influence how your students learn? (6) What do students who excel in your course or discipline have in common? What do students who are struggling in your course or discipline have in common? Interviews were audio-recorded, transcribed verbatim, and de-identified before analysis.

The analytical process was organized into three steps. First, two members of the research team developed preliminary codes using contact summary forms and close readings of the transcripts. Conceptual labels were created to describe what each instructor appeared to be attending to when discussing their experiences. At this

time, the research team consisting of all four authors also drew parallels between ideas identified in the interviews and existing constructs in the literature. This comparison served as an iterative process in which the investigative findings influenced the literature reviewed by the researchers, which in turn informed the refinement of data analysis. Second, these initial codes were transformed into conceptual categories by drawing relationships among the different aspects and variations emerging from the data. A constant comparative method (Glaser & Strauss, 1967) was employed to compare descriptions and definitions for each category with those from previously analyzed transcripts. This allowed for the confirmation or disconfirmation of previous conjectures, the guarding against biases, and the maintenance of consistency. Finally, data for each aspect were revisited to further refine and delineate the outcome space, resulting in different conceptions of diversity held by the instructors.

Our research team consisted of diverse perspectives including different nationalities and varying intersections of race, ethnicity, and gender. We used a process of argumentation at all three stages of the analytical process (Schoenfeld, 1992) to come to a consensus regarding the development of the codes, aspects, conceptions, and outcome space. Any disagreements were debated and fully resolved in research team meetings. Engagement in this activity provided a check against personal biases and aided with reliability. Åkerlind (2005) described this process as dialogic reliability in phenomenography, where researchers reach agreement "through discussion and mutual critique of the data and of each researcher's interpretive hypotheses" (p.331).

Findings

Instructors in this study attended to five aspects when conceptualizing diversity: (a) student identities, (b) intelligence mindset, (c) student engagement, (d) pedagogical motivation, and (e) legitimized membership. Based on the variations within each of these aspects, we identified three qualitatively distinct conceptions. The first conception maintains a focus on fixed qualities about groups of students and standards for higher education. Borrowing from the field of philosophy, we term the first conception *essentialist,* as essentialism defines the nature of entities in the world by a set of immutable traits. The second conception centers on student achievement, with students divorced from their context. We call the second conception *functionalist* because the functionalism ideology in philosophy asserts that entities in the world are defined by how well they function within their environments. The third conception, which we designate *existentialist,* foregrounds individual student experiences. In existentialism, individuals are not merely thinking subjects but are acting, feeling, and living humans with stories that extend beyond their immediate environments. We describe how instructors with these three conceptions interpret and enact each of the five aspects in a phenomenographic outcome space (Table 1).

Table 1

Outcome Space for Instructor Conceptions of Diversity

	Essentialist	Functionalist	Existentialist
Student Identities: How an instructor interprets student characteristics	Static: Student traits are permanent	Malleable: Student attributes can adapt to the learning environment	Experiential: Students' lived experiences are inseparable from them as learners
Intelligence mindset: How an instructor perceives student intelligence	Fixed: Intelligence is an innate quality that cannot be changed	Deficit: Expertise in a discipline can be developed over time with resources	Asset: Different experiences can be leveraged as intelligence in learning
Student engagement: How an instructor perceives the impact student diversity has on student engagement	Irrelevant: Student diversity does not contribute to learning	Supporting weaknesses: Students who are more successful can help students who are struggling	Reciprocity: Students can learn from one another's perspectives and unique experiences
Pedagogical motivation: How an instructor perceives their role in teaching diverse students	Equal treatment: Students are regarded equally to maintain fairness	Accommodation: Student deficits should be attended to	Intentional implementation: Student diversity should be engaged in the course
Legitimized membership: How an instructor positions students relative to the implicit classroom norms and structures	Outsiders: Students who cannot conform to instructor expectations do not belong	Guests: An instructor scaffolds learning environment to help students meet expectations	Rightful presence: An instructor centers student knowledge, experiences, and stories

Student identities

Student identities describes how an instructor interprets the characteristics that make students diverse. In the essentialist conception, an instructor views student characteristics as permanent and unchanging or, in other words, *static*. In the functionalist conception, an instructor perceives student characteristics as *malleable* and acknowledges that student differences position certain students better for success than others. In the existentialist conception, an instructor foregrounds the origins of student identities and recognizes these identities as outputs of the *experiential* lived histories of each student.

> *Static (essentialist):* "Linguistic diversity, well, some of my Chinese students have been great in terms of effort. Some of them, I think, never understood a word I said. And I don't know why they're here. So there's diversity of background in that respect."

> *Malleable (functionalist):* "I went, 'Here's a bunch of readings. Let's read and talk about them.' They didn't know what to do. Some had good high school backgrounds, some not up to that. That's always been a challenge. I've always been sympathetic to students. I've tried to make things as accessible as I can."

> *Experiential (existentialist):* "I'm not going to be able to sit with all 200 students and find out what it is about their background that resonate with what they're trying to learn. By background, it might mean the stories their family told, the way they were taught to approach an assignment in high school (…) The fact that they come from different backgrounds and have had different educational opportunities until they walked in the door affects how they learn and whether or not they feel confident or a bit imposter-ish on campus."

Intelligence mindset

Intelligence mindset describes how an instructor perceives student intelligence. In the essentialist conception, an instructor views intelligence as a *fixed*, innate quality of a student that defines their ability to succeed. In the functionalist conception, an instructor views intelligence from a *deficit* perspective as a characteristic that can be developed over time. In the existentialist conception, an instructor values students' *assets* as forms of intelligence.

> *Fixed (essentialist)*: "I was a person who told my students if they did poorly on the test, 'Maybe you should consider changing your major.' I'm basically telling that student, 'You cannot get better than this' and 'You will always do bad on the exams no matter what you do.'"

> *Deficit (functionalist)*: [Referring to students at a two-year institution] "Sometimes I tell my students, 'When I look at you, a lot of you are as motivated and as intelligent as my class at [four-year institution]. But all of you lack the background from age 13 to 18 to study harder. It's the discipline to solve problems.'"

> *Asset (existentialist)*: "You don't want to feel, 'Everyone seems to be getting it but I'm not. I must be dumb.' It's like, 'No, wait. What's your major? A music major? What can you tell us about this?' Including and trying to figure out how everyone can participate, feel like they belong, and are helping."

Student engagement

Student engagement describes how an instructor perceives the impact diversity has on students' interaction with the course content and with one another. In the essentialist conception, an instructor considers student diversity as *irrelevant* to student learning and engagement. In the functionalist conception, student engagement is oriented around how the learning environment can be organized to *support the weaknesses* of certain groups of students. In the existentialist conception, student engagement is characterized by the interpretation that every student possesses a unique combination of knowledge, experiences, and skills; thus, the learning environment should facilitate *reciprocity*, or a sharing of these individual characteristics.

> *Irrelevant (essentialist):* "You're saying that from the student's point of view, does their own diversity influence the way they learn? I wouldn't think so. I think we all learn in similar ways."

Supporting weaknesses (functionalist): "If I give my students group work, that means that there's a group of four but only two people work because the smart kids do all the problems (…) I say, 'After you're done, I'll pick one random person to do the problem.' So then, everybody needs to know it. They need to talk to each other."

Reciprocity (existentialist): "More experiences that students have in and out of the classroom—in terms of working with a diverse student population—is going to help them in the long run. Whether they go to academia or another job, they're going to work with diverse employees. The more they understand how to work with different personalities, mindsets, the more prepared they're going to be to help make a change for the world. (…) It will really benefit them in creating a more meaningful existence in their work or personal life."

Pedagogical motivation

Pedagogical motivation describes how an instructor perceives their role in teaching students from diverse backgrounds. In the essentialist conception, an instructor views a responsibility to attend to the idea of fairness and employ instructional strategies based on *equality*. In the functionalist conception, an instructor recognizes that diversity impacts student circumstances and affects student performance; thus, an instructor should alter instructional strategies to *accommodate* student diversity. In the existentialist conception, an instructor attends to the importance of diversity within the classroom and *intentionally implements* pedagogical strategies and curriculum that fosters thinking and conversations centered around diversity and social justice issues.

Equal treatment (essentialist): "I treat everyone the same. I grade everybody the same. I'm grading based on the quality of their work."

Accommodations (functionalist): "I try my best to have policies in class that make it clear to students that it's okay for them to have other things going on in their lives. I do that by dropping a homework and a quiz without any penalty."

Intentional implementation (existentialist): "I thought, 'Who cares if this class is about mechanics and materials? This is still about humans.' Bringing in some of these conversations into my class. I feel like it's my duty. The first female crash test dummy was just designed. Because we've always used the standard male crash test dummy, women are more likely to be injured and die in car accidents. (…) I showed them this picture, 'Here's the first female crash test dummy. Why is this important? Why do we need to create different crash test dummies?'"

Legitimized membership

Legitimized membership describes how an instructor positions students relative to implicit classroom norms and structures. In the essentialist conception, an instructor considers students as *outsiders* and attends to the lack of skills and abilities that students have. In the functionalist conception, an instructor positions students as *guests* and holds a sense of responsibility to help students navigate the rigorous expectations of higher education. In the existentialist conception, an instructor attends to the *rightful presence* of students in higher education and values the knowledge and experiences that students bring, even if it does not align with existing norms and practices.

Outsiders (essentialist): "My first semester ever, I would teach, then give a midterm, and say, 'We did all these problems and lectures. How come they don't know how to do this?' The first expectation when you teach is everything you say, students should know how to do."

Guests (functionalist): "I put in a ton of scaffolds. (…) I'm like, 'Here's the homework. It's really important you do it every week. Here are the applications, activities, and quizzes.' I do all of that because I think it helps the student diversity—the students that don't know that they need to study every week, right? They might not know how to really do that."

Rightful presence (existentialist): "For an instructor, it should be productively humbling to say, 'I can't know everything about your experiences.' I felt it was important to invite the students into the exploration process and make them feel like they could be experts about it. There's so much about the discourse of academic English and the discourse of higher education that is still couched in a really WASP [White Anglo-Saxon Protestant] way. And if we presume that's the

only way people will display or perform knowledge, then we're cutting people out automatically who don't want to present or speak that way."

Outcome space

All of the instructors interviewed in our study recognized diversity, yet as our findings have shown, there is a wide range of how diversity is understood and manifested (Table 1). The five aspects (student identities, intelligence mindset, student engagement, pedagogical motivation, and legitimized membership) are organized into rows and represent the compartmental characteristics of diversity that instructors attended to. Represented by the columns, we identified the three conceptions (essentialist, functionalist, and existentialist) based on a holistic integration of the aspects around similar philosophical assumptions (Table 1).

In the essentialist conception, an instructor perceives students as having static characteristics and fixed intelligence. Diversity is irrelevant to student learning and engagement. An instructor adopts pedagogical strategies based on equal treatment and meritocracy and positions students as outsiders to higher education. In the functionalist conception, an instructor holds the understanding that students can be functional in higher education with support and resources. Student characteristics are viewed as malleable and student intelligence is perceived from a deficit perspective. An instructor accommodates students' diversity and learning environments are organized so that accomplished students can support those with weaknesses. Students are guests since their presence still requires affirmation and assistance from the structures and authority in higher education. In the existentialist conception, an instructor views individual experiences as the origin for student characteristics and as assets in building upon knowledge and skills. An instructor facilitates reciprocity or exchange between students and takes responsibility for engaging them in discussions about how their experiences and the experiences of others impact their work as scholars in their disciplines. Students are rightfully present and belong in higher education spaces.

Implications

Table 1 can serve as a tool for instructors to reflect on their own beliefs. Such processing offers ways to consider new dimensions of diversity and how it impacts the classroom from both instructor and student perspectives. While the existing literature describes a handful of PD interventions aimed at transforming instructional practices, our outcome space offers a framework to support conceptual change. Given the relationship between conceptions and practices, we argue that PD that incorporates conceptual change can promote the adoption of more targeted practices to foster inclusive classroom climates. While the findings we have articulated from our study do not directly suggest any modes or mechanisms for conceptual change, existing literature has several suggestions.

The first mechanism for conceptual change is based in Relational Cultural Theory (RCT), a paradigm in which individuals grow through their relationships with others (Schwartz, 2019). RCT asserts that meaning and empowerment can be derived by instructors as they connect authentically with their students. In developing greater awareness and understanding of their students' backgrounds, instructors are positioned to recognize aspects of diversity during interactions and curriculum design. Eastman et al. (2019) conducted a case study of an engineering professor and documented the professor's changing understanding of race, privilege, and equity. They noted that the professor's interactions with minoritized students were essential experiences that promoted a change in perspective. While building relationships with students may be an informal practice undertaken by individual instructors, formal interventions can facilitate these interactions. For example, Carballo et al. (2019) reported on a training intervention in which faculty conceptions of disability and inclusive education were transformed towards a more positive understanding of how they could support their students with disabilities. They noted that an important feature of their intervention was that students with disabilities were invited to speak about their experiences at each session.

The second mechanism for conceptual change utilizes the phenomenographic lens. The emphasis on levels of awareness in phenomenography provides a pedagogical framework known as the Pedagogy of Learning (Marton et al. 2004), which allows for "the object of learning to serve as a starting point to explore the conditions that make learning possible" (Wright & Osman, 2018, p. 264). If the goal is for instructors to have and enact upon a deeper understanding of the diversity that exists in their classroom, they must be familiarized with the range of conceptions in order to reflect on their own level of awareness and current conceptions and approaches to diversity (Trigwell et al., 2005; Wright & Osman, 2018). The aspects and conceptions we have outlined in our outcome space should be explicitly presented to instructors as the object of learning. This presentation of contrasting conceptions may enable instructors to reflect on what conception of diversity they currently hold and what conception of diversity they desire to hold. The aspects provide instructors with different angles of diversity to which they should attend. These in turn can be connected to specific approaches and practices. Whether it is

through individual reflection or a formalized PD opportunity, we invite instructors to recognize the power and impact their beliefs and actions have on students.

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Using Epistemic Network Analysis to Explore Discourse Patterns across Design Iterations of a Teacher Dashboard

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Abstract: Providing high-level support to students on NGSS inquiry practices can be challenging; however, teacher dashboards can help teachers provide just-in-time instruction to students, both in-person and online. Prior work has shown some success with a dashboard that alerts teachers in real time on students' science inquiry difficulties, but teachers differed in their use of the alerts. To further support teachers, we designed a second iteration, in which the alerts included actionable, evidence-based Teacher Inquiry Practice Supports (TIPS), a series of suggested scaffolds that teachers can use to support students on the practices with which they are struggling. In this study, we investigate how the discursive support patterns from one teacher differed when using the dashboard alerts *without* TIPS followed by *with* TIPS. Findings suggest that TIPS influenced how the teacher incorporated different types of support for her students, and further, that the support given varied across different virtual lab stages.

Introduction

With increased efforts to boost national science achievement, 44 states and D.C. have adopted the Next Generation Science Standards (NGSS Lead States 2013; NGSS, henceforth), which outlines core science inquiry practices that, when richly integrated with content, reflect competencies that students need for future success in STEM careers (National Research Council, 2018). However, teachers have found inquiry to be difficult to implement in their science classrooms for many reasons, including: time, space, or material constraints (Lo et al., 2014; Zinger et al., 2020); the lack of authentic, empirically tested resources (Krajcik, et al., 2000; Schneider, et al., 2005); the time-intensive, subjective nature of grading inquiry (Deters, 2005); the arduous burden of grading multiple authentic inquiry assignments (Gobert et al., 2018); and the lack of immediate actionable data for identifying student difficulties (Kuhn, 2005).

Due to these difficulties in teaching *and* assessing inquiry, teachers need real-time, fine-grained data about their students' inquiry competencies that are typically not visible within the constraints of the class (Martinez-Maldonado, et al., 2015). One technological development that can address this need is a dashboard, a monitoring tool that provides data on student performance and progress (Dillenbourg, 2013; Holstein et al., 2019). Alerting dashboards can provide detailed, contextual information to teachers to identify and diagnose students' difficulties and to support students' learning in real time (Roschelle et al., 2017).

Although a number of dashboards consider students' content understanding or collaborative interactions in science (e.g., CK Biology curriculum dashboard; Acosta & Slotta, 2018; WISE dashboard, Matuk et al., 2016; SAIL Smart Space's tablet tool, Tissenbaum & Slotta, 2019), these tools are not designed or technologically-instrumented to gather and analyze students' science inquiry practice competencies emphasized as critical by policy documents such as the Next Generation Science Standards (NGSS, 2013). Furthermore, these science dashboards either do not provide alerts (e.g., Acosta & Slotta, 2018; Matuk et al., 2016) or only provide alerts about activity completion (e.g., Tissenbaum & Slotta, 2019), rather than providing real-time alerts about student difficulties. Thus, for NGSS to be realized, there is a need for alerting dashboards that provide teachers with actionable data about their students' inquiry competencies so that teachers can provide instruction on inquiry practices to students as they work in real-time, when deep learning is optimal (Koedinger & Corbett, 2006).

About Inq-ITS and Inq-Blotter

The Inquiry Intelligent Tutoring System (Inq-ITS) is an intelligent tutoring system platform that uses patented, educational data-mined and knowledge-engineered algorithms (Gobert et al., 2013) to assess students' competencies on key scientific inquiry practices outlined in the Next Generation Science Standards (NGSS, 2013). To better help teachers provide support to students as they are conducting inquiry within the virtual labs in the Inq-ITS environment, a teacher dashboard, called Inq-Blotter, was developed (Gobert et al., 2018). With Inq-Blotter, teachers receive real-time alerts based on the data gathered from the fine-grained automated assessments built into Inq-ITS. In the original design iteration of Inq-Blotter, these alerts provided textual descriptions and visualizations about both individual and whole-class student performance, including information on the activities students completed, progress bars with scores on each of the inquiry practices, and fine-grained data about

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students' difficulties on each of the practices (Gobert et al., 2018). To our knowledge, this is the only dashboard that provides alerts based on rigorous, fine-grained assessment of students' scientific inquiry competencies.

To test this first design iteration of the alerts in Inq-Blotter, Sao Pedro et al. (2019) conducted a randomized controlled study comparing the effects of teacher support elicited by Inq-Blotter with alerts versus without alerts (i.e., no performance data) and found that students supported by a teacher using alerts improved more than students helped by a teacher without alerts. While these alerts were helpful in notifying teachers about the specific ways in which individual students were struggling, additional studies have shown that, when provided with the basic alerts alone, teachers may tend to deliver lower levels of support to students (e.g., telling students which variables to hold constant in an investigation; Dickler et al., 2019, 2021). Although the lower levels of support may help students in the short term, the students who received more sophisticated combinations of high-level inquiry support (e.g., explaining what controlled variables are and why they are important) showed more robust improvement in their inquiry practice performances over time (Dickler et al., 2019, 2021).

Therefore, for the second design iteration of the alerts, we used high-level exemplars of teacher support that were associated with student improvement (Dickler et al., 2019) to develop Teacher Inquiry Practice Supports (TIPS; Adair et al., 2020). Embedded directly into the alerts, TIPS offers suggestions on *how* teachers can provide inquiry support to a student for the specific practice with which they are struggling. Due to its importance for teachers' instruction of NGSS practices, more in-depth research is needed to determine how TIPS influence the types of support that teachers provide when guiding their students' scientific inquiry.

In the present case study, we build on our prior work that used Epistemic Network Analysis (ENA; Shaffer et al., 2016) to examine teacher discourse when using Inq-Blotter (Dickler et al., 2019, 2021). Specifically, we use these same methods to deeply examine the discursive support patterns of one teacher, Mrs. A, and compare the ways in which those patterns change when the Inq-Blotter alerts contain TIPS versus when they do not. In short, we seek to understand: *How do the discursive patterns of support differ when Mrs. A uses the teacher dashboard alerts with TIPS versus without TIPS?*

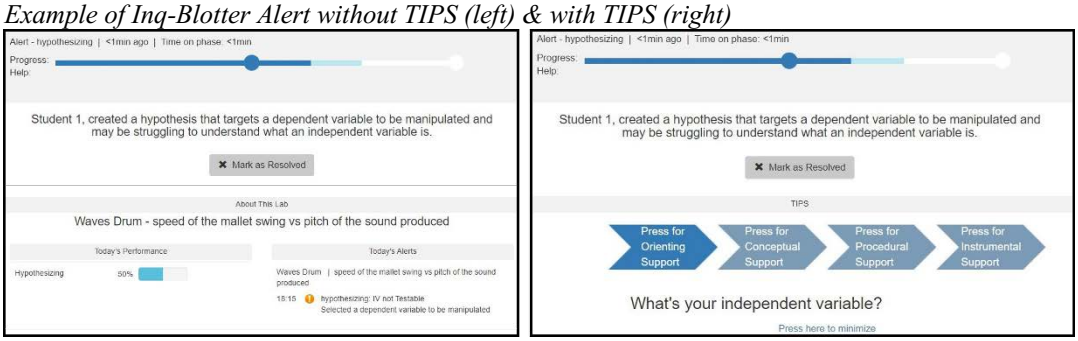
Method

Participants include one teacher, Mrs. A, and her eighth-grade physical science students from a Title 1 middle school located in the Northwestern United States. Mrs. A reported that, of her 157 students, 97% receive free/reduced lunch, 74% are English Language Learners, and 83% identify as students of color. Mrs. A has six years of teaching experience, including five years using Inq-ITS in her classroom. However, she had no experience with Inq-Blotter prior to the data collection days.

Data was collected over two days in January 2021, during which Mrs. A was conducting synchronous classes fully remotely via Zoom due to the COVID-19 pandemic. The school followed an alternating A/B schedule, in which students on "Schedule A" had class with Mrs. A on Tuesdays and Thursdays, while students on "Schedule B" had class with Mrs. A on Wednesdays and Fridays. In total, 65 students logged in and worked on at least one stage of the virtual lab during the two data collection days – 30 students on Day 1 (Tuesday) and 35 *different* students on Day 2 (Wednesday).

Figure 1

Example of Inq-Blotter Alert without TIPS (left) & with TIPS (right)



Materials

The students used Inq-ITS to conduct an NGSS-aligned virtual inquiry investigations on the topic of waves, related to NGSS Performance Expectation MS-PS4-2. The goal of the investigation was to determine how the speed of a mallet striking a drum influences the pitch of the sound produced. As part of the inquiry investigation, the students complete four stages: (1) asking questions/hypothesizing, (2) carrying out investigations/collecting data, (3) analyzing/interpreting data, and (4) constructing explanations/communicating findings. For the first three

stages, students are automatically assessed in real time through algorithms built into Inq-ITS, which then trigger fine-grained alerts for the teacher to view on Inq-Blotter (Gobert et al., 2013, 2018). Development of the automated scoring and dashboard alerts, for the communicating findings stage is still on-going (Li et al., 2017).

On both data collection days, Mrs. A used Inq-Blotter (Gobert et al., 2018) to receive real-time alerts about her students' difficulties on specific inquiry practices as they were working on the lab. Specifically, on Day 1, the teacher used the original version of Inq-Blotter *without* the instructional support of TIPS, and on Day 2, the teacher used the iterated design version of Inq-Blotter *with* the instructional support of TIPS embedded into the alerts (see Figure 1). The TIPS (Teacher Inquiry Practice Supports; Adair et al., 2020) are a series of suggested scaffolds, which were modeled from the supports (Adair et al., 2020) that teachers had generated in real time when responding to the first design iteration of Inq-Blotter alerts and that were shown to improve student inquiry performance in prior studies (Dickler et al., 2019, 2021).

Measures

All teacher-student interactions during the designated class times over the two data collection days were audio-recorded via the video conferencing platform Zoom. Audio recordings were transcribed, and 211 teacher-spoken segments were identified from across the class sessions. A segment was considered a new segment if the teacher: (a) shifted from addressing one individual student to another, or (b) shifted to addressing the whole class rather than an individual student or vice versa. Two researchers coded all teacher-spoken segments, with 86% agreement initially between the researchers. Disagreements were discussed and clarifications to the codebook were made until 100% agreement was reached. The agreed-upon codes were used for analyses.

The codebook included seven types of support (see Table 1) developed and used in prior studies with Inq-Blotter (Dickler et al., 2019, 2021). The first four types of support (orienting, conceptual, procedural, and instrumental) are scaffolds that are implemented specifically in supporting students on inquiry practices, whereas the last three types (scientific content, evaluative, and technical) are not directly related to inquiry support. Codes were not considered mutually exclusive and could co-occur within teacher-spoken segments. Each teacher-spoken segment was also labeled according to the inquiry stage on which the student was being helped. Of the 211 teacher-spoken segments, 113 segments occurred on Day 1 and 98 on Day 2.

Table 1
Types of Teacher Support

Type	Description	Example
Orienting	Direct student attention to components of inquiry practice	"Let's look at your goal"
Conceptual	Explain key terms and components of inquiry practice	"The dependent variable is the thing we're going to measure."
Procedural	Provide guidance on the steps involved with an inquiry practice	"You need to be changing one thing at a time."
Instrumental	Tell exact actions needed to move forward on an inquiry practice	"So, we need to pick the one that says, 'does not support my hypothesis.'"
Scientific Content	Explain information about a scientific concept or phenomenon	"Pitch has to do with how high or low the note sounds to you."
Evaluative	Provide comments on the quality/accuracy of student work	"It looks like you're having some trouble…"
Technical	Help with online challenges (scrolling, screensharing, etc.)	"Oh, will you scroll up a little bit?"

Analysis

First, we addressed whether there were differences in the patterns of support provided by Mrs. A throughout all teacher-spoken segments on Day 1 (when the Inq-Blotter alerts did not include TIPS) versus Day 2 (when the alerts included TIPS). To do so, we compared the proportions of the types of support across the two conditions and conducted chi-squared tests to determine the significance of the associations between the condition (i.e., the presence of TIPS) and the occurrences of the types of support.

Additionally, we conducted an epistemic network analysis (ENA; Shaffer et al., 2016) for all 211 teacher-spoken segments (see "Comprehensive Epistemic Network Analysis" in the Results section). To further understand if and how the discourse patterns differed across the different inquiry stages with TIPS versus no TIPS,

we conducted additional epistemic network analyses to compare how Mrs. A's support patterns differed for each condition on each inquiry stage (i.e., Hypothesizing, Collecting Data, and Analyzing Data).

We created the epistemic network graphs using an online graphical tool (Marquart et al., 2018). In the graphs, the nodes represent the types of teacher support (see Table 1), and the thickness, or strength, of the lines connecting the nodes represents the frequency of co-occurrence between the two types of support. We evaluated the differences between the networks quantitatively using t-tests on the mean centroid values, which are determined by the average strengths of the connections between the types of teacher support in the network, as well as qualitatively by visually comparing the strengths of the connections in the subtracted networks.

Results

Overall, we found that Mrs. A provided her students with different types of support (see Table 1) when TIPS were embedded in the alerts versus when they were not. In particular, the proportions of all four types of inquiry support (orienting, conceptual, procedural, and instrumental) that occurred in the teacher-spoken segments with TIPS (Day 2) *increased* from the proportions of inquiry support that occurred without TIPS (Day 1). A chi-squared test showed that there were significant relationships between the presence of TIPS and the occurrences of the orienting, conceptual, and procedural supports, but not between TIPS conditions and instrumental support. These results suggest that the availability of different types of inquiry support embedded directly into an alert (see Figure 1) helped the teacher to include these supports more frequently in the guidance she provided to her students.

Additionally, there was a significant relationship between the presence of TIPS and the occurrence of evaluative support. One explanation for the increase in evaluative remarks with TIPS (Day 2) is that the teacher referenced the dashboard more, and, as a result, she more often led conversations with individual students by directly commenting on a particular aspect of the practice with which they were struggling (e.g., "It looks like you've been changing a lot of variables") rather than asking the student about their general progress (e.g., "How is it going?"). Although she had access to alerts both days, TIPS may have lessened the acute complexity inherent in addressing frequent and on-going student needs, and in turn, provided pedagogical support for assessment conversations at the boundaries of curriculum, instruction, and assessment (Duschl & Gitomer, 1997).

However, we found no significant association between the condition and the occurrence of scientific content support or technical support. A Fisher's exact test was used to test the relationship between the condition and scientific content support due to the limited number of instances in which the teacher used this type of support. These results are not surprising since the TIPS embedded in the alerts provide suggestions for *inquiry*, rather than scientific content support and are categorized into the four types of inquiry-related support. Also, Mrs. A had five years of teaching experience with Inq-ITS, and the very few instances of scientific content support may have been due to her familiarity with the system and her understanding that the NGSS (2013) emphasizes competencies with the practices that can be transferred across science domains.

Table 2

Proportions of Each Type of Support Occurring in Teacher-Spoken Segments

Type of Support	Without TIPS (N = 113)	With TIPS (N = 98)	Statistics
Orienting	19.5%	35.7%	$X^2(1) = 7.025$, $p = .008$*
Conceptual	8.0%	21.4%	$X^2(1) = 7.801$, $p = .005$*
Procedural	25.7%	46.9%	$X^2(1) = 10.369$, $p = .001$*
Instrumental	23.9%	31.6%	$X^2(1) = 1.577$, $p = .209$
Scientific Content	2.7%	0.0%	$p = .250$, Fisher's exact test
Evaluative	22.1%	40.8%	$X^2(1) = 8.603$, $p = .003$*
Technical	48.7%	51.0%	$X^2(1) = 0.116$, $p = .734$

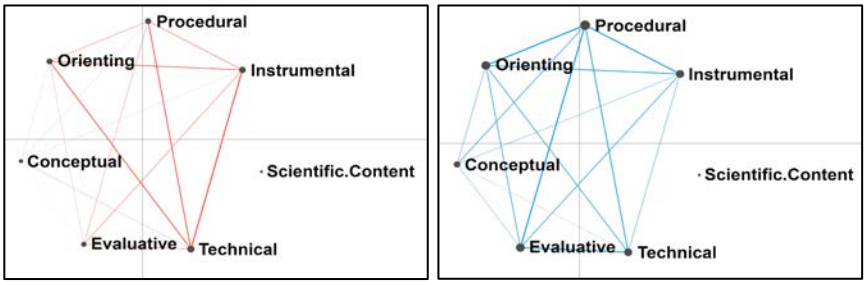
Findings from the Comprehensive Epistemic Network Analysis

We conducted an ENA (Shaffer et al., 2016) to compare how the 112 teacher-spoken segments that occurred on Day 1 (without TIPS) differed from the 98 teacher-spoken segments that occurred on Day 2 (with TIPS) in terms of the types of support provided. When comparing the mean centroid values of the networks (see Figure 2), the ENA revealed a significant difference in Mrs. A's support patterns when she used the alerting dashboard with TIPS ($M = -0.12$, $SD = 0.40$) versus without TIPS ($M = 0.10$, $SD = 0.27$; $t(164.39) = -4.58$, $p < 0.00$, $d = 0.65$).

Moreover, the subtracted networks show that conceptual and procedural supports co-occurred more often with the other types of inquiry support on Day 2 than on Day 1. That is, when responding to alerts with TIPS, the teacher used and integrated more of the different types of *inquiry* support than she did when responding to alerts without TIPS, demonstrating greater complexity of support appropriate for the sophistication of the practices.

Figure 2

Comprehensive Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)



Findings from the Epistemic Network Analyses for Each Inquiry Stage

We also sought to understand how the teacher's support patterns changed depending on the inquiry stage with which the student was being helped. To do this, we identified the teacher-spoken segments associated with each of the four inquiry stages and used the same ENA technique, comparing the teacher-spoken segments that occurred on Day 1 (without TIPS) to the ones that occurred on Day 2 (with TIPS) for each of the four inquiry stages.

For the first three inquiry stages (i.e., Hypothesizing, Collecting Data, and Analyzing Data), the ENA revealed significant differences in the patterns of support provided by the teacher when she had access to alerts with TIPS versus without TIPS (see Table 3) when comparing mean centroid values of the networks (see Figures 3, 4, and 5), indicating that TIPS influenced Mrs. A's pedagogical discourse on Day 2. However, for the last stage (i.e., Communicating Findings), there was *not* a significant difference in the patterns of support provided by the teacher on Day 2 versus Day 1 when comparing the mean centroid values of the networks. Because automated scoring for the Communicating Findings stage is still in development, alerts were not available for this stage. Nonetheless, the teacher may have used a combination of her pedagogical content knowledge for both inquiry (Magnusson et al., 1999) and for communicating findings (McNeill & Knight, 2013) as well as knowledge of the alerts and TIPS from the previous stages to inform the kind of support that she would provide her students on this last stage. Though we do not see a significant difference between the two conditions here, future work is needed to determine if and how the alerting dashboard could further augment teacher support on communicating findings during inquiry, especially given the importance of this inquiry competency.

Table 3

Epistemic Network Analysis on Discursive Support Patterns for each Inquiry Stage

	No TIPS			TIPS			
Inquiry Stage	Mean	SD	N	Mean	SD	N	Statistics
1. Hypothesizing	0.52	0.53	22	-0.45	0.81	25	$t(41.80) = -4.90$, $p = 0$*, $d = 1.39$
2. Collecting Data	0.92	0.37	8	-0.57	1.15	13	$t(15.60) = -4.31$, $p = 0.00$*, $d = 1.58$
3. Analyzing Data	-0.77	1.63	7	1.08	0.92	5	$t(9.67) = 2.50$, $p = 0.03$*, $d = 1.33$
4. Comm. Findings	0.37	0.79	10	-0.28	0.82	13	$t(19.89) = -1.92$, $p = 0.07$, $d = 0.80$

ENA for Inquiry Stage 1: Hypothesizing

For the first inquiry stage (Hypothesizing), an examination of the subtracted networks (see Figure 3) shows a similar change in Mrs. A's discursive patterns as we had seen in the overall networks (see Figure 2), which showed stronger connections between more types of inquiry support when TIPS were embedded in the alerts. For example, when helping a student on the first inquiry stage *without* TIPS in the alerts, Mrs. A said:

> Will you scroll up…so we can see the goal on your screen? [Technical; Orienting] Okay…it says determine how the mallet speed influences the pitch of the sound produced. So first, we're going to look at the mallet speed. And then second, we're going to look at the pitch. [Orienting] So in the first box where it says, "What I Will Change," you're gonna find...the option that says mallet speed [Instrumental]...And then we're gonna see how it influences the pitch of the sound. [Procedural] So then…in the box [where] it says, "What Will Happen," you're gonna find the one that says pitch of the sound. [Instrumental] There you go…Perfect [Evaluative].

In this example, the teacher employs both non-inquiry supports (evaluative and technical) as well as inquiry supports (orienting, procedural, and instrumental). However, the inquiry support focuses on low-level

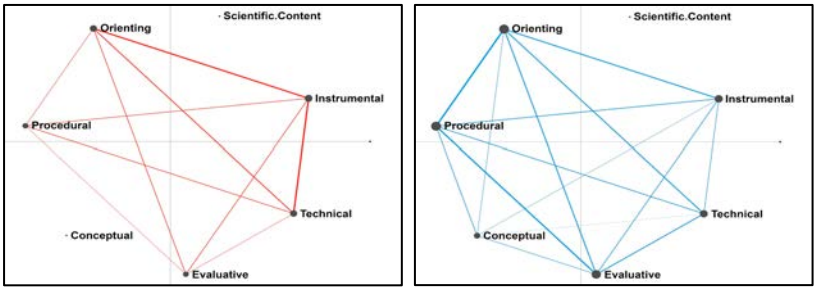
instrumental support, in which the teacher is telling the student exactly what to select in the virtual lab. In contrast, when helping a different student on the same stage but *with* TIPS, Mrs. A said:

> Okay, so let's start by looking at your goal. [Orienting] The goal says determine how the mallet speed influences the pitch of the sound produced. So, in that goal is where you are going to get your independent and your dependent variable. [Procedural] So the independent variable is the thing that you're going to change. [Conceptual] So that's what you're going to click in that "What I Will Change" box [Instrumental]. If you're not sure what's supposed to change, you can look at the goal [Orienting]…usually, the independent variable is listed first. [Procedural]

Instead of telling the student the exact answer as she did in the previous segment, Mrs. A provides a combination of targeted inquiry supports (i.e., orienting, procedural, and conceptual). Moreover, through explaining what an independent variable is, Mrs. A implements a high-level *conceptual* support, which is typically associated with greater student improvement (Dickler et al., 2021).

Figure 3

Stage 1 Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)

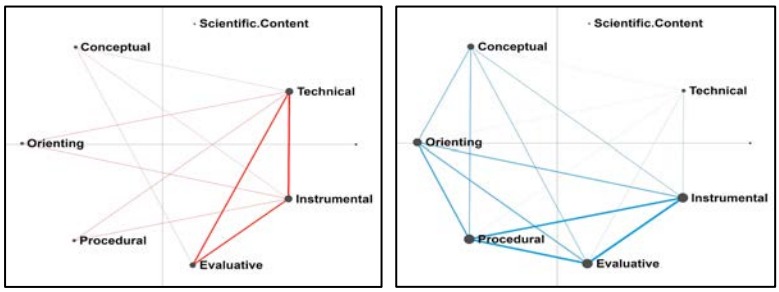


ENA for Inquiry Stage 2: Collecting Data

For the second inquiry stage (i.e., Collecting Data), an examination of the networks (see Figure 4) shows that, on Day 1 (without TIPS), Mrs. A mainly provided support with technical, evaluative, and instrumental components. On Day 2 (with TIPS), we see stronger connections between evaluative, instrumental, and procedural supports, as well as some increased strength in the connections to orienting and conceptual supports. The stronger connections toward the other inquiry support types on Day 2 show that Mrs. A shifted to include more elaborate supports to help students *notice* aspects involved in conducting investigations (i.e., orienting support) and piece together *how* (i.e., procedural support) and *why* (i.e., conceptual support) they should conduct investigations, without providing direct instruction of exactly what to do in the virtual lab (i.e., instrumental support).

Figure 4

Stage 2 Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)

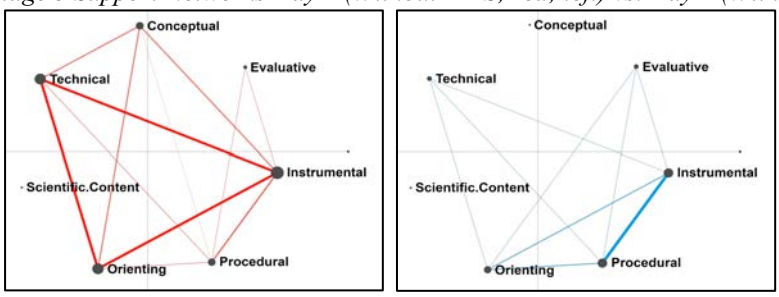


ENA for Inquiry Stage 3: Analyzing Data

Lastly, for the third inquiry stage (i.e., Analyzing Data), an examination of the subtracted networks (see Figure 5) shows that, on Day 1 (without TIPS), Mrs. A mainly provided support with technical, instrumental, and orienting components (similar to the types of support she provided on the previous stages), but she also combined conceptual support into the guidance she provided to her students as well. However, Mrs. A focused primarily on instrumental and procedural support on the analyzing data stage on Day 2 (with TIPS).

Figure 5

Stage 3 Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)



While the shift to include more procedural support when using TIPS is consistent with the shifts that we see in the previous stages (i.e., Hypothesizing and Collecting Data), it is perhaps surprising that no conceptual support occurred in the teacher-spoken segments on Day 2 since we would expect that Mrs. A would use TIPS to implement conceptual support more often for the Analyzing Data stage as she had done for the previous inquiry stages. One explanation is that the teacher had fewer opportunities to provide conceptual support on this stage because several students (approximately 13% of the students on Day 1 and 26% on Day 2) did not reach this stage of the virtual lab. Moreover, the complexity involved with the data analysis stage may have led the teacher to choose certain types of support over others. Further work is needed to determine why a teacher chooses to use certain supports, whether some supports are more effective than others on different inquiry stages, and if and how teachers would incorporate the conceptual support suggestions offered in TIPS when given more opportunities.

Discussion

With the rollout of the NGSS (2013), there is a need for resources that help teachers in assessing and supporting their students' competencies with science inquiry practices (Kuhn, 2005; Pruitt, 2014). Alerting dashboards, when paired with a system like Inq-ITS that is instrumented to provide fine-grained data in real time on students' inquiry difficulties (Gobert et al., 2018), can be helpful to teachers' instruction of NGSS and, in turn, to students' learning of these competencies (Dickler et al., 2019). However, even with fine-grained data about students' difficulties, teachers still may not provide support at the level of sophistication needed to help students improve on the practices (Dickler et al., 2021) without pedagogical guidance in the form of TIPS (Adair et al., 2020).

In this study, we addressed how instructional guidance in the form of TIPS could influence a teacher's pedagogical discourse practices related to science inquiry. We found that, for Mrs. A, a teacher with five years of experience teaching with the virtual lab investigations in Inq-ITS, there was significant evidence of her pedagogical content knowledge for inquiry (Magnusson et al., 1999), since, even without TIPS, she prioritized inquiry support. Nevertheless, she still benefitted from TIPS, as they allowed her to more frequently blend high-level inquiry supports (i.e., conceptual and procedural), which tend to be associated with student improvement on inquiry practices (Dickler et al., 2021). As revealed through the ENA, the more frequent co-occurrences of the high-level supports in the *with*-TIPS condition demonstrates that TIPS helped Mrs. A in growing the sophistication and complexity in her informal formative assessment practices, which are essential for fostering effective scientific inquiry learning (Ruiz-Primo & Furtak, 2006).

This research not only provides a rich example of how iterative design and research-based improvements can improve alerting dashboards, but also furthers understanding of how to support and optimize teachers' use of alerting dashboards. These findings suggest that alerting dashboards, like Inq-Blotter, that include actionable data through real-time alerts as well as instructional support for teachers (such as, in the form of TIPS), have great potential for helping teachers in realizing the vision of the NGSS (2013).

Lastly, since TIPS were modeled from the supports (Adair et al., 2020) that were generated by real teachers in real-time when responding to first design iteration of Inq-Blotter alerts and that were shown to improve student inquiry performance (Dickler et al., 2019, 2021), future work will address if and how teachers' continued usage of TIPS over time supports student improvement on the inquiry practices.

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International Society of the Learning Sciences

Dancing with Data: Embodying the Numerical and Humanistic Sides of Data

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Abstract: Data literacy is important for supporting individuals to incorporate information from research studies into their own perspectives and decision-making processes. However, it can be challenging for students to read, understand, and relate to data. Students have to be able to traverse the representational forms that data takes on (i.e., numerical, graphical, etc.) and connect it to their understanding of a topic. We explore the implementation of a co-designed data-dance unit in which middle school students created their own embodied metaphors to represent and communicate about graphs through dance. In analyzing dance artifacts and post-study interviews with the learners and teachers, we demonstrate how the creation of embodied metaphors in dance led to new ways of exploring the data as learners reflected on different perspectives on topics across numerical values, contexts, and implications.

Introduction

Dance encompasses technical and creative problem-solving practices that center the body. Dance education supports non-verbal expression that packs and unpacks meaning through movement (Hanna, 2008; Koff, 2000). Dance is not just a practice meant for professionals, but a discipline that offers everyone a way of developing "self-expression and interpretation through motion" (Koff, 2000). The unique embodied practices of dance create opportunities to expand the ways that learners can explore and build understanding with and about data. We co-designed a unit that combines math and contemporary dance practices in which learners explored a set of graphs about chosen topics, and developed dances to represent and communicate about their data. We present findings from this experience answering the following research question: ***How did learners engage in embodied meaning-making around data in a contemporary dance and data unit?***

Background Literature

Data Literacy and Data Art

Data literacy has been critiqued for focusing mostly on technical skills with disregard for broader concepts like *citizenship* and *empowerment,* which can exacerbate educational and social inequities (D'Ignazio, 2017). A creative data literacy framing that incorporates art production with data practices can attend to these issues (D'Ignazio, 2017) and help students achieve the same rigor in learning as traditional curricula (Bhargava et al., 2016). In particular, creative data literacy can support students in developing their identities in relation to data (Stornaiuolo, 2019) and seeing themselves as able to "speak data" through creative practices (D'Ignazio, 2017). Bhargava & D'Ignazio (2017), for instance, show that creating data sculptures helped students overcome initial barriers while attending to their complex ideas. Data art has helped students explore the social-situativity of data through developing narratives, argumentation, and perspective taking (Viégas & Wattenberg, 2007). Data sculptures, for example, have helped students develop their contextual understanding of data, connecting data sets to the social setting where it lives (Sauvé et al., 2020) and facilitated students' data interpretation in relation to the social context through the sculptures' ability to embody data using metaphors (Zhao & Moere, 2008).

Embodiment of Mathematical Concepts

Our work takes a grounded cognitive approach (Barsalou, 2010) to explore ways to promote engagement with data. Specifically, we examine how a data-dance context provides opportunities for learners to create embodied metaphors to think about, represent, and communicate about data. Research suggests that the embodiment of mathematical concepts can benefit students' learning of abstract ideas in math (Moerman, 2016; Mickelson & Ju, 2010). Several studies have found a positive link between physical movement and cognitive skills associated with mathematical concepts (Fenyvesi et al., 2019; Namukasa et al., 2007). For instance, work by Rosenfeld (2013)

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supported children in understanding mathematical concepts by building original choreographies. Similarly, Helsa and Hartono (2011) found that traditional dance could support students' understanding of symmetry. Embodied metaphors with dance have the potential to center the body, movement, improvisation and play within our reflective practices (Petsilas et al., 2019). Divergent approaches to data literacy education embrace context-bound inquiry and encourage the challenging of neutral, objective representations of data. In this study, we explore how dancing with and about data can support the understanding of mathematical concepts such as number sense, contextualization of data, and making meaning with data.

Methods

We engaged in co-design with one math and one dance teacher in a public charter school in the Midwestern United States. The teachers taught the data-dance unit to eleven 7th grade students who were in both the math and dance classes. The middle school student population is 65% White, 19% Hispanic, and 6% Black—46% of the student population qualifies for free or reduced lunch. A team of four researchers met every other week with the two teachers for a semester prior to implementation. They created activities to frame different concepts and determine how best to support students in creating a final dance performance integrating data. In the unit, students: (1) picked a topic of interest, (2) interpreted and analyzed data sources on that topic provided by the co-design team, and (3) created a dance in response to the data and their questions grounded in the data. Students performed these dances and presented an artist statement explaining them at an exhibition attended by other students, teachers, parents, and community members.

In the math classroom, students met over three weeks, for a total of six sessions. Topics of these lessons included statistical questions, data visualizations, measures of central tendency, and recognizing/interpreting trends in data. In the dance classroom, students met over 18 weeks (4 sessions per week), with the sessions starting prior to the math sessions. The teacher dedicated the first seven weeks of the semester to introducing contemporary dance and developing contemporary dance techniques with students. In Weeks 8 and 9, students created a smaller scale, collective version of the larger project (interpreting data, creating questions, and developing dances in response). In Weeks 11-18, students independently created, presented, and reflected on their dances developed through an analysis of their graphs. We collected data from five separate project groups that engaged with data on: (1) *Women's Rights*—Emily, Gabby, Amber, Cameron, (2) *Minecraft*—Cory, (3) *Animal Populations*—Irene, Debbie, (4) *Mental Health*—Margaret, and (5) *Social Media and Mental Health*—Will, Brooke, Ashley. Student names used in the analysis are pseudonyms.

Our data include: student group interviews, dance planning materials, and a paired teacher interview. The student group interviews were conducted with each of the five student teams. The dance planning materials were created by each of the student teams and made them connect *claims/supports* from the data to *movements* in their dance. The paired teacher interview was conducted after unit implementation with both the art and math teachers. We engaged in an iterative coding process beginning with open descriptive coding (Saldaña, 2015) that was refined through social moderation (Frederiksen, 1998). For each iteration, conflicts and differences in interpretation were discussed and codes were refined. The codebook was reviewed and checked for clarity with researchers outside of the project team, who discussed the coding of a subset of data.

Findings

In this paper, we focus on one of our analytic themes, ***embodied data characteristics***—*characteristics of the data that students used to create embodied metaphors*. We identified three data characteristics that students used to create embodied metaphors: graph shape & numerical value, data context, and data implications (Table 1).

Table 1
Embodied Data Characteristics Codebook

Graph Shape & Numerical Values	Movements representative of the physical appearance of the graph or the data patterns within the graphs (rate, percentage, or summary of data)
Context	Movements that provide an example of the data points, categories, or attributes.
Implications	Movements representative of what happens as a result of the data

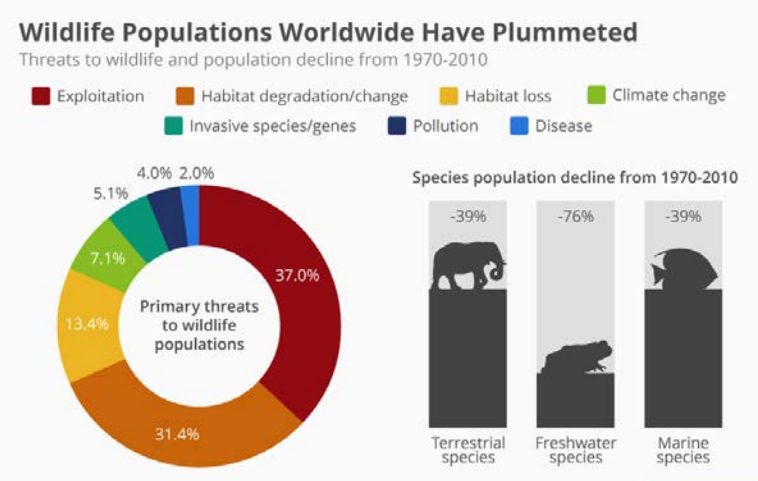
Embodying Graph Shape & Numerical Value

One of the initial activities, students engaged in with their graphs was to explore the shape of a graph through movement, "Like for one day, we would like physically shape out the graphs, like actually show the ups and

downs of it." One student in the animal populations group (Figure 1), explained how this was a useful exercise, "looking at [the graph] at different angles and like even just making its actual shape…really helped us understand how it was going down or up and in what ways we can help fix this...It made us look at the graphs in a different way. Like at all angles to figure out what is the best view we can get of this graph to make movements to help others understand what is happening."

Figure 1

Graph used by the Animal Populations Group (Statista, 2014)



Through examination of the shape the students began thinking about why the graph was the way it was. While this was a starter activity, the final performances often also had some movements where learners were embodying the graph shape or numerical values within the graph. Students would often transpose a dance dynamic, such as levels or body position, onto the value of a data descriptor of a categorical variable that they would embody within the movement. Emily in the women's rights group, for example, describes how her group embodied the different countries (Figure 2) in order to communicate the percentage of women and men who agree that "A woman's most important role is to take care of her home and children" (data in Figure 3): "[They] all came from a sitting position and rise up…representing certain countries…to show like how high the percentage was on the graph…I went from a higher position downward, [to] a really low percentage…we're trying to take the image of the graph into our dancing." Illustrated in Figure 2 are three dancers from the women's rights group (representing the majority from the graph data) rising up from a sitting position, while another dancer (representing North America) goes from standing to sitting. This movement drew the student's attention to what the data values were as well as the differences across categories, as well as changes over time. For example, in the Minecraft dance the student did a dance move where his forearm traced the shape of the data over time, "It is meant to represent the main change in the number of hours watched of Minecraft on Twitch and shape of the graph" (Figure 4).

Embodying the Context of the Data

Most of the movements that students discussed and performed embedded data into a context. At the high level, learners created movements that were literal relationships to their topic, such as Cory doing the robot walk to represent Minecraft. However, the majority of these movements embodied some trait or feature of a categorical variable or data point outside of the numerical value represented in the graph. For example, in the case of Debbie and Irene who created dance sequences that were graceful like a bird or representative of a fish's swimming movements, learners had to examine some aspect of the category beyond what was represented in the graph to create their movement. For example, Debbie and Irene also depicted exploitation:

> **Claim/Support**: One of the first things we noticed on this graph was that exploitation is one of the biggest causes of all of this. Exploitation is in this case when humans take advantage of animals and almost use them, giving nothing in return...
> **Movements**: In our dance we do a trust fall [deliberately falling and trusting someone to catch them] with a very narrow and low drop. This is showing how humans are taking animals for granted

Figure 2
Women's Rights Group performing a routine captured in three frames over time

Figure 3
Graph used by the Women's Rights Group (Facebook, 2021)

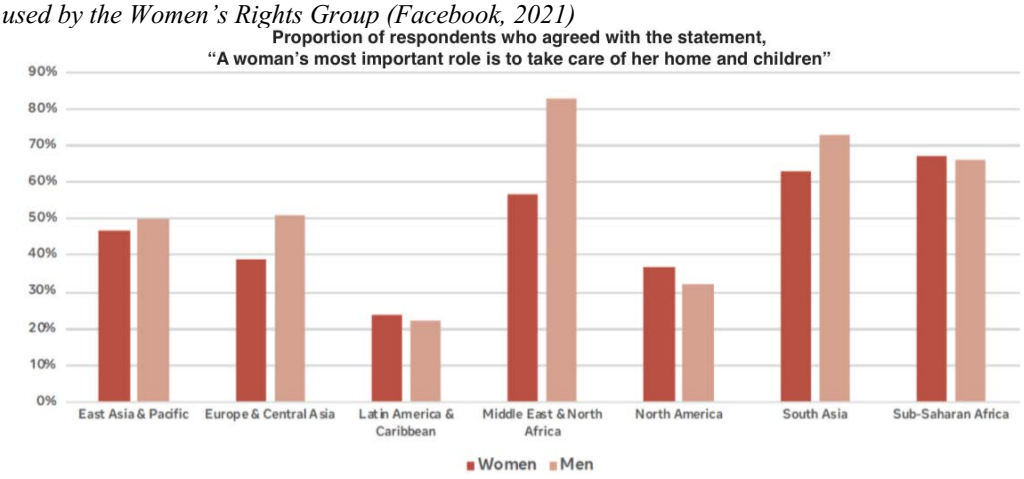
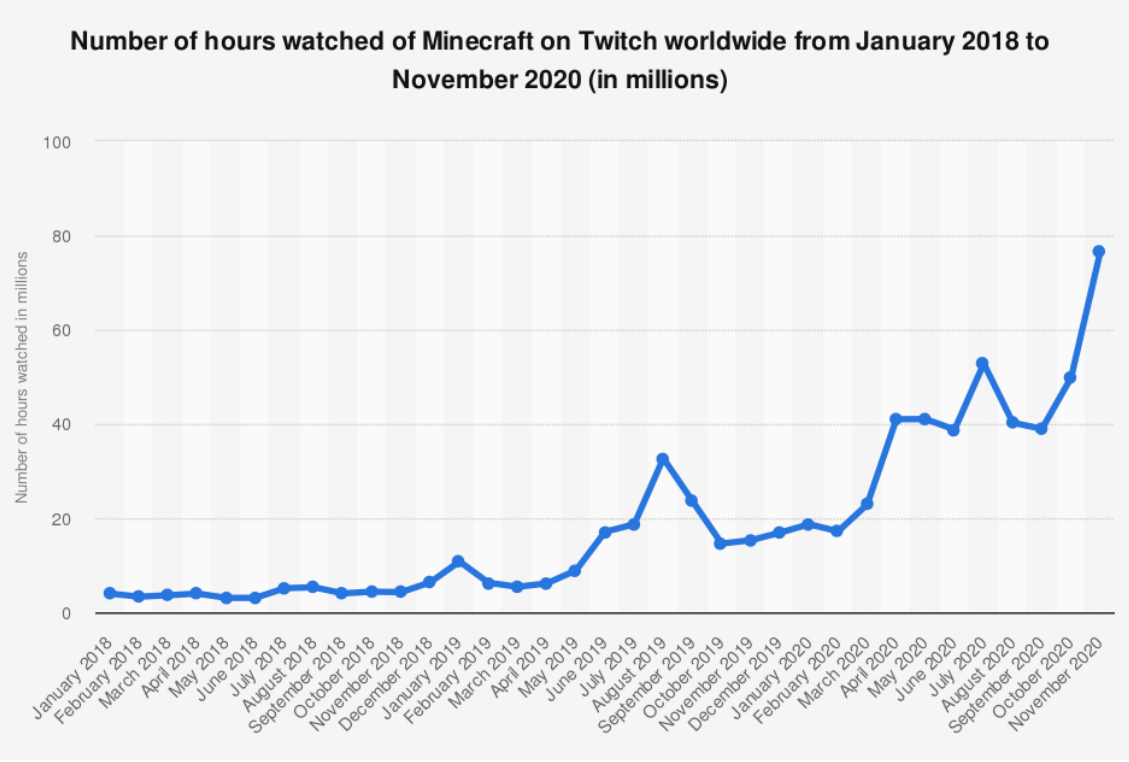


Figure 4
Graph used by Cory focusing on Minecraft (Statista, 2020)



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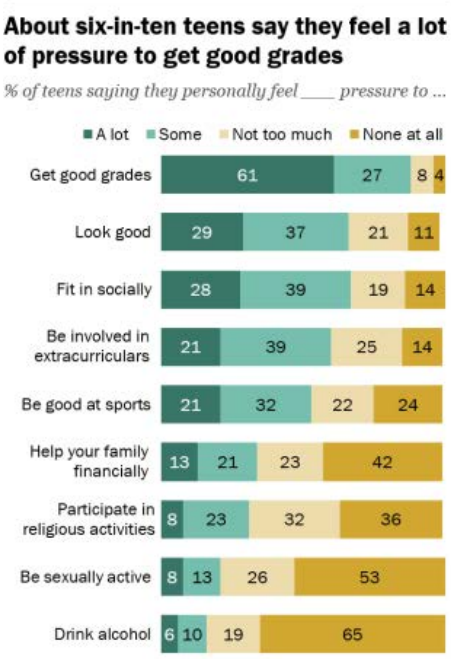
Similarly, Margaret highlighted how there was a higher percentage of girls receiving treatment for depression than boys. At one point in her dance, she "was looking more through the viewpoint of a girl. And doing those reaching movements helps me like show I was able to get help" (Figure 5b). Students also constructed narratives around the data illustrating how scenarios might play out around the data. For example, the Social Media and Mental Health group outlined a movement using the graph in Figure 5a:

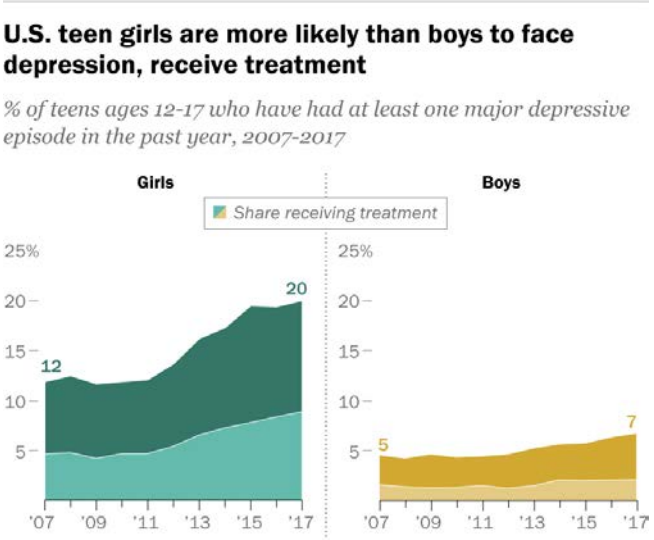
> **Claim/Support**: The main stressor that teens face is related to getting good grades in school. 88% of teens reported feeling at least some stress to get good grades.
> **Movements**: I fall down to represent struggling in school, then I pull back up the rope to represent getting back on track. I do this three times to show the ups and downs that teens face with getting [good grades].

Figure 5

(a) Graph used by the Mental Health and the Social Media and Mental Health group (Pew Research Center, 2018)



(b) Graph used by the Mental Health group (Pew Research Center, 2017)



Embodying Implications of the Data

In some of the movements, students began to explore the implications of the data through their choreography. In the Women's Rights group, their dance highlights what can happen if perceptions of a woman's role are changed,

> **Claim/Support**: While some regions have not changed their perception of what women can do, there are regions who have changed their perception. (The lower bars in North America/Latin America vs the higher bars in the middle east/asia) In those regions, women now take on different careers and have more freedom to work toward what they want to accomplish.
> **Movements**: All four dancers are representing females. We start by doing movements lower and work toward higher levels to show women working up toward their goals over time. All dancers then walk in circles to show different roles women can take if the perception is changed like it has been in…North America and Latin America.

Additionally, students created movements about what an attribute implied about a variable, such as Maragret in the mental health group showing the implications of lgbt youth who were not able to get mental health care,

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Claim/Support: 16% of lgbt youth did not get mental health care because their parents did not allow them to go
Movements: "Shampoo" to express the feeling of being caged in, unable to move

Discussion: Evolving Data Practices with Dance

Dance practices fundamentally changed how learners built knowledge with data, including how they examined, reasoned around, related to, and represented the data. We focus on creation practices and performance practices.

Creation Practices: Data Reasoning through Embodied Metaphors

Learners needed to understand the data in order to translate it into a metaphor with bodily movements. The embodied metaphors covered the spectrum of what Zhao & Moore (2008) describe as the metaphorical distance from the data: these metaphors both drew attention to certain aspects of the data, while also *hiding* other aspects of the data. Part of learners' examination of their data involved embodied exploration of the numerical values and physical characteristics of the graph and the variables represented. They had to think through the values and angles within the graph then translate them into body positions and movements that they then experienced. This process helped students notice particular trends and compare values of categorical variables. This finding aligns with Goldin and Kaput's (2013) assertion that multimodal sensory imagery can help facilitate a *number sense,* which involves understanding the meaning and size of numbers as well as equivalent representations and expressions (McIntosh et al., 1992). In our work, learners were able to draw on the grounded kinesthetic and embodied modalities of dance to experience the data. This has implications for how the learners' number sense of the data is shifted by having to embody the data.

The learners also engaged in what Hanna (2008) calls "concretization" in which dancers reflect outward aspects of a concept through movement. Learners explored different aspects of the variables within the data and characteristics surrounding the data in the real world in order to create movements around it. This was evidenced by their exploration of how a fish moves, roles that women take on, or what exploitation means. *Concretizing* the data encouraged learners to think about and convey the broader context of the data, including the people, actors, environmental context, and emotions. At times they embodied the cases within the variables and other times they embodied things that were implicated within the cases in order to convey meaning. In Eisner's (1997) reflection on alternative forms of data representation in research, he highlights how examining different forms are necessary to cultivate data representations that stimulate empathy, connect to individuals in the data, and increase the types of questions that we ask about the data. As we try to humanize data for learners (Lee et al., 2021), examining artistic representational forms like dance show promise in the ways they facilitate a contextual grounding and reflection on people and the environment in ways that stimulate personal, cultural, and societal exploration.

The collaborative dances also stimulated learners to reason about data via each other's movement and body positions. The collaborative work expanded their potential region of focus on the data as they could now simultaneously represent multiple categorical variables or multiple actors in their metaphorical representations. This enabled them to portray relationships and interactions across the dancers and thus the data and actors they were representing. Through this process they reflected across the similarities and connections and the differences and departures in their representations. This was done in both the numerical sense—i.e. differences in value—and the characteristic sense—i.e. a woman's role versus a man's role. The representations conveyed a meaning that was dependent on the dancers coordinated movement together. The dance created opportunities for what Ma and Hall (2018) have termed *ensemble learning* wherein learners engage in collaborative activity that cannot be done alone and results in a performance. This type of learning stimulates engagement in the representations, learner agency over sections of a routine, and distributes mathematical concepts across learners. We observed ensemble learning as learners distributed roles within their danced metaphors to communicate through a "*sequence of unfolding movement,* including who does what to whom and how" (Hanna, 2008).

Performative Practices: Audience and Interpretation

The performances engaged the audience in cognitive sensemaking with data and in kinesthetic empathy—feeling as though their bodies are participating in the movements they see as well as experiencing the feelings that the performance evokes (Carlson, et al., 2019). For instance, in the Women's rights dance, the raised fist movement not only serves to communicate the role of power in data on perceptions of the role of women in society, but also, as described by one of the learners, seeks to generate an affective state that is "powerful." The consideration of music—i.e., the tempo and cultural references—were also forms of embodying affect to elicit certain audience responses, or what one learner referred to as "actual feelings." While meaning was made through the movements and dance phrases, the students' dances came together in a locus of meaning that was centered around the "*whole pattern of performance,* emphasizing structure, style, feeling, or drama" (Hanna, 2008, p. 493). This involved

creating new meaning of the data through the coordination between music, movements (individual and collaborative), performance, and experience of the audience.

This tension of balancing data representations with affective and aesthetic considerations speaks to a broader dialogue in the field of data literacy education and data visualization around humanistic data literacy (Lee, et al. 2021) that challenges claims of data as objective, neutral, and universal. In work by Klein and D'gnazio (2020) that connects feminist theory to data visualization, the authors note how embodiment and affect are too often not situated on par with more more quantitative methods of knowing and experiencing the world. In providing principles that encapsulate 'data feminism' the authors write, "the third principle of data feminism, is to elevate emotion and embodiment" (p. 95). Increasingly, data visualization approaches are exploring activating emotion, leveraging embodiment, and creating novel presentation forms to help people grasp and learn more from data-driven arguments (e.g., Rust, 2014). Learning experiences, such as creating and performing data dances from both a math and art disciplinary perspective has potential to center tensions on the role of affect in making claims about how the data should feel, how audiences engage in embodied and affective forms of sense-making through kinesthetic empathy, and the use of artistic dance practices that center this affective communication in data visualizations (e.g., music, gestures).

Conclusion & Limitations

The case study of dance and data demonstrated the potential of the embodied processes to develop learners' sensemaking of the data. Embodiment provided learners with an opportunity to develop a number sense as they deconstructed an understanding of the graphical representations. Further, their movements concretized their ideas about the data which grounded their numerical understanding in the real-world context of the data. Last, learners' creation of distributed representations across multiple learners facilitated collaborative sense-making about the data. In addition to embodiment, the performative practice had learners attempting to engage the audience to develop their own understanding of the data through their dynamic performances that were explicitly not neutral or objective. Although this study alludes to a number of important connections between data literacy and embodied learning, there were some limitations. First, the study was situated in the context of contemporary dance, limiting the range of embodied practices. Second, we ran into challenges in understanding learners' affective responses relying mostly on their verbal descriptions instead of embodied emotional responses during the curricular unit due to our limited ability to observe during classroom activities. Future research could more deeply attend to the contextualized instantiation of the data and dance practices. Additionally, we should continue to explore additional forms of dance to understand the breadth of embodied learning that can support data literacy while expanding the types of practices that can support learners in contextualizing and humanizing their data investigations.

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ReviewAid: A Scaffolded Approach to Supporting Readers' Evaluation of Health News

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Abstract: As health news stories affect the audiences' decision and behavior, readers need to understand and evaluate the information. However, assessing the quality of health news stories is challenging for non-expert readers, as it requires both media and scientific literacy. In this paper, we design a web interface, ReviewAid, that guides online readers' evaluation of health news stories with the evaluation criteria designed for non-experts. ReviewAid scaffolds readers' evaluation process by providing 1) explicit guidance that asks readers to distinguish the quality of media and scientific findings and 2) example comments for each criterion. Results from our study with 44 participants show that ReviewAid helps readers better connect the evaluation criteria to the specific news story. ReviewAid also enabled participants to conduct a more grounded and accurate evaluation of the content of scientific research.

Introduction

The media coverage of scientific research has been an important channel of scientific information for the public, and health is among the most preferred topics for both science journalists and their audience. As health news affects audiences' decision or behavior (Pew Research Center, 2017), health news should deliver accurate information on the scientific findings and discuss its implication for readers. However, health news stories are often criticized for being oversimplified, inaccurate, or biased (Dudo, 2015), and social media worsens the situation by accelerating the spread of sensational and clickbait stories (Waszak et al., 2018). Recent COVID-19 misinformation scandals (e.g., the effectiveness of Hydroxychloroquine in COVID-19 treatment) show how the inappropriate dissemination of scientific research can actually harm public health (Wong, 2020).

Modern science education has been focusing on nurturing the public's ability to understand and evaluate scientific information in their everyday life (NRC, 2012). However, it is known that the public, even those who are scientifically literate, tends to take news stories at face value by deferring the evaluation to the science journalists or relying on their gut feeling (Shah et al., 2017). In fact, assessing health news stories is a complex task for readers, as it necessitates the use of both scientific and media literacy. One needs to gauge the quality of scientific evidence and evaluate how properly the information is delivered and interpreted at the same time.

The most widely used strategy is to use explicit evaluation criteria (see Table 1 for examples) that question the quality of media and scientific research. Evaluation criteria can provide conceptual knowledge on the required inquiry steps and, at the same time, can serve as a basis for quantifying the quality of news stories. Unfortunately, previous research showed that understanding and applying evaluation criteria itself is a challenging task, and people easily make a superficial or incorrect evaluation (Nicolaidou et al., 2011; Zhang et al., 2018). Therefore, in the classroom setting, instructors provide additional guidance on how to apply criteria and correct students' inappropriate assessments. In this paper, we bring this strategy of using evaluation criteria to support readers' assessment of health news stories in an informal, everyday reading context.

However, as there is no such instructor who can guide readers' evaluation process in the informal reading context, it is important to understand the potential misuse of evaluation criteria and provide preventive measures. We conducted a series of observations in which participants were asked to evaluate a health news story following the evaluation criteria by themselves. We found that readers confuse the quality of news stories with the quality of scientific research and fail to apply the evaluation criteria in the context of a specific news story.

Based on the observation, we designed a web interface, ReviewAid, that guides readers' assessment of health news stories. ReviewAid uses criteria designed for non-expert readers and guides readers to evaluate the level of information coverage, the validity of the research, and the quality of the interpretation of the research separately. ReviewAid presents example questions for each evaluation step to help readers understand and apply each criterion to the specific news story. We conducted a between-subjects study with 44 participants to understand the effect of ReviewAid on the quality of readers' assessment and self-efficacy in assessing health news stories. The result shows that participants in the ReviewAid condition better connected the criteria to the specific news story and conducted a more grounded and accurate evaluation of the content of scientific findings. Also, participants in the ReviewAid condition reported a higher level of self-efficacy in explaining how the news story can be improved than participants in the baseline condition.

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Background

We first provide background on what makes public communication of scientific research challenging. Then we review existing evaluation criteria developed by scholars and practitioners and discuss differences between the criteria used in science education and journalism.

Challenges in public communication of scientific research

Health news stories are a result of the sequential effort of multiple players (e.g., scientists, PR team, and science journalists) in the production pathway. While there exist many factors that make the public communication of scientific research challenging, the most important and inevitable challenges are those raised by the complex nature of scientific research. Scientific research consists of components such as theoretical background, experiment design, and analysis, and this innate complexity of scientific research makes it hard for journalists to accurately deliver the information (Dunwoody, 1982). Another factor that complicates the public communication of science is the tentativeness of scientific research. The complex and conditional nature of scientific research sometimes limits the scientists' knowledge and control of a subject matter, making some studies have limited validity (Bromme et al., 2014; Peters & Dunwoody, 2016). Health-related research has an especially high level of tentativeness as it often involves human or living subjects, whereas researchers have less control over the condition (Sumner et al., 2014). Therefore, the certainty of the finding is not determined solely by single research but can be only established from a number of studies that align with it (Lee et al., 2012). Communicating the tentativeness of the finding is a very demanding task for journalists as it requires a huge amount of time and effort and sometimes costs readers' engagement and trust in scientific research and the media (Stocking, 1999).

Evaluation criteria for health news stories

Researchers and practitioners in science education have developed sets of evaluation criteria to teach students how to conduct a scientific inquiry when reading media reports on scientific findings. They aim to teach what to consider in evaluating a scientific claim and what can threaten the validity of the claim delivered through the media (Jarman & McClune, 2007). They guide students to question the *content* of scientific research, such as participants, procedure, measures, or who the researchers are (Oliveras et al., 2013; Tsai et al., 2013). However, previous research showed that students tend to make a superficial or incorrect evaluation of the content of research and have to practice the evaluation multiple times to understand the evaluation criteria and use them appropriately (Nicolaidou et al. 2011; Donnelly et al., 2014).

While criteria developed for students are focused on the *content* of the research, criteria developed for the general public put more emphasis on the *context* of the research. Criteria developed by journalists (e.g., Health News Review.org) or public organizations (e.g., NCCIH (n.d.)) guide readers to ask questions on how news stories deliver scientific research, interpret it, and discuss it in a broader context. They include questions on cost and potential side effects of interventions studied (e.g., new medicine or doing a specific exercise), how strong the study findings are, or how certain and novel the finding is. However, it is difficult to assess the context of research without prior knowledge in the research delivered, and this remains a question as to how well an average health news reader can use these guidelines to evaluate health news stories.

It is important to assess the health news story regarding both *content* and *context* of the research. With evaluation criteria on the content of the research, readers can judge the validity and reliability of the research conducted. On the other hand, the evaluation criteria on the context of the research help readers understand the certainty of the research finding and appropriate application or consequences. In this paper, we design a system that guides readers to evaluate a health news story on both content and context of the research.

Formative Study: Readers' challenges in evaluating health news stories

To better understand the challenges that readers face while evaluating health news stories, we conducted a series of observations and semi-structured interviews. Specifically, we sought to identify readers' difficulties in understanding and applying given evaluation criteria in the online reading environment, where no additional guidance and support from an expert or instructor is expected.

Method

We recruited eight participants (6 male, 2 female) from an online community of a technical university in South Korea. Participation was limited to those who are fluent in English and have no prior research experience. Five participants were undergraduate students, two were entering graduate students, and one was a first-year graduate student. We prepared two news stories titled "How Your Morning Coffee Might Slow Down Aging" (Park, 2017) and "Weight-loss pills can help. So why don't more people use them?" (Carroll, 2018), from stories with low

expert ratings (less than 3 out of 5) in HealthNewsReview.org. Participants were asked to choose a news story they are more interested in, evaluate the story by following evaluation criteria provided, and explain rationales for their assessment. After the session, we conducted a short interview on their overall experience and difficulties they faced during the evaluation process. All of the sessions were conducted individually. Each participant was paid KRW 10,000 (approx. $8) for their hour-long participation.

We asked participants to evaluate one health news story following two sets of criteria, Always Ask (AA) (Jarman & McClune, 2007) and HeathNewsReview.org (HNR). AA is evaluation criteria designed to teach scientific inquiry steps for students and has more focus on the content of research. AA comes with detailed and explicit subcriteria for each high-level criterion. On the other hand, HNR is criteria developed by groups of journalists and scientists and has more focus on the context of research and how the story frames and discusses the scientific research. We used both sets of criteria to observe readers' difficulties in applying criteria on the content and context of the research. Table 1 shows example criteria from AA and HNR. Four participants were guided to follow AA first, and the other four were guided to follow HNR first.

Table 1

Example evaluation criteria used in Always Ask and Health News Review

Source	Always Ask	Health News Review
Example criteria	How was the research conducted? - What were the subjects of the study? - What was the sample size? - How was the experiment carried out?	Does the story adequately explain the harms of the intervention? Does the story establish the true novelty of the approach?

Findings

First of all, seven (out of eight) participants said that the evaluation criteria helped them to learn what to consider. Four participants explicitly mentioned that they could realize that some questions are very important only after seeing them. Despite their positive comments on having evaluation criteria, participants had difficulties across various steps, from understanding each criterion to applying the criteria to evaluate the news story.

Providing a rationale for their evaluation

Participants often failed to provide a rationale for their evaluation. This happened a lot when participants were evaluating the news story with HNR, which does not give explicit subcriteria for each criterion. P8 said, "I think I understood what each (HNR) criterion is asking for, but this does not mean I know what to consider. I can give a score based on my impression, but I cannot explain why I gave that score." Most participants said they are more confident with their evaluation given to AA than HNR as the subcriteria helped them understand concrete questions that they can ask and develop their thoughts. To prevent readers assessing health news stories by their gut feeling or impression, it is important to guide them with detailed and explicit criteria.

Facing evaluation criteria that require prior knowledge or external information

Criteria that ask about the value (e.g., novelty or implication) of the delivered research require external information or expert knowledge. To answer questions such as "Does this story establish the true novelty of the approach?" (HNR) or "What is the importance of this study?" (AA), readers need to have prior knowledge in the topic or even knowledge of previous research in the domain. Participants said that they feel helpless when they are asked to evaluate such criteria. P4 said, "It seems that I need to conduct an extensive investigation to really judge the novelty of this research, and I don't think I can correctly answer the question even after the investigation." P2 said that "Some criteria were meaningless to me as there was nothing that I could do."

This does not mean, however, that those criteria should not be given to readers. Having such criteria is still valuable as they suggest and teach readers what to consider with health news stories. Rather, the benefits of such criteria can be maintained without discouraging the readers by adjusting the scope and target of the evaluation. For example, rather than asking readers to evaluate the novelty of the research, readers can still check whether the news story has explained or discussed how novel the research is.

Distinguishing the quality of news story and the quality of scientific research covered

The quality of research and how it is delivered affect the quality of health news stories. However, participants failed to distinguish the quality of the story from the quality of the research. Six participants mistook the lack of information for lack of validity in the research. For example, there were three participants who concluded the research has limited validity by making a wrong assumption that researchers did not control potential confounding variables. Only two participants said that there is not enough information to evaluate the validity of the research.

It is important for readers to clearly distinguish the source of the problem because the consequences of evaluation can differ a lot. For example, suppose a patient reads a low-quality health news story on a potentially effective intervention. If the patient concludes that the finding is insignificant or invalid, the consequence can be just ignoring the information. On the other hand, if the patient concludes that the media did a poor job delivering the research, the patient can find more information about the research or consult with his doctor.

Applying evaluation criteria to the context of an individual news story

As scientific research varies in its topic and methodology, specific information that is critical for readers can also vary for each health news story. In our observation, participants expressed difficulties in applying criteria to the specific health news story being evaluated. This happens even when participants think they conceptually understand what the evaluation criteria are asking for. Participants said they could point out that some criteria are not met, but they could not explicitly say what should be included or improved in the news story. For example, regarding the criterion "What data were collected" (AA), P5 noted that "I can see that there exists limited information on the data collected but cannot think of what it is specifically."

ReviewAid

Based on our observations, we designed a web interface called ReviewAid that scaffolds online readers' evaluation of health news. In ReviewAid, readers review a health news story by following the evaluation criteria designed for non-expert readers. For each subcriterion, ReviewAid provides explicit guidance on medium-research distinction and helps readers connect the evaluation criteria and the target news article with examples.

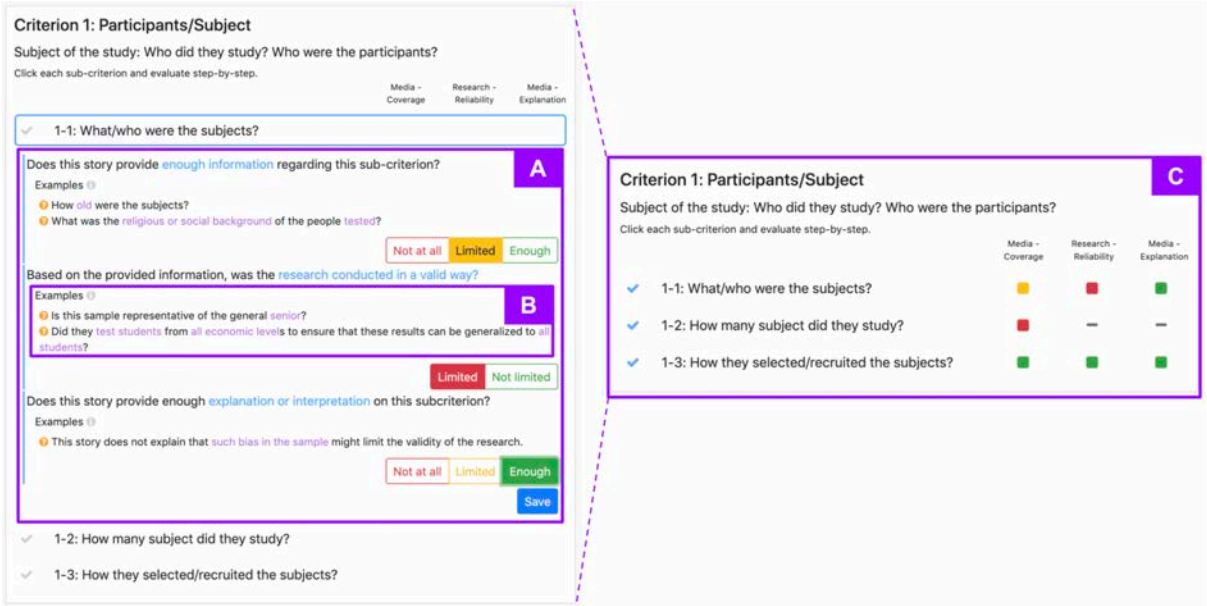
In ReviewAid, readers evaluate a health news story by following seven evaluation criteria that we developed by restructuring existing criteria, namely AA, HNR, and the criteria based on the taxonomy developed in Korpan et al. (1997) (e.g., Zimmerman et al., 2001). Criteria were chosen and designed so that they support scientific inquiry on both the *content* and *context* of the research. Criteria 1-5 are introduced to scaffold the scientific inquiry process explicitly. Criterion 6 is on its connection with other research or theory, and criterion 7 asks about its application and implication to the real world. To help readers better understand each criterion, ReviewAid provides two to four subcriteria (see Figure1-(C), for example) for each criterion. When a reader selects a criterion to review, corresponding subcriteria are prompted. Readers evaluate the story for each subcriterion and then assess the high-level criterion based on it.

1. Participants/Subject: Who did the research study? Who were the participants?
2. Research Design: How and why is this research designed, and how is it done?
3. Measure: How were the factor (putative cause) and effect defined and measured?
4. Data & Statistics: How were the raw data and statistical results?
5. Social Context: Is there any social factor that may have influenced the research? Who did the research, funded it, or who is advertising it?
6. Theory & Related Research: Does the finding align with other research? Is there a theory that can explain the observed effect?
7. Application & Implication: What is the implication of this study finding, and how should I relate this finding to the real world?

When a reader selects a subcriterion to evaluate, ReviewAid provides procedural support to prevent them from confusing the quality of media and research. ReviewAid guides readers to evaluate the news article on 1) how well the story provides information (coverage), 2) how reliable the research is (reliability), and 3) how well the story explains or interprets the reliability of the research (explanation). The system prompts the evaluations of these aspects in order of coverage, reliability, and explanation. To prevent potential confusion between the media coverage and research validity, the step for research reliability is skipped if the reader answers there is no information. For the criteria on the contextual information (6 and 7) that require prior knowledge or external information, readers are not asked to assess them by themselves but to assess how the news story discusses them (explanation). Figure 1-(A) shows the evaluation steps ordered by the aspects.

For evaluating coverage, reliability, and explanation, ReviewAid shows example questions or comments related to each aspect. While each criterion comes in a general form that can be applied to any news story on health-related research, examples serve as concrete instantiations of each criterion that readers can refer to understand the criterion and apply it to their context. We constructed the example pool based on students' questions raised on scientific news briefs collected in Korpan et al. (1994) and questions and comments left in expert reviews in HealthNewsReview.org. Phrases that are specific to the news stories that each question or comment is raised on were indicated separately (in purple color), as shown in Figure 1-(B).

Figure 1
Overview of the scaffolded evaluation process in ReviewAid. (A) For each subcriterion, the user evaluates the story for each of media coverage, research validity, and media interpretation (B) Example comments raised in other news stories are shown. Terms that are specific to the source news story are colored in purple. (C) Evaluations on the subcriteria are summarized.



Evaluation

ReviewAid system scaffolds readers' assessment with 1) explicit and detailed evaluation criteria, 2) explicit procedural support to distinguish media and the research, and 3) examples that instantiate each criterion to a specific news story. We conducted a study to assess the effect of ReviewAid on the readers' evaluation of health news stories. As the benefits of having explicit and detailed criteria are well studied in previous research (e.g., Reiser et al., 2001), we focus on the effect of explicit guidance on medium-research distinction and examples. Specifically, we aim to understand readers' experience in evaluating health news stories with ReviewAid and the quality of assessment that they make.

Method

We conducted a between-subjects study with two conditions: Baseline and ReviewAid. In both conditions, participants were asked to evaluate a health news story with seven criteria with 2-4 subcriteria for each. In the ReviewAid condition, participants were asked to follow the designed evaluation process for each subcriterion before giving a score to the story. In the Baseline condition, participants were shown the subcriteria, but the scaffolded evaluation process in ReviewAid was not presented.

Participants and procedure

As ReviewAid is designed to support health news readers in their informal reading context, we tried to recruit participants from the general population. Previous research (Berinsky et al., 2012) showed that population samples recruited in Amazon Mechanical Turk (MTurk) tend to be more representative of the U.S. population than samples from in-person recruitment. We recruited 44 participants (20 male, 24 female) from MTurk and randomly assigned them to one of the two conditions. We had 21 and 23 participants for the Baseline and ReviewAid conditions, respectively. For their 40-60 minutes-long participation, participants were paid $8. The average age was 36.5 (SD: 8.69). A total of 35 participants had tertiary education, and three among them had postgraduate education.

In the pre-survey, we asked questions on factors that may affect their experience and outcome of the main task, such as education level, prior experience in research-related activities, perceived media literacy, and how they prefer cognitive work (NFC scales in REI-10). In the main task, each participant evaluated a health news story titled "Tofu might harm memory in elderly." (Kahn, 2008) (adapted from Leung et al. (2015)) with seven criteria. For each criterion, participants were asked to rate the story in a 1-5 scale and explain their rationale for the score. In the post-survey, participants were asked to describe how the evaluation criteria and scaffolded evaluation process affected their evaluation. Also, we asked participants to rate how confident they are about 1)

judging the quality of a health news story, 2) pointing out inadequacies of a health news story, and 3) suggesting ways to improve a health news story in a 7-points Likert scale.

Measuring the quality of assessment

To measure the quality of participants' assessment, we conducted a discourse analysis of the evaluation comment written by each participant. We measured the number of rationales provided in each comment, the number of rationales specific to the news story, and the number of incorrect rationales. The analysis was conducted with 88 comments on criterion #1 (participants/subject) and criterion #6 (theory and related research). These two criteria were chosen so that we can analyze comments on both content and context of research.

The analysis was done in three steps. One of the authors and one external coder (Ph.D. student in biology) worked together in every step. In the first step, we split each comment into multiple arguments so that each argument contains a single intention or meaning, and a total of 88 comments were divided into 417 arguments. In the second step, we marked whether each argument contains a rationale. To ensure consistency between coders, the two coders divided the first 10% of comments together and then divided the next 10% independently, compared the result, and discussed to reach an agreement. After the consistency building session, each coder independently coded the remaining arguments, and the inter-coder agreement was 0.79 (Cohen's Kappa). The two coders finalized the result by discussion. Out of 417 arguments, 318 (76.3%) were of rationale-type. In the last step, we labeled whether each rational-type argument is specific to the news story (binary) and correct (binary). The inter-coder agreements (Cohen's Kappa) were 0.86 and 0.83 for specificity and accuracy, respectively.

Results

Overall, participants showed a moderate to high level of confidence in their media literacy (Mdn=5). There were no between-group differences in media literacy, as well as in the perception of health news and need for cognition. The average time spent on the reviewing task was 19 minutes (longest: 45 mins, shortest: 7 mins). The average completion times for the Baseline and ReviewAid conditions were 17.3 and 21.0 minutes, respectively.

Table 2

The numbers of participants who provided rationale, specific rationale, and incorrect rationale and the number of arguments provided respectively with median.

		Criterion #1		Criterion #6	
		Baseline	ReviewAid	Baseline	ReviewAid
Participants	(1) Total	21	23	21	23
	(2) Rationale	17 (81.0%)	22 (95.7%)	21 (100.0%)	23 (100.0%)
	(3) Specific rationale	9 (42.9%)	19 (82.6%)	10 (47.6%)	18 (78.3%)
	(4) Incorrect rationale	10 (47.6%)	5 (21.7%)	3 (14.3%)	4 (17.4%)
Arguments	(5) Total	97, Mdn=4	149, Mdn=7	81, Mdn=3	90, Mdn=3
	(6) Rationale	60, Mdn=3	116, Mdn=5	66, Mdn=3	76, Mdn=3
	(7) Specific rationale	32, Mdn=0	89, Mdn=4	20, Mdn=0	28, Mdn=1
	(8) Incorrect rationale	14, Mdn=0	7, Mdn=0	5, Mdn=0	5, Mdn=0

Table 2 shows 1) the number of participants who provided rationale, specific rationale, and incorrect rationale and 2) the number of arguments with a rational, specific rationale, and incorrect rationale in each condition and criterion. Participants in ReviewAid condition provided significantly more rationales (Mdn=5) than the Baseline participants (Mdn=3) for criterion #1 (Mann-Whitney (MW) Test, U=139.5, $p < .005$). However, there was no significant difference in the number of rationales for criterion #6 (Mdn=3 in both conditions), which is about the context of the research (MW Test, U=226.5, $p > .05$).

The proportion of participants who provided rationale that is specific to the news story (see Table 2, row (3)) was higher in the ReviewAid condition, for both criteria (χ^2 Test, $\chi^2(1, N=44)=7.50$, $p<0.01$ and $\chi^2(1, N=44)=4.45$, $p<.05$, for criteria #1 and #6 respectively). The median number of specific rationale provided in each review was 0 and 4 for criterion #1, 0 and 1 for criterion #6 for Baseline and ReviewAid, respectively. The difference was statistically significant for criterion #1 but not for criterion #6 (MW Test, U=122, $p<.005$ and U=187.5, $p=0.184$, respectively).

Regarding the accuracy of evaluation, for criterion #1, ten and five participants provided incorrect rationales in the Baseline and ReviewAid conditions, respectively. Among those who provided at least one rationale, 58.7% (10 out of 17) in Baseline and 22.7% (5 out of 22) in ReviewAid made incorrect arguments in their comments and the difference between the conditions is statistically significant (χ^2 Test, $\chi^2(1, N=44)=5.27$, $p<0.05$). For criterion #6, 3 (out of 21) and 4 (out of 23) participants provided incorrect rationales in Baseline

and ReviewAid conditions (χ^2 Test, $\chi^2(1, N=44)=0.12$, $p=0.720$). The median number of incorrect rationale in each comment was 0 for both conditions and both criteria.

Overall, participants showed a high level of self-efficacy with median score 5 for questions on how confident they are with 1) judging the quality of a health news story, 2) pointing out inadequacies of a health news story, and median score 6 for question on 3) suggesting ways to improve a health news story. There was no difference between the conditions for the first (Mdn=5 in both conditions) and second (Mdn=6 in both conditions). For the third question on suggesting ways to improve, participants in the ReviewAid condition (Mdn=6) gave significantly higher scores than participants in the Baseline (Mdn=5) (MW Test, $U=172$, $p<0.05$).

In both conditions, participants said that having detailed evaluation criteria helped them conduct a grounded evaluation. P19 in the Baseline said, "The subcriteria were very helpful in that it made it simple to know which direction to go in my evaluation." Participants said that the scaffolded evaluation process in ReviewAid helped them conduct detailed and accurate assessments. P21 noted, "I think it (distinguishing media and research) added to my ability to see piece by piece what was affecting my opinion and better articulate my thoughts in my reviews. It helped me notice what was missing." Also, P14 said, "Examples helped me fully understand what was being asked and how it applied to this specific article."

Discussion and future work

In our evaluation, ReviewAid had different effects on the type of evaluation criteria. For criterion #1, which is on the content of the research, participants in the ReviewAid condition provided more rationales and more specific rationales than those in the Baseline condition. Also, compared to the Baseline, the proportion of participants who provided wrong rationale was significantly smaller in the ReviewAid condition. For criterion #6, however, there was no difference between conditions in the number of rationales and the ratio of participants with incorrect rationales. As criterion #6 is on the context of research, ReviewAid does not present the guidance on medium-research distinction and the only difference between the Baseline and ReviewAid condition was the presence of examples. Our results illustrate that the examples given for criterion #6 helped participants better connect the criteria to the specific news story but not in providing more ground or accurately assessing the news story.

In our study, participants in the Baseline condition showed a moderate to high level of self-efficacy in assessing health news stories and said that having detailed evaluation criteria helped their assessment. However, we saw that such confidence does not guarantee the accuracy of their assessment. As readers are confident in their evaluation, it is hard for them to realize that their evaluation is incorrect. This illustrates how simply adapting tools from formal learning can result in undesired outcomes in the informal learning context. It is important to understand the differences between the two learning conditions and specific challenges in the informal setting.

Although our study results show the benefits of having the scaffolded evaluation process, we note that the observed effect needs to be further verified in future studies. The effect of having the ReviewAid system should be further evaluated in studies with large numbers of participants and on various health news stories. Another limitation of this study is the lack of consideration of readers' prior knowledge and beliefs on the subject matter. Prior research showed that prior knowledge and beliefs on the subject matter could significantly affect one's reasoning process, especially with socio-scientific issues such as climate change and genetic engineering (Christenson et al., 2014). Future studies can investigate online readers' challenges in relation to their prior knowledge or belief and design a system that supports their evaluation of health news stories.

We also emphasize the need for designing a system that guides online readers' evaluation of health news stories that is more practical to be used by online readers. In our study, participants spent 20 minutes evaluating a single news story on average. This questions the practicality and impact of the ReviewAid system. In our future work, we will investigate a more practical use of the ReviewAid system by supporting collaborative and shared evaluation of health news stories among readers.

Lastly, while this work focuses on the health news stories, the idea of supporting non-expert readers to distinguish media and the source information and conduct contextualized evaluation can be transferred to other domains where expert knowledge is disseminated and communicated to the public, such as economy or policy. We envision a future where non-experts can actively engage in a structured evaluation process with various types of information.

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Learning science while caring for pets: Findings from a virtual workshop for teens

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Abstract: Pets are beloved family members in many cultures. Companionship with pets motivates and positions humans as inquirers as they find out their pets' experiences with them. With the need to advance science education from dualist notions of the world and the learner as separate entities, our research team conducted a two-week online summer camp to engage teens and their pets in investigations around pets' senses. Following a qualitative analysis of participants' talk and projects at the workshop, we found that teens engaged in science learning practices while investigating aspects of their pets' lives and designing experiences for them. Additionally, participants adopted an ecological and relational approach to science learning that positioned themselves and their pets as subjects. We discuss implications for future work with pets, and for the design of other STEM learning environments that engage perspective-taking, empathy, and care.

Introduction

The field of K-12 science education values science content and scientific practices and endeavors to reach learners across socioeconomic boundaries to create a just and equitable society (National Research Council, 2007). Although most agree that science education is crucial to an informed citizenry, the field's view of what constitutes science learning is often restricted to thinking, acting, and practicing like a certain kind of a scientist. In the historically dominant view, a scientist represents a positivist objective view of the world and treats and studies nature in isolation using valuable skills such as conducting controlled studies while maintaining objectivity. Based on this view of what constitutes scientific work, K-12 science education typically encourages learners to use an emotion-free, impersonal approach to study the world independent of their lives and contexts. Although such a view of science education has produced promising outcomes for some science learners, its relevance and appeal to many others remain limited. There are other, less acknowledged soft skills such as a meaningful relationship with nature on which scientists rely that positions them as members of an ecosystem and affects the very depth and breadth of scientific knowledge. For example, Barbara McClintock's cultivation of a close relationship with the corn maize she studied that led to the discovery of transposable genetic elements (Keller, 1984) and primatologist Jane Goodall's research among families of chimpanzees in Tanzania is the basis of modern-day primatology research (Peterson, 2015).

As individuals, learners exist in relation to the world. To fully appreciate these relationships as rich contexts for science learning, we need knowledge and appreciation of contexts and inquiry skills where relationships are central. Engaging in inquiry with pets at home affords us this unique opportunity. We conjecture that humans' nurturing relationships with pets in a familiar ecology encourage teens to engage in holistic science practice. Based on this motivation, we infused a group of teens' home settings with Augmented Reality (AR) technologies to understand the sensory experiences of pets. Following this, we studied the teens' use of soft skills such as perspective-taking, care, and empathy in shaping their inquiry into the pets' lives. We designed our study as a two-week virtual workshop where teens engaged in tool use, investigations to understand their pets' preferences and behaviors, and experience design. In the following sections, we elaborate a theoretical framework, detail the study design and analytical methods, highlight a few initial findings and consider the implications of our work to the field of science education.

Theoretical Framework

Western scientific methods are founded on the principles of control, isolating study subjects and variables from their contexts, among others. These methods have led to scientific discovery and innovation in modern times, but have fallen short in solving some problems, such as environmental pollution. Such failures are noteworthy because products and methods of Western science are, at least in part, responsible for these problems. The lack of a viable solution indicates that a shift in thinking about and doing science is necessary.

The *Framework for K-12 Science Education* (National Research Council, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013) aim to prepare students to learn particular science practices. However, there exist other holistic scientific methodologies from which learners could benefit. Overall, these

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methods rely on what we know of the world in relation to the mutual, structural, and social interconnectedness of life where agency of all elements and multiple ways of knowing are key. For example, naturalistic methods rely on observing phenomena with minimum intervention (Boyd, 1980). Indigenous knowledge derives from the ecological interconnectedness of nature of which humans are but a member (Bang et al., 2013; Brayboy et al., 2008; Cajete, 2000). The principle of agency of all non-human elements of nature is instrumental to so-called posthuman (Pickering, 1995) and new materialist (Latour, 1987) methods. Common to these ways of knowing and doing science are at least two principles. First, nature and culture are inseparable (Haraway, 2003; Fuentes, 2010); an integrated, multispecies, contextual knowledge of nature benefits all. Second, there are methods, ways of knowing, and skills that privilege such intimate knowledge.

Donna Haraway's notion of naturecultures stresses the entanglement of the natural and the cultural, the bodily and the mind, the material and the semiotic. The reduction of the boundary between humans and nature, especially between humans and pets as companion species, is foundational to our study. As elements of natureculture, humans and companion species like dogs live in close association and the agency of both species is important; therefore, our interconnectedness rather than seeing other animals as objects of study is essential. However, any species of animals, including humans, are limited in perceptive capacities. Therefore, to inquire into animal sensory experiences, we must understand that sensory experiences are not uniform across the living world - each creature has its own "umwelt" (von Uexküll, 2001), a German term usually translated as "the world as experienced by a particular creature." Animal umwelts are unique in each of the five senses and are not accessible to us humans to a great extent, leading to various misconceptions and misunderstandings. Technology, especially AR, can broaden the window of sensory perception for users to better understand the natural world by overcoming the cognitive and biological challenges first by creating unique experiences and second by inquiring into those experiences. Doing so might allow us to adopt a relational and ecological understanding of animals' lives with humans by adopting the animals' perspective. Perspective-taking is the cognitive ability to consider the world from another individual's viewpoint (Galinsky et al, 2008) and has both perceptual and conceptual aspects. Perspective-taking based on direct observation and experience forms the background for empathy (the ability to connect emotionally with another individual) and care (the motivation to attentively rehabilitate through companionship and commitment).

The use of technologies in this way has implications for our understanding of human actions within the ecosystem as well. We need to move beyond the traditional conceptualization of learning ecology that recognizes a range of factors that affect the learner (for example, Bronfenbrenner, 1979) to include the learner and animals as active agents and in certain positionalities within the web of coexistence. Learning in this context implies valuing human-animal coexistence as a mutually reciprocal, dynamic, ever-evolving web of relationships. In our view, a workshop designed with such a goal could be the site where teen participants come to understand and define nature-culture relationships in their local contexts. Consequently, the workshop could help us understand how teens' soft skills such as perspective-taking, empathy, and care help them redefine science learning and related practices.

With this motivation, we answer two research questions:

1. How do teens at the workshop engage in the science learning practices of questioning, planning and carrying out investigations, and constructing explanations and designing solutions?
2. How do perspective-taking, empathy, and care shape the teens' science learning practices?

Methods

Overview of study

We structured this study as a two-week virtual summer camp that situated scientific inquiry and design work within adolescents' home environments with their pets. We designed this virtual camp with a mixture of synchronous and asynchronous at-home activities because of the COVID-19 pandemic. We shipped a box of materials to each participant that contained pet toys, treats, and craft materials to support their remote participation. During camp, we met with participants as a group for an hour each morning over Zoom to orient the participants to the tools and their use, and later asked participants to share their work from the previous day's at-home activities.

Recruitment

We recruited middle school and high school aged adolescents through a university-run STEM mailing list for youth who had previously engaged in STEM summer programs and were looking for similar experiences. The participants were between the ages of 13-18, had at least one dog or cat at home, and had internet and computer

access for the two weeks. Thirteen adolescents joined the program, along with 9 dogs and 5 cats. We examine the participation of the 11 participants who completed the study. All names used in this paper are pseudonyms. Each participant chose either one cat or one dog to be their main companion for the camp, with the exception of one participant, Riley, who participated with both of her dogs.

Camp activity design

Overall, we used research in the fields of human- and animal-computer-interaction, to develop the above-mentioned tools and the workshop plan. We designed the **first week of camp** to investigate their pet's senses and behaviors through the use of two tools - one, a set of two Snapchat filters called DoggyVision (DV) and KittyVision (KV; Authors, Year) that mimic the selective blindness of dogs and cats, two, a paper pinna modeled after canine and feline external ears and worn as human ear-accessories. The filters (the tools relevant to this paper) show the camera's view with an approximation of a pet's dichromatic vision making the images appear brown and dull, muted (Figure 1). At the workshop, participants were prompted to use the filter to photograph familiar objects and environments and to interpret how those images look relative to their own experience of it. Based on this observation, participants then planned their own investigations. In the **second week of camp**, participants worked on experience design projects that enriched some aspects of their pets' lives. Participants tested and evaluated their pets' interactions with their projects and conducted multiple iterations of their investigations and shared these to the entire group. In addition to these activities, we assigned a "Blog Prompt of the Day" which included prompts to write narrative journal entries from their pet's perspective, with the goal of connecting learning outcomes to perspective-taking and empathetic practices.

Figure 1
Images captured by a participant.
(a) A cat's food and water bowl on a tray using a regular camera, (b) and the KV filter.

Data Analysis

To begin the analysis, we observed five out of the ten workshop session recordings closely. We then created content logs detailing the participants' plans and actions as captured in their talk and photographic details of their investigations. Next, we analyzed the content logs for three specific Science and Engineering Practices (SEPs) as detailed in the Next Generation Science Standards (NGSS) for middle and high school-age learners. We chose three SEPs (Questioning; Planning and carrying out investigations; and Constructing explanations and designing solutions) to focus on in this preliminary analysis. In doing so, we explored these practices in depth while compromising the breadth of all eight SEPs. In parallel to this, we analyzed the content logs to identify instances of perspective-taking, empathy, and care. In the second round of analysis, we looked for SEPs informed by perspective-taking, empathy, and care and identified how they were connected.

Findings

We report two main findings. **First,** the camp design encouraged participants to engage in science learning practices, specifically, questioning, planning and carrying out investigations, and constructing explanations and designing solutions. **Second,** these science learning practices were rooted in perspective-taking, empathy, and care that serve the goals of science education.

Perspective-taking using tools

"I wonder why my dog's favorite toys are, like, not red." Wade (male, fifteen) wanted to find out why his dog Popper played with a select few toys. On what basis was the dog choosing these toys over the many others? As he photographed objects in and around the house using the DV filter, Wade noticed that red appears as green to dogs, which would mean that the red toys blend in with the grass when he plays fetch with the dog on the grass.

Surprisingly, despite not liking red-colored toys, the dog seems to like a red, white, and blue volleyball. Wade wondered how Popper perceived this tricolored volleyball differently from other solid red toys. Using the DV filter helped Wade understand why the dog does not play with red-colored toys on the grass, he thought aloud why can't dogs see red and green? By extension, what are the colors that would pop out in a dog's perspective and why? Further, if this is what his dog's vision constitutes, how might vision affect his dog's choice of toys? Wade's words indicate the direction of his inquiry - he wanted to find out the basis of the animal's selective colorblindness and how this unique sensory ability affects the dog. Wade's inquiry is situated in the careful observation of his dog's behavior and his willingness to enhance his dog's playtime experience. The empathy that he feels for the animal becomes relevant in light of what he has observed using the filter tool. When Wade compared what he observed in his dog's behavior every day with what the DV filter revealed to him, the pet's choices seemed obviously connected to the animal's sensory experiences. His attentive companionship shaped his questions. Siobhan's (female, fifteen) inquiry, like Wade's, is situated in close companionship, empathy, and care for her cat, Tigger. When Tigger rejects toys, Siobhan interprets the cat's response as different from a human rejection of a toy, i.e. not liking the toy for one or more reasons. Tigger's rejection of a toy could mean many things, from a lack of visibility in the current environment to a lack of suitability for play, rather than just dislike or a different preference. Wade concluded that if Popper could see a toy, especially as a ball, he would play with it, implying that Popper liked the ball as a toy. The only way for Siobhan and Wade to learn more about the pets is to interact with the pets intentionally and in close association and study the animals' behavior in different microenvironments within their home.

As the participants and facilitators continued to use and inquire with the DV/KV filters and what selective color blindness implies for their pets, Siobhan observed that her cat Tigger saw colors, primary and secondary, differently. For example, using the KV filter, she found that her purple sweatshirt looks closer to blue to her cat because Tigger cannot see the red in the purple. As Siobhan adopted the cat's perspective using the KV filter, she examined objects and colors of objects that are not immediately interesting to the pet, unlike a toy. Like Wade, she too examined her understanding of selective color blindness in the context of her cat's behavior and observed that her cat could not distinguish well between some shades of blue and purple, leading her to pay close attention to the colors her cat does prefer. Later, she wondered if the right color was enough for Tigger to like a toy. What if a toy was the right color, but not a suitable toy for play? The design and materials of the toys could be important factors too. What if Tigger could not play with it like he wanted to by batting it on the floor? Siobhan wanted to examine the texture of the cat toy materials to understand the cat's playtime as an experience that is affected by selective color blindness but constituted of many more factors including the sensory modalities of touch and movement. Using the filter gave them access into an area of inquiry. Using pet toys in slightly varying settings such as playing outside versus playing inside the home, and playing with different toys, and observing the pet's response, they extended their inquiry. Such a systematic inquiry initiated by tool use and intentionally extended in an everyday setting is a promising sign of science learning.

For both Siobhan and Wade, investigating pet vision through the filters led to an inquiry into pet vision in the context of play with toys where vision has a particular role. For example, if pets cannot see a toy such as a ball, if they cannot use the toy in a particular way, such as bat it or track it and chase it, they find it challenging to play with it. In this respect, playing with toys served as a meaningful context for inquiry into the sensory experience of vision, the animals' umwelt, and the unique natural, material, and social ecosystem. Finally, Siobhan and Wade's inquiry was not just about pets' vision, but the pets' sensory experiences in an ecosystem they share with humans and interact with them.

Conducting investigations with pets

As the workshop progressed to the second week, the participants planned and conducted investigations to inquire how their pets would behave in a particular setting designed to understand their preferences and behaviors based on what they could see. Adrianna (female, thirteen) considered finding out her dog's favorite color, specifically, a favorite lacrosse ball color since her family buys packs of assorted lacrosse balls to play with the dogs. Adrianna was not sure that her dog, Wally, would choose the balls at all if he was not in the mood to play. Hence, she planned to smear all the balls with peanut butter and place them at an equal distance from Wally. Adrianna based her plan on the knowledge of her pet - the animal does not play with all toys equally, might not play on command, might need to be rewarded for following instructions from time to time, and has favorite incentives. She recognized that smearing all the balls with Wally's favorite treat, peanut butter, might result in Wally eating all the peanut butter negating the influence of a favorite color on the dog's choice. Upon recognizing this limitation in the setup, Adrianna sought to refine it or use a control rather than force Wally to act on command or take away the incentive. Although she wants to find out more about her dog's behavior, Adrianna is mindful of the animal's likes and dislikes in planning and carrying out her investigation. She recognizes that her investigation is not going

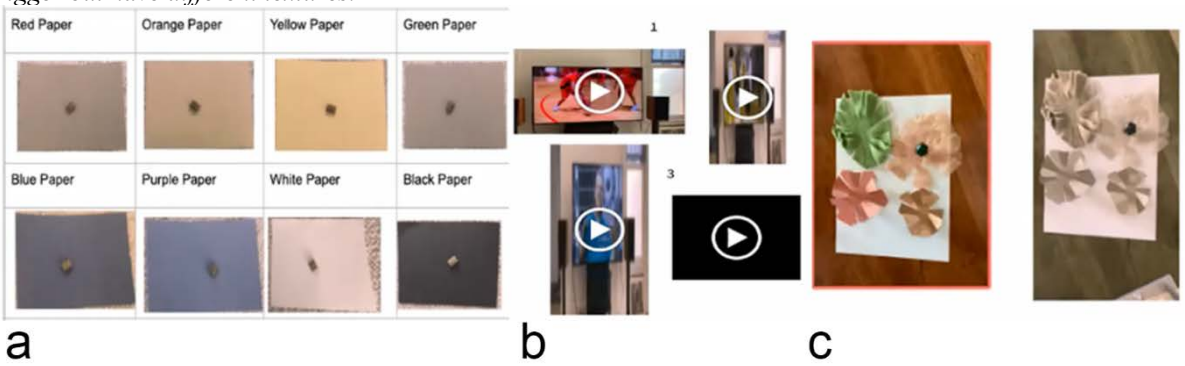
to be successful because of the use of peanut butter as a treat for the dog and she is open to considering other alternatives. Here, Adrianna's knowledge of her pet informed the design of her investigation, her understanding of dog behavior in general helped her evaluate and reflect on it. Her willingness to find out more about the animal and her desire to conduct a successful investigation motivate future refinements.

Evee's (female, sixteen) cat Saskia has a favorite treat. The treat is reddish-brown in color and Evee offers treats to Saskia on the light-brown wood-paneled floors. Using the KV filter, Evee has observed two things, first, that the treats appear as brown rather than reddish-brown to the cat, and second, they are close in color to the brown floor. Evee wonders if this is the reason her cat cannot see the treats very well. To find out a way to make the treat more visible to Saskia, Evee conducted an investigation (Figure 2a). She cut out small squares of construction paper in all colors of the rainbow, white, and black, and placed one piece of the favorite treat on each cutout. She placed the cutout-treat combination in an array and waited for the cat to choose one for each of the two iterations of the investigation. To her surprise, the cat chose the orange cutout-treat combination and consistently chose from the reg-orange-yellow-green row rather than the blue-purple-white-black row on both iterations of the investigation. Evee captured an image of the investigational setup using the KV filter to investigate the setting from the cat's perspective. Based on what she observed, Saskia's choice intrigued Evee. Evee expected the cat to choose the white cutout-treat combination because it appeared very close in color to the orange and yellow cutout-treat combinations. The treat stood out equally well against the yellow and orange, and moderately against the green and red. The treat stood out very well against the white cutout and yet, Saskia ignored it. Unable to explain Saskia's choice, Evee concluded that there could be other factors involved that influenced the outcome of her investigation. For example, was something other than visibility of the treat by virtue of color and contrast guiding Saskia's choice? Could smell be a factor? Evee recalled that often she needed to tempt Saskia with a sniff of a treat to lead her to her food and treats and once at the location, Saskia sniffed further before eating her food. She often missed treats that were farther away and Evee wondered if Saskia was acting out of habit as well as. Despite her meticulously planned investigation and an initial conjecture that the cat relied on smell only to guide her because she could not see her food well against the floor, Evee cannot accept Saskia's omission of the white paper-treat unit as the cat simply overlooking the treat. She felt the need for further inquiry into the combined effect of visibility, smell, and habit in Saskia's treat eating habits.

Figure 2

Investigations conducted by participants at the workshop.

(a) Evee's treat contrast investigation with treats placed on colored construction paper cutouts; (b) Luna's TV show investigation where she observed Rocco's reaction to different TV shows with and without sound; (c) Siobhan's color and texture investigation with Tigger where she chose colors that would appear the same to Tigger but have different textures.



Evee designed her investigation to make Saskia's experience of living in her home better for the animal. She wondered if it might be inconvenient for the animal to not be able to see her food and to not be able to seek food independently at home. This close observation of her cat and the commitment and affection she has for the pet drive her inquiry. In her narration of the investigation and its outcome, Evee was reluctant to call her cat disobedient or her investigation a failure; she accepted the cat's behavior and perception as factors she had to design her investigation around. Evee attentively observed Saskia and used the animal's response to the investigation to shape and elaborate her understanding of feline perception and related behavior. The investigation answered some of Evee's questions about Saskia's behavior and partially solved the cat's problem of not being able to see her food. Yet, new questions emerged and Evee demonstrated willingness to inquire further into Saskia's sensory experience.

Luna's (female, fourteen) dog Rocco likes to watch TV, and Luna wondered what aspects of the TV shows the dog liked the most. Using the DV filter, she rejected her preliminary hypothesis that the dog likes very colorful scenes; the scenes that appear colorful to Luna's human eyes appear pretty dull to the dog. Luna then considered that the dog probably likes scenes that include barking dogs and moving objects. To examine the effect of sounds versus sight on her dog's behavior, she muted the TV (Figure 2b). She observed a less enthusiastic response from Rocco - the dog did not jump onto the TV but still paid attention to moving objects such as basketballs. However, the dog was less willing to watch TV when the news was on, indicating that only certain sounds appealed to him. In a discussion during a group synchronous Zoom, another participant related how her cat refused to watch TV even when she turned on the nature channel and specifically pointed at birds. Luna shared that her dog had favorite TV shows. Siobhan added that her cat liked her iPad, especially when she played Minecraft on it. They wondered if moving objects and sounds attracted pets to TV shows and if all cats and dogs were attracted to these in the same way and to the same extent. These participants were surprised to learn that the color on the television screen made no difference to the pet – they learned using the filters that their pets' world was quite visually dull.

In her investigation, Luna carefully manipulated one variable at a time to understand what Rocco was responding to - sights, sounds or both. She found that her dog, and her friends' pets, had very particular tastes; they like certain sounds and sights and not others. In the context of this observation of Rocco's preferences and the findings of her investigation, Luna concluded that Rocco perhaps likes watching basketball and baseball because he liked balls. Rocco also liked playing with other dogs which explained why he got excited when other dogs appeared on the TV screen. Her experiment was carefully designed and implemented, and Luna relied on the findings of the investigation and her knowledge of Rocco's preferences to better understand why Rocco liked to watch TV. However, Luna's investigation did not require Rocco to do anything new in a controlled study condition, rather, Luna used a situation Rocco already was familiar with and liked to learn more about the animal. The findings of the investigation help Luna refine her understanding of Rocco's behavior, in turn, it makes Rocco's TV time more enjoyable as Luna knew what he liked best. The careful observation of the dog's everyday actions helped her design the investigation; the close companionship and commitment with her dog gave Luna a thorough understanding of the factors that were in play in the investigation and led to the outcome.

Siobhan's cat Tigger is full of energy and likes to play with toys, and at times, Siobhan finds it difficult to keep up with the energetic kitten. Her plan was to design a toy Tigger could independently play with leaving Siobhan enough time to attend to her schoolwork. Tigger liked toys that are visible to him and are easy to move across the floor so he can bat them. Siobhan noticed that the toys' visibility and movement across wooden floors contribute to the cat's willingness to play with the toy. So, she conducted an investigation to test the effects of textures on the cat's choice of toys by choosing fabrics that would appear close in color to Tigger but feel different to him (Figure 2c). To ensure that she would be studying the effect of texture only in her investigation, she examined several fabric pieces through KV to ensure that these would appear similar to the cat and ensured that the toys were similar in design. Siobhan designed her investigation specifically to test her hypothesis - her cat liked certain textures over others and needed to see the toy against a background. She controlled for the color of the fabric swatches in her investigation because using the KV filter she saw that most colors appeared quite dull to cats implying that contrast and visibility were more important than any particular color. She assumed that most toys looked quite dull to her cat and hence, other toy features must be attractive to Tigger and other animals. Her choice of toy design was evidence of her close observation of her pet, his tendencies and preferences, and her caring relationship with him. Although she wanted to conduct an investigation with the cat, the purpose of the investigation, the processes that the cat has to go through are incentives for the animal.

Overall, in this section we observed that the teen participants engaged in the following science learning practices (further details are in Table 1.). In the context of an AR-mediated tool use, they asked and refined questions about their pets' behavior (For example, Popper choosing some toys over others), they planned and carried out investigations to illuminate pets' everyday choices and habits (for example, Saskia needing to be hand-fed treats) and constructed explanations and designing solutions (for example, Rocco preferring some TV shows over others). The ways in which they carried out their inquiry revealed a strong sense of care and empathy towards their pet companions. In their investigations, the teens strived to be mindful of and uphold the animals' agency and living conditions.

Table 1

An example of science practices enacted by a participant with perspective-taking, empathy, and care.

Science practices	Enactment of practice	Enactment of perspective-taking, empathy, and care

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Questioning [Careful observation; Seeking clarity; Examining understanding; Determine relationships; Clarify and refine understanding] Planning and carrying out investigations [Plan and design to produce data; Produce evidence; Select appropriate tools; Manipulate variables and collect data] Constructing explanations and designing solutions [Make a claim; Construct an evidence-based explanation; Reason scientifically]	Luna: I was wondering why Rocco liked watching TV shows, so I filmed some of his favorite scenes from movies and shows. They did not have a lot of vibrant colors in DV but had a lot of dogs barking or a lot of motion. I muted the TV a few times and he ran up to the TV only when there were dogs running around. His favorite toy seems to be balls. When my mom turned on the news he went away.	Luna tried to understand her pet's preference for some TV shows. Understanding this helps her support a better life for the pet rather than assuming their likes and dislikes based on one factor. Using the DV filter she observed that most TV shows appeared very dull to the animal and she wondered if there were other aspects of the shows that attracted Rocco. She planned an investigation to find out what the pet likes to watch on TV and why. Luna had a thorough understanding of her pet's likes and dislikes and relied on this knowledge to plan her investigation. Most TV shows she uses for the investigation are those that the dog already likes. The pet's enjoyment is paramount and Luna does not force the dog to participate in the investigation when he walks away.

Discussion

Ecological perspectives privilege our knowledge of nature as the function of at least two key factors - our interactions with the world and our positionality as just one element of nature. On the other hand, as users and practitioners of Western science, we presume a divide between the world as an object of study and the learner as the outsider individual manipulating the world for the sole purpose of gaining knowledge (Bang & Marin, 2015; Hecht & Crowley, 2019). Knowing about the world around us requires more than factual knowledge to include relationships within the ecosystem involving us and those with which we interact. Although such an undertaking might seem challenging, approaches such as the one adopted in this study can shape a change in a promising new direction.

Tools like the AR filters we describe here permit participants to experience the world as experienced by another species and serve as an invitation into another species' sensory experience. In doing so, these tools support a more profound, relational science learning, one that makes room for inquiry through perspective-taking, empathy, and care and builds on the learner's familiarity with and knowledge of their environment. In the above-mentioned instances, the human participants positioned themselves as equals to their animal companions, respecting and valuing their agency. When the animals choose to respond to some investigations and conditions and not others, the participants found ways to work with the animals rather than coercing them to act against their own interests. In fact, in the above examples, the animals were co-participants rather than research subjects. The human participants exercised their agency and so did the animals, making them co-participants and their relationship a subject-subject relationship. Further, the participants saw the animals' unexpected response to conditions and environments as relevant information that shaped their understanding of the animals as research subjects rather than an unexpected factor that negatively influenced their investigation and needed to be controlled. We wonder if the close relationship between the participants and their pet companions infused these investigations with affect and in doing so, contributed to rather than detracted from their success.

Conclusion

Overall, the findings above indicate that intimate knowledge of a pet at home is an excellent starting point for learning science. Further, as participants questioned the form, function, and scale of pet sensory experience, they situated themselves in an empathetic and caring relationship with the pet where the pet's agency was just as important as theirs. Their inquiry was situated in and motivated by this relationship. Such motivations and the soft skills of relating to them became relevant to learning science at the workshop. These observations lead us to the following refinement of what the science education community values as successful science learning. First, successful science learning experiences can take many forms rather than just one, stringently structured form of a closely controlled investigation involving defined variables. Evee, Luna, and Siobhan's investigations did not resemble standard science investigations and yet, were rich contexts for learning, and relevant and meaningful to them as learners. Second, we need to broaden our understanding of what science learning constitutes. We see that

in the context of the workshop, adopting the perspective of another species, learning to be in an ecosystem by sharing agency are important aspects of learning that shape how and what we know as learners.

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Supporting Teachers' Concept Development Through Aggregation

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Abstract: This study analyzes transcripts of conversations in which mathematics teachers and researchers debrief videotaped lessons by, in part, examining aggregated classroom data from the videotaped lesson. We conclude that aggregating data in debrief conversations can support teachers' concept development when the aggregation a) demonstrates internal contrasts and b) is underscored by participants' discursive moves. Consequently, we recommend that facilitators seeking to prompt teacher learning use lesson-level aggregations to identify and press on comparisons and distinctions in teaching practice. This study can inform research on teacher learning by unpacking how a common practice—aggregating data—contributes to teachers' concept development and has implications both for practitioners and for the emerging field of classroom data visualization.

Introduction

To summarize information about how teaching unfolds throughout a lesson, practitioners—administrators, evaluators, and teachers themselves—often aggregate data from observing teachers' classrooms, such as tallying teacher or student behaviors or quantifying time-on-task (e.g., Mason et al., 2019; Simonsen et al., 2013). A growing body of work on data visualization aims to make such aggregations accessible to teachers, with researchers developing software that illustrates which students are asked which types of questions or which solicitation methods teachers use to ask questions (Herbel-Eisenmann & Shah, 2019) or how class time is spent on different activities or in different configurations (Nagro et al., 2020). Such research, whether rooted in coaching, teacher evaluation, or data visualization, often claims that aggregating data can lead to teacher improvement, but rarely reports how teachers perceive or use such data. In a notable exception, Chen and colleagues (2020) demonstrated that seeing and discussing aggregated evidence of academically productive talk increased teachers' use of academically productive talk but did not investigate how or why it did so. Without understanding how or why aggregating classroom data contributes to teacher learning, aggregators risk the co-optation of powerful tools for problematic purposes, such as teacher or student surveillance under the guise of accountability (Webb, 2005). At best, introducing new data collection practices may increase demands on teachers' time and resources with little benefit for teachers and students. Therefore, this study investigates *how the aggregation of classroom data can support teachers' concept development in lesson debrief conversations.*

Conceptual framework

To do so, we draw on situative theories of teacher learning that take knowledge, and therefore concepts, to be both shared and distributed among actors and artifacts (Hall & Horn, 2012; Hall & Jurow, 2015). Rather than being individually held and carried from situation to situation, the concepts in circulation in any given situation depend on context. This context may include teachers' values, beliefs, and goals (Aguirre & Speer, 1999); the available representational infrastructure (Hall & Jurow, 2015); and the conversational routines, frames, and stories that are common in a particular community (Bannister, 2015; Yoon, 2016); among other things. Concepts serve explanatory purposes in that they help teachers coordinate and "ge[t] information from the world" (diSessa & Sherin, 1998, p. 1171; see also, Philip, 2011) and in doing so, enable pedagogical judgment (Horn, 2020). For this paper, we operationalize a concept as something—a topic, word, phrase, or idea—that 1) carries local meaning; 2) is related to beliefs, values, explanations, definitions, and other concepts in articulable ways; and 3) make interpretation, decision-making, and action possible.

To understand concept *development*, then, we draw on the conceptual change literature. Instead of treating concepts as purely additive (see diSessa [2006] for the limitations to additive conceptualizations of concept development), we take concepts to be pre-existing and gradually transformed through social interaction. In other words, the set of associated definitions, explanations, values, and beliefs that are attached to a concept shift as teachers engage in—among other social practices—conversations about teaching. Shifts in these associations become evident through shifts in teachers' activity patterns (Hall & Jurow, 2015) or, sometimes and more immediately, shifting narratives and mobilizations for future work (Horn et al., 2017; Kane, 2020).

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Research methods

Context and data collection

Data for this study was collected as part of a larger research-practice partnership where the research team and the leaders of a professional development organization (PDO) collaborated to understand and improve their support of veteran mathematics teachers' growth (Horn & Garner, 2021). In this partnership, we engaged in video-based formative feedback (VFF) cycles with school-based teams of teachers. In each VFF cycle, teachers identified inquiry questions about their own practice and selected student groups to record; researchers filmed the teachers' classes using a point-of-view camera worn by the teacher, a whole-class camera mounted on a rotating tripod, and four audio recorders, one for each selected student group; researchers reviewed the collected video and audio to identify clips that would support co-inquiry around teachers' inquiry questions; and the teachers, their school-based colleagues, and researchers engaged in a lesson debrief conversation centered on the selected clips. For timely feedback, each VFF cycle took place within two to four days. We collected the aforementioned classroom video and audio recordings, classroom observation fieldnotes, video recordings and transcriptions of the VFF debriefs, researcher memos, and artifacts from the classroom observations and debrief conversations.

Over two years of data collection, we worked with 13 teachers across six school teams. These teachers had between 5-25 years of teaching experience, and most had obtained or were nearing completion of National Board Certification. We conducted 32 VFF cycles and aggregated lesson-level patterns in 15 of them; in three of those VFF cycles, researchers did not share the aggregated data with teachers during the debriefs. In three of the remaining 12 VFF cycles, multiple types of data were aggregated and shared (e.g., teachers' use of class time and strategies used in students' boardwork). From the 12 VFF cycles, then, there were 15 total instances where lesson-level patterns were aggregated and discussed with teachers during the debrief.

Phase 1 data analysis: Identifying instances of concept development

To select focal and comparative cases, we created analytic memos and tables (Miles et al., 2020) to summarize each instance where lesson-level patterns were aggregated, classified the data aggregated, and identified why the data was aggregated. The most common aggregated data included instances of a particular pedagogical move in a lesson (e.g., list of times teacher tried to get the whole class's attention), teachers' uses of class time (e.g., minutes per activity), and students' boardwork (e.g., list of strategies represented). Aggregation was roughly equally prompted by researchers' hunches (eight instances) and teachers' requests (seven instances). Next, three researchers independently coded each instance for the concepts evident in the debrief and how associated concepts shifted over the course of the debrief. Through discussion, we reached consensus on two instances where aggregation clearly contributed to concept development. Then, we wrote narrative memos tracing the evidence for concept development across each instance. Discussing these memos across the broader research team, in conjunction with reviewing relevant literature, led us to two hypotheses about the mechanisms that contributed to concept development: H1) concept development depends on the aggregated data presenting a clear contrast between what teachers expected to see in their classrooms and what actually happened and H2) concept development depends on participants' use of strong discursive moves to introduce and shift associated concepts.

Phase 2 data analysis: Comparative case analyses

To explore these hypotheses, we conducted comparative case analyses (Yin, 2014). Through open, concept-driven coding, we identified three relevant comparative cases that had similar surface characteristics as the two focal concept development cases but that did not result in clear concept development (see Table 1). Next, we used MAXQDA qualitative analysis software to inductively code the focal and comparative case debrief transcripts (Miles et al., 2020) and visualize the coded data over time.

Table 1
Cases coded in Phase 2 analysis

Case (* denotes focal case)	What was aggregated	Participating teachers
* Including Students	How teachers included students during small group work	Abigail, Clark, Veronica, Franck
* Goes Into	Students' uses of "goes into"	Lizette, Julie
Questions	Teacher questions during small group work	Lee, Doha
Boardwork Creativity	Students' solutions to a particular problem	Clark, Franck
Class Time	Minutes per activity	Clark, Franck

We operationalized H1 by identifying contrasts in aggregated data and then coding debrief transcripts for associated concepts. Visualizing these codes revealed clusters of associated concepts, shifts in associated concepts, when these shifts happened, and what prompted the shifts, which we summarized in analytic memos. For H2, we coded researchers' and teachers' discursive moves with deductive codes drawn from research on activities that support teachers' conceptual change (e.g., proposing solutions [Hall & Jurow, 2015]; asking clarifying questions, offering different interpretations [Horn et al., 2017]) and inductive codes developed for additional moves that were common (e.g., elaboration, affirmation). We examined instances of the most frequent codes using techniques from discourse analysis to determine the meanings, accomplishments, and significance of these moves (Gee, 2014). For example, if a researcher offered a differing interpretation of a problem, we considered whether and how this interpretation was taken up, and by whom, in subsequent turns of talk; if a teacher asked a clarifying question, we considered whether the question served to fact-check what had happened in the videotaped lesson and/or to establish common ground among participants, etc. Finally, we articulated connections between contrasts in the aggregated data, shifts in concepts, and participants' discursive moves.

Findings

We found that although a contrast between teachers' expectations and the aggregated data was neither necessary nor sufficient for concept development (H1), internal contrasts within the aggregated data did seem to be necessary, if also not sufficient, for concept development. For example, in the Including Students Case, teachers did not demonstrate any surprise after seeing an aggregation of their strategies for including an excluded student in small group work. However, the aggregated strategies highlighted a contrast between the intention of supporting students' equal participation as a proxy for equity and supporting individual students' participation as a way of meeting their emotional, social, and agentic needs. Conversely, the Boardwork Creativity Case did not show concept development despite internal contrasts within the aggregated data. Teachers continued to rue the homogeneity of students' solutions even though researchers—and in some cases, the teachers themselves—pointed out instances where students demonstrated unexpected and creative solutions, perhaps because researchers accepted teachers' initial dismissals of the surprising solutions without following up.

Findings from H1 confirmed the importance of participants' discursive moves in prompting concept development, but contrary to H2, we found that researchers' strong moves were neither necessary nor sufficient for concept development. Instead, concept development occurred when either researchers or teachers *offered different interpretations* and then *elaborated* on concepts in ways that diverged from what had been taken as shared. For example, in the Goes Into Case, the teacher initially attributed students' interchangeable uses of "goes into" for exponentiation and multiplication to latency and to her leniency in allowing imprecise language. The lead researcher repeatedly proposed students' unclear conceptual understanding as a factor instead, but the teacher did not take up this interpretation and associate different concepts with it until a second researcher elaborated on how to assess students' conceptual understanding. In the Lee Questions Case, the researcher also repeatedly queried the teacher's interpretations of his questioning strategies, asking about his intentions and how else he could have accomplished them. However, neither the researcher nor teacher elaborated on, say, why his questions did not accomplish his intentions. Although the teacher acknowledged the researcher's queries, even indicating agreement with her concerns, he elaborated extensively on his own pre-existing interpretations and brainstormed how he might revise his future questioning strategies without taking up the researcher's ideas.

In brief, our findings suggest that aggregating patterns supports teachers' concept development when multiple possible interpretations of internal contrasts within the aggregated data are unspooled by participants' discursive moves. Next, we illustrate this finding by describing the aggregated contrasts, shifts in associated concepts, and how both researchers and teachers elaborated on differing interpretations in our focal cases.

Case 1: Including Students

Context and aggregation

In the Including Students case, four Algebra 1 teachers at Banneker High School—Abigail, Clark, Franck, and Veronica—were filmed teaching similar lessons in which students worked at whiteboards in randomly-assigned groups of 2-3 students to write and solve series to find the number of blocks in various towers. Abigail had asked to see examples of how each teacher had promoted discussion or equity, so the research team, led in this VFF by Grace, aggregated a series of six videoclips in which one student in a small group appeared to be left out and a teacher had done something to bring that student into the small group conversation. For example, in one clip, Franck lightheartedly asked a student to talk to another student "because he looks lonely." In another, Veronica directed a follow-up question at a student who had not been participating in the conversation. Taken together, these clips highlighted contrasting strategies for supporting students' participation in small groups.

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Shifts in associated concepts

In the first third of the debrief, Grace showed the video clips in rapid succession and teachers engaged in mostly binary assessments of students' participation and of the efficiency and effectiveness of intervention strategies for supporting student participation (e.g., "that's it, quick;" "she looks like she's thinking;" "success"). Then, Grace prompted teachers to share their pedagogical reasoning around the aggregated clips. In the second third of the debrief, teachers named forms of student participation other than discussing solutions and analyzed the aggregated intervention strategies in more detail. For example, Clark wondered whether he should create more opportunities for students to ask their group members for help when they do not do so "naturally:"

> Franck: A problem I have with that is that one kid will definitely always be the asker.
> Veronica: The asker?
> Franck: Yeah.
> Veronica: Or the person being asked.
> Franck: Yes, all the time. Especially in a certain makeup of that group, and I don't know how comfortable that would feel to a kid, being the asker or the askee or whatever, you know? So I just wonder, I don't know.
> Abigail: […] I tell them when who's talking. So that's part of the equity thing that I think is important is that like [students assigned to] reds talk first. There's red and yellow, reds talk first. All reds have to talk and so then all yellows have to talk…

In this portion of the VFF debrief, teachers discussed the associated concepts of *equal participation as a proxy for equity*, *mitigating status differentials across students*, and *participation as an opportunity for academic learning*. These associated concepts represented a shift from the binary assessments demonstrated in the first third of the debrief and contrasted participation for participation's sake with participation for learning's sake and were made salient by teachers' further discussion of the strategies shown in the aggregated videoclips.

Differing interpretations and elaborations generate further contrasts

Then, Grace invited Franck to introduce Roberto, a student who Franck had described as having a substantially different skillset compared to other students in the class. Teachers viewed a clip in which Franck tried to include Roberto in his small group's conversation, and the final third of the VFF debrief became substantially more complex. Continuing to frame *participation as an opportunity for student learning*, Clark initially interpreted the dilemma as one of preserving Roberto's learning opportunities while maintaining the status-equalizing advantage of randomly-assigned and thus heterogeneous groups. He proposed strategically assigning Roberto and a partner to just work on the first problem while other students moved on, and then added:

> It's kind of sad to me that [the first problem is] still sitting there probably unsolved for him and very solvable, and [it would be] a nice accomplishment for him. And he doesn't get to do it because we're already moving on to this other thing. So I'm just wondering how we could make it without, honestly, tracking your grouping…

Franck asked how he could assign Roberto and a partner to work just on the first problem "without singling [Roberto] out." In response, Clark and Veronica brainstormed another strategy: still using random groups but then assigning Roberto to write his groupmates' ideas on the whiteboard. They surmised that Roberto could still have learning opportunities from writing mathematical solutions, even if he did not contribute to figuring them out.

Franck offered a differing interpretation: "But maybe that's like you forcing him to do something he doesn't want to. I mean, is that agency?" Teachers did not immediately take up the concept of *student participation as a reflection of agency*; Veronica and Clark elaborated further on Clark's original interpretation, generating and troubleshooting additional strategies that could elicit Roberto's participation while preserving his learning opportunities. After several minutes, Franck re-introduced his question more directly.

> Franck: Do you think he's getting something from standing up there with those two?
> Clark: I personally would say no.
> Veronica: You say no?
> Clark: Very little. Not—
> Franck: More than if he sat by himself.
> Veronica: There's more to school though.
> Clark: Abigail?

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Abigail:	Yeah, I do think he's probably getting some, I mean, I don't know. I don't know the student, but I think that he is.
Franck:	[turns to his aide] Do you think he's getting something?
Aide:	Roberto? I don't think so.
Veronica:	But you have to think about the social context, too. It looks like he's participating, his body language is "hey, I'm doing this thing that I'm supposed to be doing" and so maybe we're meeting a different need, which is allowing him to be near and participate in a low-risk way.
Abigail:	Participate in school.

In this exchange, Franck prompted his colleagues to reconsider his differing interpretation: that participating in small groups might be meeting students' needs beyond learning mathematics. This time, Veronica picked up and elaborated on this interpretation, suggesting that Roberto's current form of participation may be serving social needs. Abigail and Clark followed up with additional ways that students' social and emotional needs might be met by listening quietly to their groupmates rather than actively figuring out solutions. Finally, Franck asked what would happen if he simply told Roberto's group that "when I come back, I want Roberto to be explaining number one. Now how does that make Roberto feel? That's my question." In contrast to teachers' earlier discussions of strategies for supporting student participation, Franck identified a proposal with the potential to address both Roberto's mathematical learning and his social need to perform participation in a low-risk way, and solicited his colleagues' feedback on how this strategy would make Roberto feel, as opposed to simply whether it might "work" in the sense of compelling Roberto to talk.

In the final third of this debrief, the concepts associated with supporting student participation shifted from *participation as a proxy for equity* and *participation as an opportunity for academic learning*—both of which suggest that teachers' primary goal is to increase student talk and thereby student learning—to *participation as meeting students' social, emotional, and agentic needs*. These shifts occurred when teachers shared differing interpretations of pedagogical dilemmas illustrated by the aggregated videoclips—specifically, questioning how intervention strategies might affect students' agency and their needs other than academic learning—and then elaborated on these differing interpretations. Doing so led to concept development and mobilization for future work by expanding what teachers considered when assessing intervention strategies.

Case 2: Goes Into

Context and aggregation

In the Goes Into case, Lizette had taught an Algebra 2 lesson in which students engaged in small group work to practice evaluating logarithms. Lizette asked researchers (Brette and Lani) to attend to how students were thinking about logarithms. While reviewing video, Brette and Lani noticed that students were using the phrase "goes into" to describe both multiplication (e.g., "two goes into 128 sixty-four times") and exponentiation (e.g., "three goes into nine twice"). This pattern appeared across multiple student groups and throughout the lesson. To highlight the contrast, Brette and Lani selected two videoclips of the same student group using "goes into" in different ways. Brette introduced the data by saying, "there's also the issue of 'goes into' and the way that students were using that. This group, which was the blue group, they were using 'goes into' in both ways." Lizette initially interpreted Brette's observation as an issue of *imprecise language risking miscommunication*:

> So then, if someone is talking to a person who's using it both ways, they don't necessarily know—maybe the kid who's saying it has it in their head straight, but the people who are listening might not. And also maybe the one who's saying it might not.

Brette, however, suggested that "it was interesting that some students were using it both ways to mean both things at different points." By highlighting internal inconsistencies within the same students, rather than inconsistencies between how different students were using the phrase, she gestured towards *imprecise language as an indicator of students' conceptual understanding*.

Shifts in associated concepts

Lizette then explained that she had originally taught logarithms using a number line representation to conceptually illustrate the difference between multiplication and exponentiation, but she had done a long time ago and students may have forgotten in the intervening months. In doing so, she attributed students' *imprecise language to be a reflection of latency* rather than an indicator of their (potentially unclear) conceptual understanding.

Lizette: But when it's so far separated from when we did that—'cuz that was in the beginning of the semester or the end of last semester, I can't even remember. It was like months ago either way, right? […] It's been so long that then, especially when the vocabulary stuff comes up, makes sense that it's all over the place.

Brette: But there were also things like the $log_b b = 1$. A lot of kids were like, "Oh that is clearly one." And [student] back here was like, "Yeah, y'all, that's one."

In identifying a similarly-aged concept that students appeared to remember clearly, Brette contradicted Lizette's interpretation that latency was the primary cause of students' imprecise language. Lizette, however, continued to elaborate on the pedagogical dilemmas that latency presented. She noted that her Calculus students still struggled with logarithms even though some had also learned the number line representation and wondered whether she ought to be reteaching logarithms to them too. In doing so, Lizette recognized that the number line representation alone could not ensure students' conceptual understanding but continued to attribute student confusion to latency.

Later in the VFF debrief, Brette took a different approach to probing students' uses of "goes into:"

Brette: I got the sense that maybe [students] came up with the 'goes into' language and you were rolling with it?

Lizette: […] I just wasn't intentionally trying to go with it but I also wasn't as strict about—like when we did the warm up, I probably wasn't very strict about it. […] I should have said something. […] Sometimes in my head maybe I'm like, "Yeah okay now we've got it revoiced the way I wanted it." But I didn't articulate why that was the way I wanted us to go. And so then they don't see that one way is going to be better for them to use than another when it comes to later stuff.

Lizette's elaborations suggested that she interpreted Brette's prompt as associating *imprecise language with teacher leniency*. She said she should have been stricter about monitoring students' language and more explicit about explaining why precise language mattered. Although she shifted her associated concepts, attributing latency to teacher leniency instead of latency, this was not the shift that Brette had hoped for.

The importance of elaboration

Brette made another bid for her interpretation of students' understanding by positing that students might not have understood that there *were* multiple meanings of "goes into:"

Brette: I didn't get a sense that kids who were using the "goes into" phrasing knew—

Lizette: —not to

Brette: Or were like clearly aware that there were two different uses of "goes into."

This time, Lani jumped in to elaborate on Brette's interpretation.

Lani: We listened to a bunch of these last night, the "goes into" examples, and we were just listening to a lot of their talk. And I was trying to see if I thought there was a kind of shared understanding of that inverse relationship between exponentiation and logarithms. Like if they saw it as a process or if they saw it as a procedure.

Brette: Yeah, it felt like sort of a translation thing?

Lizette: Yeah, that makes sense.

Brette: Like log whatever of whatever is a language that I'm not familiar with, and so I'm going to rewrite it into words that I know.

Lizette: Yeah, instead of understanding conceptually that it undoes.

Lani's elaboration, and Brette's further elaboration, seemed to finally cement for Lizette the differing interpretation that Brette had been trying to present throughout the VFF debrief, and she articulated in her own words that students' imprecise language likely indicated the extent of their conceptual understanding. Next, Brette and Lizette reviewed some of the specific examples that Lizette had used in her activity and how they may have contributed to students' confusion. As Lizette began to identify changes she wanted to make to this lesson for next year, Lani pressed Lizette to continue thinking about her current class of students and the state of their conceptual understanding of logarithms:

> With how they're talking about it, if they forgot the procedure a month from now, could they recreate it with the words they're saying about what's going on? And I didn't think so. I think that they were kind of like going through the number line and doing things with it and they were kind of powering through that one calculation.

Lani provided a concrete model for how Lizette could treat students' talk as evidence of their conceptual understanding; this elaboration framed students' imprecise language as a useful source of formative assessment rather than merely an inevitability due to latency or a consequence of teacher leniency.

After researchers' persistence in offering an interpretation of students' imprecise language that differed from Lizette's initial interpretations, and more importantly, elaborating on it, Lizette incorporated their interpretations by planning how she would revisit students' conceptual understanding of logarithms on Monday:

> So I think I want to just do just generally solving equations, and kind of like scaffold it and end with logs maybe? […] So looking at a lot of those inverses. That's kind of where my head is at currently so we can kind of go through inverses again and then throw in an exponential. […] So reintroduce it again as "this is the tool that we need to be able to undo."

The solution that Lizette proposed, reintroducing logarithms as a type of inverse, took *imprecise language as an indicator of students' conceptual understanding* instead of reflecting her previous interpretations of imprecise language as a reflection of *latency* or *teacher leniency*. This demonstrated a shift in the concepts that she associated with students' imprecise language. Although the aggregated videoclips made clear the contrast between students' different uses of "goes into," and although Brette had repeatedly offered an interpretation of the contrast focused on conceptual understanding, Lizette did not fully take up this interpretation until Lani (and then Brette) elaborated on this interpretation, suggesting that *elaboration* as a discursive move is critical to concept development.

Discussion

Examining the highlighted contrasts, associated concepts, and key discursive moves in the Including Students and Goes Into cases suggests that teachers' concept development can be supported by 1) the aggregation of patterns in classroom teaching that reveal internal contrasts and 2) elaboration, whether by teacher colleagues or researchers, on different interpretations of those patterns.

Aggregating patterns across student groups, across the minutes of a lesson, across instances of a particular routine or pedagogical move, or other things, collapses an otherwise-disperse set of data points to a more manageable scale, making comparisons and distinctions more obvious and easier for teachers to make sense of. Lampert writes that zooming in and out between scales—what happens in an interaction compared to what happens over multiple interactions, for example—"enrich[es] our understanding not only of different levels of phenomena but also their relationships to one another" (2001, p. 44). In other words, aggregating data coordinates processes that occur at different scales, highlighting what is typical and where there are possibilities for change (Lemke, 2000; Taylor & Hall, 2013). By doing so, aggregation supports shifts in the beliefs, values, and ideas that teachers associate with particular concepts about teaching, thereby developing their intuitions and ability to make in-the-moment decisions (Horn, 2020; Lampert, 2001).

This study brings research on teacher learning into conversation with the growing research on classroom data visualizations, identifying mechanisms by which aggregating data can support teacher learning. We suggest that researchers designing data visualization tools consider how their tools illuminate contrasts at different levels of scale and also attend to the types of conversations about teaching that might be sparked by their tools. Our findings recommend that facilitators who aim to support teacher learning (and/or instructional improvement by way of teacher learning) may find it useful to aggregate lesson-level data and share the aggregations with teachers not because the aggregations themselves necessarily prompt conceptual change but because aggregations can often make visible internal contrasts, whether between teachers' intentions or expectations and observed classroom practice or between their initial assumptions or interpretations and alternate possibilities. This internal contrast, in turn, can provide fodder for the types of discursive moves that lead to concept development, especially if facilitators are able to attend to and even introduce differing interpretations and to prompt elaborations on these different interpretations. Furthermore, classroom observations should be extended beyond the limited "pop ins" that administrators often employ; our research shows the promise of aggregating data and identifying patterns across full lessons instead of focusing on short episodes. Finally, we hope that future research can examine whether aggregating data across lessons and/or across teachers supports learning in similar ways.

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Constructing an "Us" in Teacher Work Groups: Affordances and Limitations for Learning

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Abstract: Research on teacher collaboration suggests that shared values and a sense of solidarity are important resources for generative discourse and robust teacher learning. Drawing on data from two groups of elementary mathematics teachers, this paper examines how teachers construct identities as "us" and the effects of these processes on teachers' opportunities to engage in equity- and justice-oriented sensemaking and learning. The analysis demonstrates that constructions of "them" sometimes accompany constructions of "us" and shows how this inhibits teachers' opportunities to learn. Strategies for building solidarity without sparking us/them dynamics, grounded in data, are discussed.

Background and purpose

Studies of teachers' collaborative work groups often point to shared values and a sense of being "in it together" as important for the kinds of critical, reflective discourse that support robust teacher learning, suggesting that these groups benefit from developing a collective identity or sense of "us" (Baldinger, 2018; see also Lefstein et al., 2020; Bolam et al., 2005; Louis et al., 1996). A sense of "us" appears to be especially salient for groups with shared commitments to centering students and advancing equity and justice (e.g., Benitez et al., 2009; McCotter, 2001; Picower, 2011). Yet constructions of "us" may define what is bad, deficient, and wrong as well as what is normal, valued, and good. In this paper, we examine how teacher groups construct identities as "us," what values anchor these group identities, who may be constructed as "them," and the effects of these dynamics on teachers' opportunities to engage in equity- and justice-oriented sense-making and learning.

Prior research

While many studies highlight the potential of teacher collaboration to support teacher learning (e.g., Bolam et al., 2005; Darling-Hammond et al., 2017), others indicate that such collaboration may fall short of producing the intended learning or change (e.g., Author, 2016; Stokes, 2001). Little (1990) has gone so far as to observe that teacher collaboration is often "contrived, inauthentic, grafted on, [and] perched precariously … on the margins of real work" (p. 510). One reason for this is that collaboration is inherently laden with the risk of others' judgment, particularly when it involves opening one's practice for the kind of examination and reflection that is needed to foster learning. As one teacher explained to Le Fevre (2014), "It is hard to show what you do to the others, because … you just do what you think is best for your kids, what you feel in your heart but then it might not match up as good enough against someone else's way of teaching" (pp. 59–60). Vedder-Weiss and colleagues (2019) have further found that teachers work to avoid "face threats" not only to their own public image, but also to colleagues' images. For example, various studies have shown that teachers may focus their collaboration on administrative tasks, limit themselves to swapping classroom activities and practices in a superficial way, actively silence critical perspectives, or cancel meetings altogether, all of which can be understood at least partially in terms of managing the threat of unfavorable judgment from peers (Louie, 2016; Vedder-Weiss et al., 2019).

Trust, shared values, and a sense of safety for intellectual risk-taking can support teachers to manage the risks of collaboration more productively (Bolam et al., 2005; Vescio, 2008; Lefstein et al., 2020). However, little is known about how groups of teachers develop these characteristics. Some studies suggest that convening groups based on core values that are already shared (such as a commitment to social justice) allows teachers to exist in a "sacred space" of support, honest dialogue, reflection, and critique (McCotter, 2001, pp. 690-691). Yet this obscures the moment-to-moment work that goes into co-constructing any learning environment, as well as the ongoing negotiation of meaning that is required to make abstractions (e.g., social justice) concrete and actionable.

In this paper, we add to the small body of research investigating the dynamics of teachers' efforts to navigate the risks of professional collaboration, particularly equity- and justice-oriented collaboration, focusing on how teachers construct "us" and "them" in moment-to-moment interaction and the effects on their opportunities to learn.

Theoretical perspective

A conceptual starting point for our inquiry is the awareness that all teacher learning is situated in what Horn and Garner (in press) term the "baggage of the binary," the culturally pervasive tendency to think of both specific

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teaching practices and individual teachers as either "good" or "bad." This good/bad binary imposes an evaluative frame that suggests that a good teacher should be skilled in applying "best practices" to deliver lessons that run smoothly and reliably produce measurable gains in student achievement. In this context, grappling with multiple perspectives and uncertainty exposes teachers to the risk of appearing bad at their jobs (the "face threat" described above; Vedder-Weiss et al., 2019). Moreover, when beliefs about students are on the table, particularly beliefs linked to racism and other systems of oppression, there is the additional risk of appearing to be a bad person as well as an incompetent professional (Stokes, 2001).

Teaching is much more complicated than a good/bad binary indicates. What counts as "good" practice depends on context. Furthermore, teachers must often juggle competing priorities, such as building on what their students know, can do, and are interested in learning and following externally mandated scope, sequence, and pacing (two priorities that are often in tension even when they are not directly opposed). For teachers working toward a vision for mathematics classrooms that is not yet widely practiced (e.g., equity- and justice-oriented visions), tensions and contradictions between various goals and obligations can be constant. Research on teacher learning that focuses on the mastery of particular practices or the acquisition of specific types of knowledge along a linear trajectory miss these tensions and contradictions. Here, we emphasize an understudied aspect of teacher learning: the ongoing grappling that teachers engage in as they attempt to re-solve "fundamentally unsolvable problems" (Philip, 2019, p. 5) in their everyday teaching. This grappling is necessarily social, in that local communities of practice make available certain ways of understanding young people, mathematics, and learning. When these communities are formed around a shared vision for mathematics teaching, they can provide teachers with collective resources to engage in the ongoing grappling of how to live up to their commitments in daily classroom teaching.

For teachers who are committed to anti-deficit mathematics teaching, living up to one's commitments can present an even greater need for ongoing grappling. Deficit ideologies remain widespread and are embedded within systems and structures that overemphasize what students cannot or do not do. These ideologies further locate some students as intellectually deficient and inferior to others in ways that intersect with existing social hierarchies based on race, class, gender, cultural or linguistic background, and (dis)ability, thereby functioning to reproduce these same hierarchies (Adiredja & Louie, 2020; Martin, 2009). Because deficit ideologies are culturally dominant (at least in the United States), they influence teachers' sense-making about their daily practice, no matter how committed teachers might be to working for justice (Louie, 2018). Philip (2019) has described the work involved in disrupting deficit ideologies and practices as "principled improvisation," highlighting both the unpredictable and ever evolving nature of teaching and the necessity of constantly maintaining a principled orientation toward justice when making moment-to-moment decisions. This conception of teaching acknowledges that "each moment of teaching and learning is consequential as teachers and students continually and jointly renegotiate power and possibility in every interaction" (Philip, 2019, p. 5). In this paper, we investigate teacher learning from the perspective of seeking to learn more about how teacher workgroups can be co-constructed to support the type of grappling that is necessary in equitable, student-centered mathematics teaching, especially teaching that challenges deficit ideologies (i.e., anti-deficit teaching).

Methods

The two of us, Nicole and Mallika, are united by our experiences as former teachers who have ourselves grappled with the challenges of realizing strengths-based, anti-deficit goals in our classrooms. We continued to engage in this grappling as graduate students at the University of California, Berkeley (where we first met) and still engage in it today, in our roles as teacher educators and researchers. We thus approach our research with a sense of the challenges many teachers face and an interest in understanding and supporting their ongoing learning, which contrasts with approaches that seem to blame teachers for their shortcomings. This relates to our shared goal of complexifying research on teacher learning by attending to the entanglement of this learning with political and ideological contexts and its messy, non-linear character.

In this paper, our analysis draws from two research projects, which we initially conducted independent of one another. Mallika's study was a social design-based research project of a teacher learning community that she co-designed with six first-year teachers from the same K-8 teacher preparation cohort. These teachers were all Mallika's students in a math methods course and were selected because they would be teaching elementary school locally and had voiced a shared commitment which they articulated in the first community meeting as "creating a math community where everyone meaningfully contributes to the mathematical work of the classroom." This overarching commitment grew out of shared experiences in the math methods course of seeking to disrupt processes of marginalization within the mathematics classroom which function to uphold racialized hierarchies of mathematical ability (Martin, 2009). The learning community (named Math Crew by participants) was intended to support teachers to work toward their shared commitments while navigating the tensions and contradictions of

working within deficit-oriented systems of schooling. The support structure consisted of monthly community meetings and periodic classroom visits from Mallika.

Nicole's project involved groups of teachers at four schools, all participating in a professional development program called the Elementary Mathematics Collaborative (EMC; a pseudonym, like all school and teacher names in this paper). Situated in a large American city, EMC focused on "high-need" schools in economically and politically marginalized neighborhoods, with the goal of supporting "ALL students [to] engage in mathematical sense-making leading to deep mathematical understanding" and "to develop a sense of mathematical agency and authority" (according to EMC materials). EMC's mission was thus connected to equity concerns, but in ways that did not explicitly name or interrogate systems of oppression in mathematics education. "Cycles of collaborative practice" were an important component of EMC activities. Similar to lesson study (Lewis et al., 2006), these cycles involved teachers in collaboratively planning a lesson, observing one teacher enact the lesson, then sharing what they had observed and planning next steps together. Each cycle was facilitated by an EMC coach. Nicole was involved as a participant-observer (not as a coach or PD leader).

To analyze our data, we examined the values around which solidarity was organized. What values did participants claim as their own? Relatedly, what did they characterize as qualities of "good" teaching/teachers or "bad" teaching/teachers? Because we were also concerned with whether teachers' constructions of "us" set up a dynamic of "us versus them," we asked: who was included (implicitly or explicitly) in the solidarity being constructed? Connected to our interest in teachers' opportunities to learn in these episodes, we also investigated how teachers framed grappling and struggle (e.g., as an important and necessary part of learning, or as an indication of failure) and what ideas they did or did not set themselves up to grapple with together.

We selected five episodes for close analysis, aiming for variety with respect to the answers to the questions outlined above. Two episodes were drawn from EMC's School 53, involving the EMC coach and three teachers and the other three episodes are from community meetings in Math Crew.

Findings

We use five episodes across the work groups from our two studies to elaborate how constructions of "us" and "them" are not stable characteristics of groups but instead are constructed from moment to moment in ways that shape opportunities for learning. In both Math Crew and School 53 there were moments when teachers and coaches/facilitators co-constructed "us" as a group in which teachers could struggle and grapple together toward their shared commitments, as illustrated with episodes 1 and 2 (Math Crew) and episode 4 (School 53). While in Math Crew these constructions of "us" were explicitly anti-deficit and supported teachers to grapple with deficit ideologies, the construction of "us" in School 53 focused more broadly on student-centered mathematics teaching, illustrating the ways that solidarity in teacher work groups is co-constructed toward particular goals. In both teacher work groups, when constructions of "us" also included constructions of "them," this tended to lead to binaries of "right" or "wrong" answers and "good" or "bad" teachers, which closed down opportunities for grappling and deeper reasoning about teaching as illustrated in episode 3 (Math Crew) and episode 5 (School 53). Across these five episodes we emphasize the in the moment construction of "us" and "them" as affording and constraining opportunities for teachers to grapple with teaching toward their commitments.

Math Crew

Math Crew was formed with an explicit commitment to working toward anti-deficit mathematics teaching. The community was voluntary, and all six teachers who chose to participate did so because they wanted to receive support in trying to live up to their commitment to disrupting deficit ideologies in their everyday teaching. We selected three episodes to elaborate the ways constructions of "us" and "them" afford and constrained teacher learning toward grappling with deficit ideologies. The first two episodes illustrate how constructions of "us" fostered moments of solidarity in the struggle of maintaining a strengths-based lens in everyday teaching and created opportunities for teachers to think more deeply about deficit ideologies. The third episode illustrates how, even with an anti-deficit construction of "us", moment to moment constructions of "them" can close opportunities for deeper reasoning and grappling about teaching.

Episode 1: Constructing an "us" that supports collective anti-deficit learning

To illustrate constructing an "us" with anti-deficit goals, we use an episode from Math Crew during the learning community meeting in November. In this episode, one teacher, Maritza, shared a story from her 4th grade classroom. She told the community about how, during a classroom visit, [Author 2] had helped Maritza notice a mathematical strength of one of the students in her classroom who had been labeled as "struggling" in math by school administrators. Maritza described how she had not initially noticed what the child was doing but that, once Mallika had pointed it out, she was able to highlight this strength both in the student's small group and in a whole

group discussion. She then described how this action shifted status dynamics and seemed to positively impact the student's math participation during subsequent math lessons. Right after Maritza finished sharing this story of a "success" in her commitment to working toward anti-deficit math teaching, Kara jumped in to share, "I have a connection. It was so helpful to have [Author 2] in the classroom just cause I was so scattered when Mallika came." After explaining more about why she was scattered, she went on to say, "[Author 2] was like 'it would just be nice for you to be able to take notes on strengths.' Literally the only thing I had on my notepad at the end of that session was (drawing a box in the air) a rectangle." At this, the other teachers erupt in loud, exuberant laughter, with lots of head nodding and signals of agreement. Kara further explained, "One kid asked 'what's a rectangle?' and it was a little blue rectangle. I was like 'this is a rectangle.' That's all I had taken (using air quotes) 'note' of." At this, Maritza laughed loudly, Marie put her head in her hands laughing, and Selina commented, "Oh my god, that is amazing."

While Maritza's story had focused on a positive moment in her teaching, Kara chose to draw out and connect with the struggle that Maritza mentioned about how hard it was to notice strengths on her own. With her rectangle story, Kara built on this acknowledgement of struggle to share a moment of total failure in being able to live up to her commitment to noting strengths in the day-to-day intensity of classroom teaching. The laughter in the responses from other teachers seemed to indicate a form of solidarity (Takeuchi, 2016) in the shared struggle to enact their commitments, and provides evidence of the co-construction of an "us" committed to taking an antideficit stance AND an "us" of human beings who sometimes fail in their attempts to embody that stance in their everyday teaching. In the intense reactions to Kara's story, there was a palpable sense of relief in being able to hold that failure collectively, as a community.

Episode 2: Drawing on a co-constructed anti-deficit "us" to grapple with deficit ideologies

The co-construction of an anti-deficit "us" that included struggle helped to create a space in Math Crew for beginning teachers to grapple with deficit ideologies and the ways those ideologies are embedded within structures and systems. With this episode, we show the type of grappling that teachers were able to engage in, and how that grappling connected to an anti-deficit "us" that includes struggle and imperfection. Toward the beginning of the final meeting as a learning community, Kara shared a recent tension she had experienced at her school site where she was asked "to fill out these classification cards for next year and we have to rate each of our students like high, medium, or low in math." Kara went on to describe the tension this caused for her:

> And I was like, 'oh no, that's terrible.' It felt sad that that's how the school wants to think about students and that they would think about distributing kids based on that, like 'oh we don't want to give this teachers too many "low" (air quotes with fingers) kids' to ease the burden but it also made me think about how I see my students, and the kids who I feel anxious about in math are the kids who do have trouble persevering or kids who have low self-esteem. It's not low based on any score, I'm looking more at their relationship to math and the way they see themselves as a math learner and that just makes me even more driven to set up my culture next year even more enforcing the expectation and the value that everyone is a math learner and has something to contribute. I also felt kind of like, moral, do I stand up to the system and say 'I will not fill out these classification cards' or is it like, what do I look at to fill these out, what are you asking for?

In talking through her dilemma, Kara explicitly indexed an anti-deficit "us" by using the same language that had been co-constructed in Math Crew of everyone having something to contribute to a math community. In this story, deficit ideologies were located within systems and structures, which was evident when Kara raised the question "do I stand up to the system?" (emphasis added). By bringing this "moral" dilemma to Math Crew, she was treating the constructed "us" as a resource to help her reflect on and grapple with how she was hoping to see the children in her classroom. Here, Kara interrogated the category of "low" by considering which students she felt "anxious about in math" instead of treating these categories as taken-for-granted and static, as the classification cards suggested.

Kara then talked out loud about what she might do, describing in detail her thinking about one of her students who "at the beginning of the year for addition and subtraction used his fingers and would do it under the table but felt super insecure about math." She went on to describe how this student now "is just like an awesome partner to have in math and is seen as someone who has cool strategies and is seen as someone who participates in full group math thinking and is able to ask questions and get help." She concluded by saying, "I can't see putting him high, medium, low. Where would I? I don't know, none of the above. He's just a cool kid." Throughout this storytelling, the co-constructed "us" of Math Crew was a place where deficit ideologies could be

questioned and grappled with, and where the point was not to find the "right" answer to the dilemma of the classification card, but instead to reflect and reason about how to navigate it in a way that was consistent with their shared commitment to disrupting deficit ideologies.

Episode 3: Constructing a "them" that inhibits anti-deficit collective learning

During the same conversation in Math Crew, another teacher, Selina, who taught at the same school site as Kara, told another story that also involved constructing an explicitly anti-deficit "us" (Kara and Selina had discussed these stories in the car on the way to the meeting). While Selina's construction of "us" was similar to Kara's construction, when Selina spoke about deficit ideologies, she located these ideologies in individuals rather than in systems, thus constructing "them" in contrast to the anti-deficit "us" of Math Crew.

The story Selina told involved an inquiry project about language and mathematics across different schools in her district. She described a moment during the collaborative planning process when she suggested randomly selecting a student to share and another teacher questioned that choice:

> One of the teachers was like 'well what if you choose somebody that has it completely wrong and they're totally lost and don't know what's going on?' Aaand that just felt so negative to me, like, 'what do you do with this kid that doesn't get it?' So I said, 'you know what, everybody has some kind of math thinking so we're going to tease out whatever it is that they're bringing and just talk about it. And, you know, at least in my classroom everyone has something to contribute.' And I think in that moment is really when I saw that clear division between my thinking and other people's thinking, which is crazy to realize that not everybody thinks like we do.

As in Kara's story, Selina used the shared language of Math Crew ("everyone has something to contribute") to refer to a co-constructed "us." This "us" provided a resource for her to push on the deficit ideologies she encountered during the project. However, in contrast to Kara's story, Selina also constructed "them" when she emphasized what she tried to do in "my classroom" (in contrast to other teachers' classrooms) and when she described the "clear division between my thinking and other people's thinking." When Selina concluded by saying "not everybody thinks like we do," the "us" that she constructed was in contrast to "them" as other educators who do not hold the same anti-deficit stance.

During her story-telling, Selina focused on "right" and "wrong" approaches to teaching associated with the "us" and "them" that she had constructed. We argue that this sense of "them" and of "right" and "wrong" is not supportive of anti-deficit teacher learning in that the quick offering of solutions interferes with the type of grappling that is essential for trying to engage in the ongoing task of living up to one's commitments in everyday teaching. In this instance, for example, the group might have instead engaged with the problem of practice that her colleague had raised of how to respond to children when they have an incorrect answer—a genuine dilemma in anti-deficit instruction. In addition, when "them" is constructed as other educators, the potential exists for an undermining of trust, solidarity, and risk-taking because any teacher could at some point become "them" if they do not say or do the "right" thing. Selina's and Kara's stories, which were shared during the same conversation, highlight the dynamic, moment-to-moment nature of constructions of "us" and "them." While Kara's construction of "us" made space for deeper thinking about her own practice, Selina's construction of an "us" that included "them" seemed to inhibit grappling with the everyday challenges of living up to her commitments.

School 53

We now turn to two episodes at School 53. Episode 4 reinforces our finding from Math Crew that constructions of "us" can open up opportunities for teachers to learn—i.e., to collaboratively grapple with the challenges of reconciling commitments to equitable, student-centered instruction with competing ways of understanding their own work. Episode 5 shows how even a subtle construction of "them" may close down opportunities to learn, similar to Episode 3 in Math Crew but with a "them" that is present in the room. Together, the two School 53 episodes show that "us" and "them" are not stable; rather, they are constructed from moment to moment and in relation to particular goals and values. Both of these episodes are drawn from a single lesson debrief. Ms. Scott had just taught a lesson that did not go according to plan. She is joined by two of her colleagues at School 53 (Ms. Ortiz and Ms. Edmond) and the EMC coach (Ms. Koets).

Episode 4: Constructing an "us" that supports collective learning

Coming out of the lesson, Ms. Scott was quite flustered. She was clearly aware that she had not followed the plan of allowing students' ideas to drive the lesson, explaining that she had seen them making mistakes and "being a

mother hen, I don't want them to struggle or get frustrated." Yet her efforts to guide students "in my direction," to her solution strategy, had lost many students. Ms. Koets (the coach) immediately positioned herself in solidarity with Ms. Scott, saying, "It's very hard. This is not how we were taught as children. This is not how we were taught when we went to teacher school, right? So it's hard sometimes to, like let the class kind of go free." She further noted that leading students to "the answer" is oftentimes "what [students] want, and what we kind of feel like we have to do," framing what Ms. Scott did as fulfilling an obligation for which teachers are often made to feel responsible. Ms. Ortiz also hinted at ways that their shared project of engaging students with challenging, open-ended tasks ran counter to customary instruction, noting that open-ended tasks could be "scary": "I can understand where I think you're coming from, because I would think that. You have less control because there's so much freedom." The group went on to examine the work students had done before Ms. Scott pulled them together. They focused their discussion on student strategies and insights that Ms. Scott could build on when she returned to the task the next day, as well as "good teacher move[s]" (in Ms. Koets's words) through which Ms. Scott had actually supported students to generate those strategies and insights, despite her perception that she had made a mess of the lesson.

Members of the group thus participated in constructing an "us" united around centering students' mathematical thinking, in explicit contrast to teacher-centered traditions in U.S. schooling. They made repeated use of the pronoun "we," especially Ms. Koets, and positioned themselves as sharing in Ms. Scott's struggles with giving students enough "freedom" to exercise mathematical agency (similar to how teachers in Math Crew positioned themselves as sharing Kara's and Maritza's struggles to notice strengths in Episode 1). Notably, Ms. Koets also explicitly disrupted interpretations of herself as an expert, saying, "We, in this, safe environment right now, I'm not evaluating you in any way. I will never evaluate any of you." She thus rejected the common framing of coaching as evaluative and hierarchical in favor of a collective "we." This developing solidarity went beyond empathizing with struggles to open opportunities for group members to learn together in service of their shared project, specifically, to grapple with the feelings of discomfort and fear that the shift in "control" from teachers to students brought out. The group framed this as a shared challenge that could and should be raised for discussion and collective sense-making in their meetings.

Episode 5: Constructing a "them" that hinders collective learning

One might assume that the solidarity Ms. Scott, Ms. Ortiz, Ms. Edmond, and Ms. Koets constructed around supporting students to engage with open-ended challenges would extend to "ALL students," in accordance with the PD program's stated vision. Approximately 30 minutes into the conversation, however, Ms. Edmond remarked that she had been looking for ways to support "higher-order thinking" and give students opportunities to "take more charge," musing that she could use an activity similar to the one Ms. Scott had just taught—but "maybe I would only do it for my higher-level groups, and not everyone." Ms. Scott picked up this idea, starting to say, "I really believe, if I took some of my higher learners and, put them in a small group—" before being interrupted by Ms. Koets, who placed her hand in front of her chest, palm toward the group, and said, "I gotta, here's, here's my pushback. I want it for everybody." A flood of overlapping talk ensued. Ms. Ortiz nodded and echoed, "Not only higher learners, yeah." Ms. Scott repeated, "For everybody," and shifted awkwardly in her seat. Three times, Ms. Edmond unsuccessfully attempted to break into the conversation to clarify her intent. Ms. Ortiz asserted, "There's an entry point for everyone," then qualified this statement, gesturing at the student work on the table and saying, "at least for this one. I've watched some other ones that have been very abstract." On her fourth attempt, Ms. Edmond gained the floor and clarified, "So my small groups are more like centers. So each student gets a chance to visit a center." Ms. Koets responded by briefly elaborating on her concern that "kids at this [low] level may never get such fun wonderful tasks, and they can do it," then quickly moving on to "teacher moves that have to happen" and cannot be done by students at centers if they work totally independently.

Instead of building an "us" around the challenge of disrupting the deficit thinking that "we were taught as children … [and] taught when we went to teacher school" (as Ms. Koets did earlier in the conversation), the group momentarily fractured. Ms. Koets interrupted Ms. Scott, limiting the group's access to Ms. Scott's sensemaking (and resources it might have contained for collective sense-making) and shifting the conversation to Ms. Koets's ideas. Furthermore, the coach framed her perspective as "pushback" and emphasized "I," not "we," putting Ms. Edmond and Ms. Scott on the defensive, physically on the other side of the small wall of her hand. Ms. Ortiz aligned herself with Ms. Koets, contributing to the construction of an "us" who believe in making rich, challenging tasks accessible to "everybody" and "everyone," in contrast to a "them" who thinks such tasks might be appropriate only for "higher-level" students. Notably, they worked to repair this rift in their solidarity. Ms. Ortiz's hedge, "at least for this one," left open the possibility that there might be other tasks where they would all agree on restricting access to "higher learners," and Ms. Koets responded with, "Yeah. Yeah." And when Ms.

Edmond finally got to speak, she aligned herself with the "everyone" camp, as though she had never considered "higher-level groups, and not everyone."

In some ways, the group's work in this lesson debrief might be considered successful. At a cross-school PD meeting a few days later, Ms. Scott shared her story of learning to give students more space to generate their own ideas, saying that she had returned to the task with her whole class and was "proud of my babies" for their breakthroughs. Collaborative coaching cycles continued at the school with all three teachers' involvement, and Ms. Koets reported that she did not hear any of them mention "higher learners" again. Yet the opportunities for teachers to engage in anti-deficit learning were quite limited and abstract. They were not able to grapple with the meaning of "high" and "low" as conceptual categories, or with the potential disconnect between specific experiences and observations that might seem to indicate that these categories capture important distinctions between students (in contrast to the Math Crew episode in which Kara opened a space to "think about how I see my students"). Indeed, the fact that these labels did not come up again in their conversations might indicate less that teachers learned something about the harm those labels could do than that the us/them dynamics in this episode—with the intense risk they presented of being cast as "them"—discouraged participants from using this group as a space for such grappling.

Discussion and implications

The episodes we have shared show that a sense of solidarity as "us" can be an important resource for teacher learning in collaborative work groups. In both Math Crew and School 53 conversations, participants invoked shared values and goals in ways that supported them to then grapple with the difficulty of enacting those values to achieve their goals in the context of systemic ways of thinking that emphasized competing values and goals and which continued to influence them, making it hard for them to see students' strengths (in Math Crew, Episode 1) and to give students more freedom to explore their own ideas and strategies (in the first episode at School 53).

We have also shown, however, that constructing an "us" that is defined by opposition to a concrete "them" can backfire. This opposition may momentarily unify (some) members of the group, but us/them dynamics can close opportunities for sense-making by emphasizing "right" and "wrong" answers, and create the potential for members of the group to slide from "us" to "them" at any time. This interferes with learning because it is difficult to reveal one's struggles when faced with the risk of being judged a bad teacher or worse, a bad person. Further research and practice could productively explore how teacher groups can be supported to build solidarity without constructing someone else as "bad." Our data suggest several strategies. First, groups might be guided to focus on the ways that deficit ideologies are embedded in institutions, structures, cultural traditions, and social practices rather than focusing on "bad" individuals. This appeared in our data when Kara referenced school as a system that operated by classifying students as "high, medium, or low," and when Ms. Koets referenced "how we were taught as children" as an obstacle to student-centered instruction.

A second strategy teacher groups might use to build an "us" without a "them" is to deliberately blur the line between "good" and "bad" teachers, allowing "good" teachers to make "bad" mistakes without becoming "bad" people. This was especially evident in the episode in which Maritza and Kara shared their failures to notice their students' strengths. Instead of responding with judgment or censure, their colleagues laughed in genuine solidarity. Together with the first strategy we described (focusing on deficit ideologies as embedded in institutions, structures, cultural traditions, and social practices instead of in "bad" individuals), blurring the good/bad binary recognizes that all of us are socialized into oppressive systems, so it is not a personal fault when those systems are reflected in our thoughts and actions—although we are responsible for repairing harm and for engaging in ongoing learning to do better.

A third strategy that may be vital for building solidarity as "us" without constructing an opposing "them" is for teachers and teacher educators to deliberately invite one another to grapple with the messiness of realizing anti-deficit goals in everyday practice. This goes beyond the first two strategies, which may be employed in ways that teachers experience as supportive (because they may foster a sense of belonging, camaraderie, and empathy, for example) but which may fall short of engendering anti-deficit learning. This strategy also clarifies that antideficit learning is not linear or something that can ever be accomplished once and for all. Such learning is not a matter of excising certain terms (like "high" and "low") from our vocabulary but of continuing to wrestle with the ways that oppressive ideologies persistently shape how we think and act.

Fulfilling the responsibility for ongoing anti-deficit learning in a world that remains strongly shaped by deficit ideologies is nontrivial. We have shown how participants in our studies created opportunities to grapple with the challenges of realizing their ideals, without having to fear that their struggles made them "bad teachers." We have also shown how constructions of "them" shrank rather than opened space for such grappling. If participants had built up an "us" without creating a "them" in those instances, using the strategies we have outlined here and which we saw them use on other occasions, they might have been able to engage in more meaningful

learning in those episodes and perhaps in subsequent interactions as well. More research is needed to further explore this possibility, but in the meantime, we hope that these strategies will be useful to other teacher groups, as they work to harness the power of collaboration to transform deficit ideologies and contribute to dismantling systems of domination, through daily teaching and (teacher) learning.

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Mobile Augmented Reality Supporting Community-based Learning: Families' Exploration of Land-Water Interactions

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Abstract: From a design-based research study investigating rural families' science learning with mobile devices, we share findings related to the intergenerational exploration of geological time concepts at a children's garden at a university arboretum. The team developed a mobile augmented reality app, *Time Explorers*, focused on how millions of years of rock-water interactions shaped Appalachia. Data are recorded videos of app usage and interviews from 17 families (51 people); videos were transcribed, coded, and developed into qualitative case studies. We present results related to design elements that supported sensory engagement (e.g., observation, touch) through AR visualizations related to geological history. This analysis contributes to the literature on informal learning environments, theory related to learning-on-the-move, and the role of sensory engagement with AR experiences in outdoor learning.

Understanding the scale of earth sciences scientific phenomena, such as geological time, is often difficult for learners (Cervato & Frodeman, 2012; McDonald et al., 2019). Geosciences educational researchers and educators (e.g., Orion & Ault, 2013; Resnick et al, 2017; Tretter et al, 2006) have used pedagogical techniques such as analogies, walking or moving through a scaled version of a time or space, or time-lapsed videos to address these challenging concepts. Additionally, the environmental crises that overlap the earth sciences, such as water quality and freshwater access, are complex— requiring understanding and solutions that integrate information across various geographic, geological, and time scales. To address these difficulties in learning earth sciences concepts, our team has been developing mobile, augmented reality (MAR) apps deployed on handheld computers (iPads, iPhones) to support rural families to learn these complex topics in outdoor spaces in their communities. This analysis focuses on one app, *Time Explorers*, that addresses geological time with an immersive MAR experience that illustrates how millions of years of rock-water interactions shaped one Appalachian community.

MAR layers digital material into outdoor spaces via devices' screens to expand opportunities for learning (Ryokai & Agogino, 2013; Zimmerman et al, 2020). MAR relies on digital resources to reveal scientific meanings not directly visible to learners (Dunleavy & Dede, 2014) in parks, gardens, and forests (Georgiou & Kyza, 2017; Kamarainen et al., 2013; Land & Zimmerman, 2015). Our immersive MAR designs focus on developing *micro-sites* (Sharples & Pea, 2014) for families' learning —drawing upon planned and emergent experiences to create science learning opportunities related to geological topics. In this paper, we ask the research question:

- How does a MAR app influence families' sensory engagement related to understandings of geological time in an informal learning environment as they participate in an immersive learning-on-the-move experience to understand the effects of millions of years of land-water interactions?

Conceptual Framework: Learning-on-the-Move and Sensory Engagement

Geological time is foundational to understanding the geosciences as it "highlights the way geoscientists tell time – a coarse time scale in which millions of years are the most common coins of currency" (Cervato & Frodeman, 2012, p. 3). Earth's geological time can be determined by observations and analyses of rock strata and the fossils the strata contain. Cervato and Frodeman (2012) point out numerous reasons that learning geological time is difficult for learners including that learners mistake the timing of key geological events (e.g., formation of mountains, landform movements), confuse the timing and distance between geological periods, and have limited understanding of the rate of erosion, deposition, and landform movements. Our research and development efforts on a MAR app influence brought together two key concepts to first design for and then analyze families' sensemaking about geological time: a) learning-on-the-move to illuminate the change in time metaphor of the app and b) sensory engagement (e.g., visual, tactile) to observe evidence of the past in the rocks and the simulated cave and rock strata on-site.

Learning-on-the-Move to Support the Understanding of Scale

Researchers study the use of mobile technologies in and around communities via the concept of learning-on-the-move (LOTM) (Marin, 2020; Silvis et al., 2018; Taylor, 2017; Zimmerman, & Land, 2022). LOTM describes a social learning process where people collaboratively learn as they move their bodies within and through spaces.

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Movement, especially gesture, has been found to be a supportive sensemaking approach in science and mathematics education (e.g., Alibali & Nathan, 2012) —including with technology (Kang, et al., 2021). Looking at movements within and across spaces, Silvis et al. (2018) investigated families' technology practices and found that mobile computers and other technologies were integrated as learning tools across sites. Taylor (2017) used ethnographic methods to explore how youths used mobile technologies, on foot and by bicycle, to understand their community as a designed, complex system.

In our case, we designed for LOTM, where people's movement enhanced our immersive time travel narrative and encouraged sensory engagement with the specimens and sculptures in a garden. Drawing from Ma (2017) who considered large-scale "multi-party, whole-body interactions" as critical in learning geometry, we designed learning experiences for families, whereby moving their bodies through a children's garden together, leveraged multiple body-place interactions to make sense of geological time. Relatedly, we built our research and design efforts from Marin's (2020) assertions that " walking and lands/waters have always been and continue to be central to human learning, development, and activity (p. 282)." Marin and Bang (2018) found questioning, directing, and narrating were key learning practices that families used to make sense of the natural world, and as such, in our designs, the team left space for families' conversations to allow for learning practices to emerge.

Sensory Engagement to Support Scientific Observations

Beery and Jørgensen (2018) note that when children play outside, their physical play includes body movement and sensory engagement. Ballantyne and Packer (2009) argue that sensory engagement is an essential part of learning in environmental education experiences. From McClain and Zimmerman (2016), we define sensory engagement as gestures and movements that foster visual, auditory, and tactile observations and gestures that create joint attention (i.e., pointing) and discussions.

Sensory engagement (through visual and tactile means) supports scientific observation (Eberbach & Crowley, 2009). Mogk and Goodwin (2012) argue that learning to observe is critical for the geosciences: "Observations in the field allow us to interpret and explain what has happened in the past (postdiction) in order to show us what is possible regarding present and future Earth phenomena (prediction)" (p. 141). We focus on sensory engagement in our study, as primarily tactile and visual observations. This includes the learners comparing the texture of sandstone and limestone rocks, feeling for marks of erosions, and observing rock layers and how they can move over time.

Method: Two Iterations of Design-Based Research

We use the iterative, qualitative approach of design-based research (DBR) approach (Sandoval & Bell, 2004). DBR advances theory related to LOTM and sensory engagement as it enhances practice related to the design of informal learning environments.

Participants and setting

Our study focused on rural families visiting the children's garden at the Arboretum at Penn State. We utilized our community partners' websites, social media sites, and listservs for recruiting. All participating families required internet access to complete online consent and participate in our Zoom interviews. We acknowledge that we only reached rural families with ample technological resources during COVID-19.

In Iteration 1, seven families living in two rural counties participated (8 adults, 12 youths). Guardians self-reported their families' racial affiliations as White (100%); two children were also guardian-reported as Other (10%). Children (female: 25%, male 75%, non-binary: 0%) were primarily 5-12 years old (92%). Two guardians were scientists; two were administrative staff. Other occupations were writer, farmer, and educator. One family homeschooled their children. In Iteration 2, ten families living in one rural county participated in the research (15 adults, 16 youths). Guardians self-reported their families' racial affiliations as mostly White (White: 97%, Black or African American: 3%, Hispanic or Latinx Origin: 3%). Children (female: 50%, male 50%, non-binary: 0%) were primarily 5-12 years old (94%). Four guardians were educators (e.g., teachers, instructors, professors); three were unemployed; and others' occupations were researcher, program specialist, homemaker, human resources staff, illustrator, CFO, self-employed, and military. Two families homeschooled their children.

Time Explorers app features and technology

The *Time Explorers* MAR experience was approximately 20-40 minutes as families completed a narrative time travel journey through the geological history of Appalachia in the children's garden. *Time Explorers* was divided into eight micro-sites organized by geological time (starting at prehistory). Guided by the GPS map, learners moved forward in time to understand how vital landforms of the area were formed in Appalachia: (a) Time Spiral (Ordovician Period), (b) Coral Sculpture, (c) Limestone Boulders, (d) Sandstone Boulders, (e) Arched Rock Wall,

(f) In-and-Out Creek, (g) Cave, and (h) Spring Basin (Figure 1). In Iteration 2, the MAR elements were the same; however, we added an AR filter family selfie at the end of the experience, a back button, made simple text edits for clarity, fine-tuned the GPS for the cave micro-site, and added a pre-interview task.

Figure 1

Flow of the Time Explorers app designed for the children's garden at the Arboretum at Penn State. Note: the AR Filter Congratulatory Selfie was added in Iteration 2.

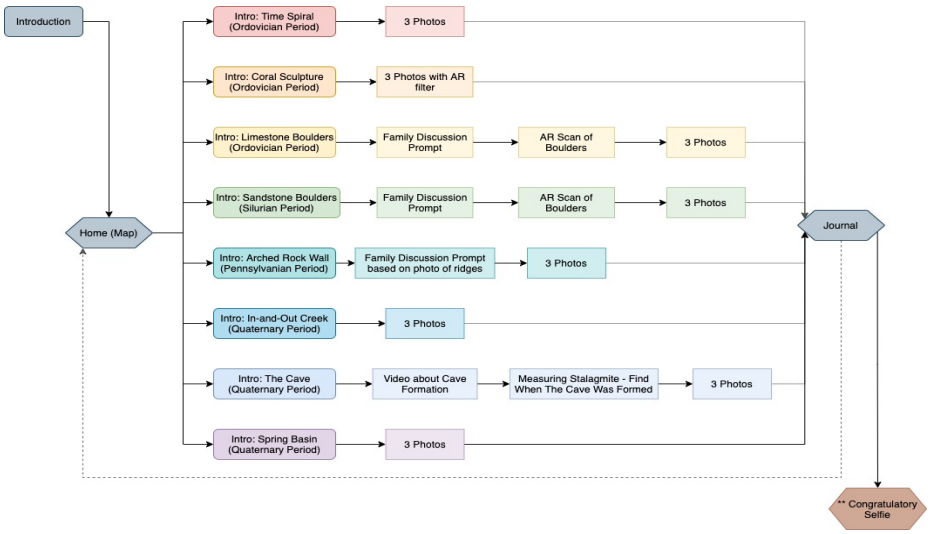
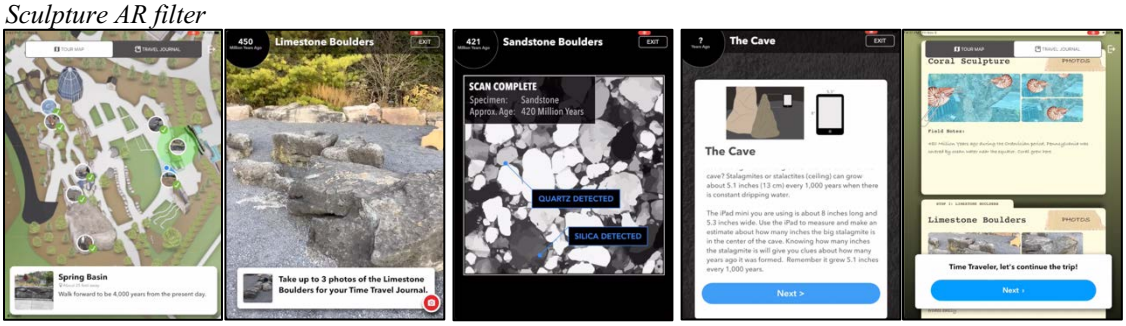


Figure 2

Screenshots from Time Explorers: a) GPS map showing completed and next micro-sites, b) photo-taking activity, c) sandstone boulder AR scan, d) Cave measuring activity, and e) travel journal with the Coral Sculpture AR filter



(2a) (2b) (2c) (2d) (2e)

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Data sources and analysis

Due to COVID-19, our data were collected with a social distancing protocol. Data include 16 families' iPad screen recordings and GoPro videos that captured their talk interactions in the MAR learning experience. One family's GoPro video and four families' screen recordings were not fully captured due to technical difficulties. Families borrowed one iPad with the *Time Explorers* app, which recorded their app interactions and talk throughout the experience. One family member wore a hat-mounted GoPro camera to record the experience in the first-person view. The screen recordings and GoPro videos were displayed side-by-side for data analysis. Additional data included 17 pre- and post-experience interviews via Zoom and 17 online demographic survey responses. In Iteration 1, the pre-experience interview included questions on how ridges, valleys, and caves formed and if the family had prior experience with caves. The post-experience interview included a) the same two questions, b) a drawing task which asked the oldest child to draw how ridges, valleys, and caves formed, and c) the family's overall impression of the app. In Iteration 2, we also included a) the drawing task in the pre-experience interview, b) questions related to how caves formed and how water shaped the landscape, and c) one question on whether the family had ever seen similar landforms. The drawing task was completed by the families' eldest child (with

any younger children having the option to also complete a drawing). The eldest child explained the drawings first, followed by a family discussion.

To analyze how families used sensory engagement and learning-on-the-move to make sense of the geological prehistory, we conducted a qualitative analysis of the screen recordings (thirteen whole and two partial) and GoPro videos (sixteen full) at the unit of analysis of the family (defined for our study as at least one guardian and one child aged 5 to 12). To conduct interaction analysis (Jordan & Henderson, 1995), the authors held co-viewing sessions to watch all screen recording and GoPro videos together (after the videos were professionally transcribed). Codes were applied to the video records by two authors to compare and contrast the families' experiences. Based on the IA session notes and coding spreadsheet, we selected three cases on how the MAR app influenced sensory engagement for this manuscript. To further analyze the three focal cases, a line-by-line analysis of the transcripts occurred, which highlighted how families' sensory engagement (verbal or tactile) was connected to verbally stated observation of hydrogeological phenomena or explanation of geological history at each micro-site. To understand the three case study families' learning outcomes, the drawing tasks from each family were analyzed to understand any changes in learning of water-rock interactions over geological history. Finally, to enhance our data analyses' trustworthiness, the team conducted co-viewing sessions, shared notes, and multiple researchers double-checking transcripts and codes.

Results

Overall, the families who engaged with *Time Explorers* successfully navigated through the learning-on-the-move time travel metaphor to move their family through the garden on a time walk from the Ordovician period to the present day. Families started at the time spiral and had an app image that moved them through key landforms that represented different periods of geological time, used the app resources to place the landforms in their appropriate geological time, and engaged in sensory engagement (primarily tactile and visual observations) to support their understanding of the formation of the Appalachian landscape.

Case study 1: MAR app supported sensory engagement without being a distraction

Given the digital technology, our team examined if our MAR materials supported geosciences-related observational engagement in the children's garden without distracting the families. We found the mobile computers did not dissuade families from engaging with sensory exploration in the outdoor learning space. During the AR experience, Tanya (Mother) and Oliver (11-year-old boy) engaged in sensory observations of the features representing the landforms. For example, at the Sandstone Boulders, following the display of a prompt, the family walked closer to the rock and touched it:

Tanya: What do you see? ((touches sandstone))
Oliver: It's smoother, and it's flatter than the other one [refers to Limestone micro-site] ((touches sandstone)). It has little dents in it. (Figure 3)
Tanya: They are picked apart in some areas ((moves a finger to an indent)). Feels bumpy and almost like sand a little bit, right?
Oliver: Mhmmm (affirmative). ((touches the indent))

Figure 3
Screenshot of the Sandstone Boulders (left); Tanya and Oliver observing the rock

Tanya and Oliver actively engaged in a visual and tactile exploration of the rock's appearance and texture caused by erosion as they moved their fingers across its surface. Tanya used her body to guide Oliver where to touch the rock and look for the evidence of erosion. Additionally, Oliver compared the last limestone micro-site to the current sandstone micro-site as he compared the rocks that formed in different geological times.

Comparing Oliver's pre- and post-experience drawings (Figure 4) and responses in the interviews, Oliver adopted scientific vocabulary related to changes in the Appalachian area over millions of year (e.g., his language moving from terms such as "jagged" rocks and mountains to terms such as limestone, sandstone, ridges, and valleys). For example, in the pre-experience interview, he included a local mountain, a river, and some houses in his drawing (Figure 4, left), and when asked how caves were formed, he said tectonic plates formed caves; whereas, in the post-experience drawing (Figure 4, right), he noted a cave was eroded by water over millions of years. Oliver demonstrated a clearer understanding of what and how natural forces (i.e., water eroding rocks over a long time) shaped his community's present-day landforms.

Figure 4

Oliver's pre-experience (left: long ago and now) and post-experience drawings (right: long ago and now)

Case Study 2: Learning-on-the-move allowed families to integrate complex information about geological historic periods across the micro-sites of learning

Our team designed for LOTM to allow for the geological time walk, anchored by MAR elements within the app. As they moved through the children's garden, families built knowledge about how Appalachia changed over geological time, as they connected information from different micro-sites of learning to see that Pennsylvania was under water millions of years ago. One example of this comes from one family, Jennifer (Mother), Amanda (Mother), Izzy (11-year-old girl), and Ethan (7-year-old boy):

Izzy: Look at this photo about ridges flowing. ((reads)) "Talk about what you learned." Let's talk about what we've learned. Sandstone. ((gestures toward Arched Rock Wall micro-site)) It's made of sandstone and limestone.
Amanda: Sandstone is made of sand and silica.
Izzy: Quartz and silica. [connects to Sandstone MAR micro-site content]
Amanda: Oh. Quartz and silica. Thank you. (…)
Jennifer: Ethan, do you remember what limestone is made from?
Ethan: Sand. ((touches arched rock wall))
Jennifer: Nope. Close. It has to do with the sea. [references Coral Sculpture micro-site content]
Izzy: Carbon — no
Ethan: Coral!
Izzy: What is coral made of?
Jennifer: It's sea creatures.
Amanda: Calcium. [connects to Limestone MAR micro-site content]

This case illustrates how the LOTM experience encouraged the family to connect information across the garden — synthesizing information from four MAR micro-sites together at the (human-created) Arched Wall, which simulated the strata of limestone, sandstone, and other rocks. Izzy, Amanda, Jennifer and Ethan discussed the connection of the sandstone and limestone in their community today (that makes up the visible ridges and valleys) to the prehistoric oceans (with coral) that covered Pennsylvania millions of years ago.

Similarly, Izzy's understanding of how Appalachia changed over geological time also shifted from the pre- to post-experience interview, illustrating her connecting multiple micro-sites and times from the immersive experience. Describing her pre-experience drawing (which both contained mountains, trees, and a river (Figure 5, left)), she said: "I would say that the land hasn't changed too much, except for the humanity that has come to, um, destroy everything in its path." Her post-experience drawings, however, show her understanding of how the land has changed over geological time as shown through multiple micro-sites in *Time Explorers*: "mountains from plates pushing the other, and trees, and rivers from erosion" (Figure 5, right). The difference in her descriptions and drawings of how Pennsylvania has changed over geological time demonstrates that she gained an understanding of how water, rock, and tectonic plates influenced Appalachia over millions of years.

Figure 5

Izzy's pre-experience (left: long ago and now) and post-experience drawings (right: long ago and now)

Case Study 3: Discussion prompts and photographic features of the MAR app encouraged talk about how geological history changed the community landscape

The discussion prompts and photo-taking activities in *Time Explorers* facilitated families' in-situ science observation. For instance, in response to the discussion prompt "*Look closer at limestone boulders and talk about what you see*," Helen (Mother), Noah (11-year-old boy), and Jesse (9-year-old boy) collaboratively observed the limestone rocks.

Jesse: ((kneels and touches the rocks)) I sort of see... Is that rust? (Figure 6a)
Noah: Yeah. It looks like some.
Jesse: It looks like rust or copper.
Helen: I think there's something growing, don't you think, Jesse? It just happens to be that color.
Noah: Yeah. It looks like this is probably what—maybe calcium? Something that definitely has hardened over time.

Later, Helen walked and pointed out another rock that had cracks on it (Figure 6b), which gathered the boys closer and led them to discuss the hypothesis of water and rock interaction in the past created the cracks in the present time:

Helen: Okay. ((walks to the right)) What do you think these things are? ((points at another rock)) (Figure 6c)
Noah: I think those were pools of water.
Helen: Are these fossils?
Noah: ((walks to the right side of Helen)) No, I think those are pools of water. Just like really like — grew.
Jesse: Yeah, because pools of water make cracks like that ((points at another rock and walks around the rock)). (Figure 6d)

Figure 6

Helen, Jesse, and Noah use the family discussion prompts embedded in the app to notice cracks in rocks to understand that water and rock, together shape how Appalachia has developed over millions of year.

(6a) **(6b)** **(6c)** **(6d)**

In the process of discussing the prompt, the family shared their observations of the limestone rocks on-the-move. Walking to different spots around the Limestone Boulders, they first shared their observations of interesting rock textures aloud then collaboratively built different hypotheses of how the cracks on the rocks might form over geological time by drawing upon each other's observation.

In addition to the discussion prompts, the photo-taking activities embedded in the app also supported families to apply the augmented information to their observation in-situ. For instance, while Jesse was taking photographs at the In-and-Out Creek at another micro-site, Noah walked around a simulated stream to find evidence that represented water eroding limestone rocks to create water gaps:

Noah: Come over here! There's something you got to see. Look, you can see how there — it's very eroded. ((Helen and Jesse walk to Noah))
Helen: Isn't that cool?
Noah: It's very eroded in that area. ((points to the rock))
Jesse: It looks like it has three layers. ((takes a photo))

The photograph-taking activity supported the family in noticing and observing rock features that matched what they learned about water gaps from the app earlier. Through taking photos, the family made collaborative observations. Though Noah was not holding the device to take photographs, he was actively participating in the learning process as he constantly moved around, looked for evidence, and shared his observations aloud with Jesse and Helen. This pattern was commonly seen across families with more than one child, where parents and siblings took turns taking photographs and helping each other locate interesting, picturesque spots.

Discussion

Theoretically, our work further conceptualizes the role of the LOTM social learning process in an outdoor learning environment. Prior work sought to understand naturalistic perspectives on LOTM with technology (Silvis et al., 2018; Taylor, 2017) and without (Ma, 2017; Marin, 2020). In our study, we designed the *Time Explorers* app with LOTM principles, so LOTM became a pedagogical tool used to advance the geological time narrative. By moving through eight micro-sites representing eight different geological times in a children's garden, families relied on a time travel narrative to support their temporal understandings of complex geosciences concepts. Both the families' talk in situ and the families' pre- and post-experience drawings (e.g., Figures 4 and 5) provide evidence of the LOTM experience allowing participants to understand how water-rock interactions shaped community landforms over millions of years.

The case study analyses illustrated how MAR can support family conversations that integrate complex hydrogeological concepts throughout the learning experiences. The prior research (e.g., Cervato & Frodeman, 2012) has shown that developing geosciences understanding can be challenging; however, families in our study nonetheless connected multiple MAR micro-sites (i.e., Jennifer, Amanda, Izzy, and Ethan) to build complex understandings of how water, sandstone, and limestone interacted to create their community's present landscape.

Given the importance of sensory observations in outdoor learning (Ballantyne & Packer, 2009; Beery & Jørgensen, 2018), we found evidence that using the MAR app encouraged sensory observation in the children's garden with the digital content supporting, not distracting, families' outdoor explorations (i.e., Tanya and Oliver). The app's prompts suggested that families compare and contrast textures of limestone and sandstone rocks and find and discuss the visual evidence of water gaps, patterns in rock strata, and erosion. All the families in the study engaged in tactile and visual sensory engagement during the observation of concepts related to Appalachian geological time in response to the *Time Explorers* prompts and activities.

Finally, our analyses elucidate how the MAR app's photo-taking activities and discussion prompts could be successful tools in an app designed for rural families' outdoor learning (e.g., Figure 2 and Noah, Jesse, and Helen). While photo-taking and discussion prompts have been used in informal spaces in prior work, our research adds to the utility of these tools while LOTM during outdoor education experiences and to support geosciences observations. Prior literature reviews (Eberbach & Crowley, 2009) found little evidence of people recording and referring to observational notes when engaging in out-of-school-time science. Here, the families used photographs to capture and conversations to reflect on their observations as they moved through a children's garden; these tools were easy to deploy on a MAR app and quickly taken up by families.

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Infrastructuring for justice: Reframing scale through a rightful presence framework

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Abstract: A challenge inherent in infrastructuring for justice lies in how existing structures and foundations that anchor education and educational reform enterprises are rooted in White Supremacy and heteropatriarchy, given their historical dominance in the disciplines, schooling and society. Drawing from justice-oriented studies of reform, and rightful presence centered participatory design-based research in long-term research+practice partnerships (RPP), we argue that infrastructuring for justice-oriented reform is contingent on scaling allied, sociopolitical activity systems in schools. Infrastructuring for justice requires on-going resistances, disruptions and transformations of existing structures and foundations that anchor educational research and reform. The objects of reform need to shift to the scalability of new relationalities from the scalability of products, tools, and ideas. Such new relationalities should be viewed as the new foundations for infrastructuring reform, with attention paid to the political clarity necessary for the conditions that make such justice-oriented reform possible.

Introduction

Justice-oriented studies of educational reform critique how current organization of educational infrastructures erase the experiences and practices of children/youth and communities in favor of schooling and disciplinary knowledge. A challenge inherent in infrastructuring for justice lies in how existing structures and foundations that anchor educational research/reform enterprises are rooted in White Supremacy and hetero-patriarchy, given their historical dominance in the disciplines, schooling and society. While it might be possible to infrastructure by building on technologies and practices that already exist (Bødker et al., 2017), the work entailed in infrastructuring for justice lies in the "redesign of components, relations, and routines" (Penuel, 2019, p. 659) towards disrupting injustices reproduced by existing systems and structures. We contend that systemic injustices are widespread, historical and enduring. Systemic injustices are not homogenous but rather, are made manifest via contextualized, local practices normalized as benign. Before we can infrastructure for justice, identifying such normalized unjust practices and structures – what they are, how they work, how they might be disrupted, who needs to be involved and in what ways – is necessary. Building on theories of critical justice and the rightful presence framework for teaching and learning (Calabrese Barton & Tan, 2020), *in this paper we argue that infrastructuring for justice is contingent on engaging in sustained, allied, sociopolitical activity systems in schools.*

Infrastructuring Educational Innovation

What and when is infrastructure?

Infrastructuring for educational innovation has become an important focus of reform efforts. As a theory useful for helping the field make sense of educational innovations – including their design, enactments, spread and scale – infrastructuring has become a useful lens for designing for conditions necessary for reform to take hold (Penuel, 2019). Penuel (2019), drawing upon Star (1999), describes infrastructuring in education as the coordination of the components of systems of practice, such as standards, curriculum, assessment, policies and organizational routines, that educators, school leaders and researchers collaboratively use to accomplish their work. Such coordination brings these varied components into relation with each other with directionality or intention. Thus, it accounts for the systems that are already in place that shape practice, and the possibilities for sustaining it. Infrastructuring, or a lack thereof, also helps to explain why, even when innovations are successful, they often do not last beyond the "hothouse" conditions under which they are typically introduced (Penuel, 2019).

A critical part of infrastructuring for sustained innovation involves redesigning infrastructure in ways that support the goals of innovation. For example, Hall et al. (2021), in their efforts to design for coherence in the implementation of the Next Generation Science Standards, across three crucial networks – mentor teachers, district specialists and assessment specialists – show that infrastructuring redesign involved not only identifying useful resources and frameworks related to the NGSS, but also fostering collegial workspaces for sharing experiences, challenges and needs as forms of productive professional learning. Such redesign work can be fraught with tensions, however, especially when innovations seek to disrupt inequalities. Studies have shown that this friction often results from both the efforts to design for and insert missing components of infrastructures,

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especially in contexts historically underserved by society's social structures, and also in the negotiation how these new components work within coordination with other components. Equitable implementation of innovation requires a more "proactive stance toward infrastructure redesign," by "allocating more and targeted resources to schools and teachers than might be provided to schools with more privileged students" (Penuel, 2019, p. 670).

Prost et al. (2019) report on one community-university partnership sought to infrastructure for food democracy. They demonstrate how the partnerships efforts initially focused on designing a food hub, a missing components of the local food infrastructure, then shifted to redesigning how the food hub worked in coordination with other structures, through establishing new coalitions and new spaces for connecting with community around the food hub, and designing new practices for how the food hub use could expand in the community. Like Hall et al., (2021), relationship building across networks, including spaces for doing so, were critical to integrating new components into existing structures. However, integration efforts were disrupted when differences arose over the direction of the project between the baker, who wished to focus on expanding their food hubs, versus the community center, who wished to improve the prototypes' operation through engaging the local community more deeply. These differences reflected different priorities and social positionings within the infrastructuring efforts.

This kind of tension is similar to the challenges that teachers in a participating school faced when their reform-oriented science lessons were observed by district leaders using a routine observation framework (Penuel, 2019). This framework did not recognize the inquiry work required of such reform, and some participating teachers received low scores. This friction made visible the different priorities of different stakeholders as they sought to integrate educational innovation into existing structures. RPP members redesigned the infrastructure to make space for new visions of what classroom teaching could look like, for example, by creating new resources that linked the routine observation framework to inquiry and by creating new routines involving district leaders to leverage these resources in coaching science teachers. Such negotiations involved developing new components of infrastructure, such as the new tools, as well as practices for when/how such components are enacted within a coordinated ensemble, such as how district leaders leveraged these tools in support of instructional improvement.

Thus, infrastructuring is also about asking "*when*", in tandem with asking "*what*" in the sense that infrastructures are dynamic interactions (Penuel, 2019). Of concern is how these components serve educators and students well more so than only whether such components exist. When infrastructures are working well, they largely go unnoticed (Hall et al., 2021). *However, since existing western schooling infrastructure is built to work for students of the dominant culture, there has been little need historically to trouble existing, foundational infrastructure, even as minoritized students have simultaneously been historically underserved by said infrastructure.* While the limited resourcing that make up the components of an infrastructure may be critical, the nature of the infrastructure itself should be called into question. *We thus further conjecture that a central question should be "who" is infrastructure, and to whom is infrastructuring useful? Whose interests does it serve?*

Who is infrastructure?

Asking the question of "who" calls into focus how infrastructuring is both embodied and historical. What we mean is that teachers and students experience how systems of practice are coordinated toward particular goals and outcomes in the present, with the materials, tools and approaches legitimized by a system that is rooted in Whiteness and heteropatriarchy. Justice-oriented reform cannot succeed if the very structures in which such reforms are enactment are themselves not called into question.

We find urgently important that infrastructuring shifts attention from the portability of materials, tools and ideas for the sustainability and scale of innovation to "a kind of mangling of innovations within varied educational contexts." Yet, mangling of innovations within entrenched structures, even when such efforts seek to redesign components of these structures, do not explicitly or even necessarily call into question the histories of practice and of people that live within, sustain and benefit from existing structures. To seek social innovation without the transformation of existing structures leads to bounded justice (Creary, 2021).

We came to ask this question of *who is infrastructure,* through our decades-long RPP involving schools, community organizations, and universities. As we sought to infrastructure for social innovation in classrooms and schools, we were confronted with the same kind of fraught tensions noted by Penuel and others, making visible fundamental differences not only in the priorities of the social innovations and the existing schooling structures, but also in the underpinning ideologies. Competing priorities tied to differentially powered stakeholders produced injustices that unfolded in micro-moments, played out through normalized school practices. Surfacing such root causes of injustices is challenging because they are hidden as the supposed benign structures of schooling. To make visible such structurally normed, unjust practices, we turn to the rightful presence framework.

The rightful presence framework was informed by empirical data from long-term research-practice-partnerships (RPPs) in middle schools and local communities across two states. We sought to have a different way to make sense of when and why innovation led to more just and sustained outcomes, and when it did not.

Three, imbricating tenets undergird this framework: 1) Political struggle is integral to disciplinary learning through asserting the right to reauthor existing rights (mired in injustices that are normalized); 2) Exposing injustices and imagining new, just, possibilities are germane to rightfulness; 3) A collective disruption of norms are necessary and contingent on allied political struggle demanding engagement from the powered and oppressed. In short, we learned that new sociopolitical activity systems are needed in order to infrastructure for justice. They involve a range of stakeholders who collectively acknowledge unjust powered dynamics that have always been at work in schooling, who work together to perturb such dynamics towards more just ends.

With the rightful presence framework, infrastructuring for justice brings into focus not only the *when of infrastructuring*, but the *who of infrastructuring*, as related to troubling established practices in schools related to teaching, learning and being. Such modes of transformation necessitate taking up new practices, with stakeholders (teachers, students, school staff, administrators, community members) taking on new roles, that has implications for how existing roles and practices might shift to transform who and what schooling is for.

Infrastructuring for justice

Justice-oriented infrastructuring seeks to redress injustice by creating new conditions to support innovative and political organizations, resistances, and transformations within systems (Bang, 2020). Deepening the definition of infrastructure in this way questions the dominance of the power-holders who built structures of practice and interaction (Dantec & DiSalvo, 2013). Infrastructuring to redress injustice must create new conditions to support innovative and political organization and disruptions within systems (Bødker et al., 2017). To take seriously a political view of infrastructuring questions the dominance of the power-holders who built structures of practice and interaction. It opens up possibilities for considering porosity, movement, and transformation to allow for democratized actions and redistributions towards ideals of justice. Infrastructuring, thus, does more than mangle new innovations with existing infrastructure of systems. It offers new tools and access points into the system for critiquing foundational systemic assumptions and designs. Infrastructuring for justice provides key insights into how scale can be sought for with justice-oriented reform interventions. We present two key points.

1. A focus on the sustainability and scalability of new relationalities

New relationalities

Infrastructuring for justice, with its focus on conditions necessary for scale and sustainability, calls into question the object of reform. Infrastructuring for justice requires on-going resistances, disruptions and transformations of existing structures and foundations that anchor educational research and reform. We suggest that sustainability and scalability should focus on *new relationalities – anchored in the Who and When of infrastructure* – rather than on products, tools, or even ideas. Such new relationalities should be viewed as the new foundations for infrastructuring education innovation, with attention paid to the ethical and political clarity necessary for the conditions that make such justice-oriented reform possible. By new relationalities we mean a practice of how we understand ourselves, others, and things, such as structures, in relationship to each other and to context, in the present and historically, as mediated through power and possibility.

This work requires careful attention to the power-mediated tensions that arise as people, ideas, and histories come into contact, along with the critical awareness and reorganization of power relations that necessarily results. It is a kind of political work imbued with political clarity and relationship building for cultivating critical awareness on racial and social injustice (Madkins & McKinney de Royston, 2019), but also oriented towards action and accountability. This kind of justice-oriented praxis of infrustructuring refuses separation of the past from the present and the possible future (Tuck, 2009). It also demands the kind of critically aware action taking that is linked to accountability in the sense that local actions make history, and have social and political consequence (Calabrese Barton & Tan, 2019).

New relationalities, anchored in rightful presence seeking allied sociopolitical struggles, are critical to re-imagining how infrastructuring for justice shapes the trajectories of reform. Such a mode of engagement reframes the work of infrastructuring away from the scalability of ideas, tools or products towards relationalities, which form the new foundations for building justice-oriented infrastructures. Scalability often hinges on "something" – a tool, model, product (e.g., recommended "best practices") – rather than on the interactions and relationships these products mediate among people and the broader organizational, political and social contexts in which reform happens. What goes to scale is designed to be flexible enough to translate across settings with the goal of broad reach. Scalability is deemed successful when such products are taken up by large numbers with fidelity. However, when a product is streamlined for transferability and scale, even when replicability is the goal, some features are reduced while others are amplified. What gets amplified inadvertently hews to the established norms operating in society, across institutions, as teachers are inclined to approaches most familiar to their

established practices, foregoing deeper and disruptive pedagogical shifts for surface enactments (e.g., bounded activities, classroom materials) of reform (Coburn, 2003). In school settings, such established norms are typically undergirded in White Supremacy and heteropatriarchy. Given the systemic nature of these norms, the "common denominator" to which scalability goals adhere are the established powered norms across settings. When scalability is dependent on maintaining unjust power dynamics across settings, scalability becomes a means by which unjust power dynamics are maintained and reproduced. We build on Coburn's (2003) notion of the depth of scaling reform. We echo her assertation that beyond taking up discrete reform products, belief systems that inform norms and practices need to be likewise shifted. When lensed with rightful presence, we contend that such deeper shifts occur via allied sociopolitical struggles as legitimate classroom and school activity systems.

Infrastructuring is a long-term and future-oriented process. It needs to account for the relational work that unfolds in participatory processes, as projects shift in direction, involve new people, and develop over time, as new power dynamics are struggled for collectively through the reauthoring of rights that amplify community voices and foster community agencies. Relational work takes shape in efforts to disrupt and transform institutional relations and practices, where the locus of power/ownership shifts towards community. This happens, in part, through evolving and expanding involvement of stakeholder in an RPP partnership, especially participants who have typically not been included, such as parents, staff from community partner institutions, youth, teachers, and the range of roles undertaken. Widening the range of stakeholders and expanding the roles within stakeholder profiles are the processes through which unjust power dynamics that have historically been at work in society and across institutions can begin to be disrupted. To identify such, researcher-embedded research practice partnership work is a robust way to unearth the forms and functions of normalized (and thus hidden) unjust practices.

Enacting in practice: Vignette from our RPP

Consider how middle school science teachers learned how to become critical witnesses of youths' STEM-related lives outside of the classroom, thus forming new relationalities with youth and with STEM. A design decision we made as an RPP at the beginning of a 5-year project focused on designing tools for middle grades engineering, and that built groundwork for new infrastructuring work, was engaging in co-design of reform-based classroom teaching and learning tools with teachers, youth and community educators in community spaces, using pedagogies of *being with* (Villenas, 2019). As we developed a teaching framework for engineering for sustainable communities with engineering design challenges, we spent time together, being with, weekly, after school, in STEM club spaces at partnering community centers. We foreground *being with* as justice-driven embodiments of mutualism and trust that occur along the powered-boundaries of race, class, gender, education, age, and geopolitical locations. *Being with* is conceptualized as intentional social activity, involving critical relationalities and practices of witnessing that seek to understand/disrupt normative power hierarchies that precipitate inequitable processes of partnering, both in the here-and-now and towards imagined futures.

Sessions took place 2-hour blocks, weekly, after school at the participating clubs, and involved activity structures that supported teachers, youth, community educators, and researchers in engaging STEM together, sharing ideas/stories, giving critical witness to others' experiences, expertise, and hopes for STEM in their lives and communities, especially across difference, and co-designing teaching and learning tools that drew upon insights from dialogues. We spent time collaboratively enacting and reflecting on co-designed tools, with stretched out enactments in these afterschool spaces, allowing for maximal time for in-the-moment and ongoing refinement of tools from multiple perspectives. This process supported collaborative construction of teaching tools that were co-owned by teachers, youth, and community, and created new spaces for teachers and researchers to build relationships with youth and community members, over time and through shared activities, hosted on community turf, thereby engaging in a version of intergenerational relations and learning.

Two teachers, Ms. D and Ms. L, reflected on how they saw their students "in their element" at a community-based STEM club instead of in their school classrooms. Both teachers spent time as community members participating with youth at a community-based STEM club that focuses using STEM as a tool and resource to address injustices in youths' everyday lives. Examples of prototypes included a 3 foot, 50 piece geodesic playdome with solar-powered LED "reading lights" that two middle school girls built for their friends in response to the lack of play structures at the community center. The teachers were "blown away" by the sophistication their students displayed through in building engineering prototypes to address community identified challenges. Ms. D marveled at "how creative the students are when they have time" and their understanding of community issues, which she opined she "would have never seen or known from interacting with them just in the classroom". Both teachers asked, "How do we do this in the classroom?" Explicitly inviting social concerns as legitimate school-science concerns was not the norm in Ms. D and Ms. L's middle school. The lack of play structures at a community club serving children as a STEM issue, a community issue and a justice-related issue (one youth said, "kids need to play, kids need to move!") became apparent to the teachers as the project unfolded.

This kind of infrastructuring builds critical groundwork for scalability that works *from and within community histories and experiences with schooling/STEM*. It emphasizes teacher and youth participants as people who contribute to reform by bringing concerns to bear, situates knowledge production and practice within local contexts in ways that give witness to teachers' and youth's experiences, and contributes to the improvement of conditions for teachers and youth. By integrating the ideas and experiences of school and community educators and researchers with youth, more relevant and sustainable results arise for research, practice and local communities. Oliver (2001) writes, "We are obligated to witness beyond recognition, to testify and to listen to testimony, to encounter each other, because subjectivity and humanity are the result of witnessing" (p. 90).

Critical witnessing is a kind of being with that demanded a critical openness to multiple perspectives that disrupted and repositioned taken-for-granted binaries such as expert/novice and insider/outsider. Ms. D and Ms. L learnt through direct observation, youth and communities' "live and current" justice-related concerns that were integrally tied to the nature of STEM engagement. What STEM is, to whom, the reach of STEM, what STEM can be and the outcomes of STEM, in short, the nature of STEM along its epistemological, ontological and axiological axes, were called into question and reconsidered. Engaging in critical witnessing broadened the horizon of the teachers regarding the boundaries of where, who, when, youth live STEM-engaged moments in their everyday lives. The community club, during after-school hours, with stakeholders that include various community members such as friends, club staff, parents, after-school teachers, were all key players in STEM. On the literal turf of the community STEM club, rightful presence allied political struggles were practices stakeholders were engaging in.

2. New political allyship towards rightful presence

Political allyship

Infrastructuring for justice requires attention be paid to how innovations support new political allyship towards rightful presence through making visible particular local injustices and possibilities. Infrastructuring work, then, is about making potential futures visible, debated, and acted upon. This includes focusing on how participants at various organizational and political levels (youth, parents, teachers, school leaders) are afforded ever expanding opportunities to act both in the present and in future activities, across spaces and scales of activity.

From a rightful presence framing, scalability needs to be twinned with sustainability, not replicability, given the very local and contextualized nature of unjust practices that require disruption and reimagination. By sustainable we mean how insights and processes, as well as design results, may be continually activated and expanded across scales of activity – time, settings (horizontal) and levels of power (vertical). If we consider how, in a justice-oriented RPP, sustainability needs to rest on communities, once justice-oriented infrastructuring is put into place, then communities should be sustainably supported to solidify new hybrid practices that center community voice and desires. For example, when parents and teachers find a way of collaborating productively together (with solidified logistical and activity-based infrastructure), the "new practices" the RPP have seeded have a higher probability of becoming the new norms that are more justice-oriented and locally-grounded.

Sustaining social innovation relates not only to how the intervention itself is appropriated in use, but also how participants at various organizational and political levels (youth, parents, teachers, school leaders) are afforded opportunities to act both in the present and in future activities. As new people work together, across communities, and intergenerationally, and people not ordinarily involved in reform design work together, they expand their understanding and opportunities for action in relation to both people (e.g., the experiences, resources and understandings others bring and how they relate to them) as well as the design context itself (e.g., what the problem space is, how we work together to address it). Penuel notes, "Interventions themselves are contested spaces, filled with tensions and resistance from a range of stakeholders" (Penuel, 2019, p. 21). Foregrounding relational design work as integral to scalability is important because it centers the messy, political, and sometimes contentious work of participatory reform processes, especially those processes meant to disrupt systemic forms of power. We see such relational design work – another form of allied political struggle between researchers, teachers and youth – as equivalent to building new justice-oriented foundations as a part of infrastructuring that disrupts White Supremacy. It is through such struggles that ownership of the more just and new practices is cultivated and deepened within the insiders of the community with power (e.g., teachers, school staff and administrators) that sustainability of the reform might develop and settle.

Enacting in practice: Vignette from our RPP

In the next example, which took place five years into the design work described in the previous example, we focus on one teacher, Ms. B. She was in her third year enacting pedagogical tools focused on community ethnography as pedagogy in her 6th grade classroom. In a unit focused on engineering for sustainable communities, Ms. B's students had opportunities to engage defining authentic problems that they felt their classroom communities faced in relation to sustainability. They were learning to use engineering practices and core

disciplinary ideas focused on energy systems to design solutions to these problems. Integrated into the design process was explorations of the needs and expertise of their local community as students sought to design and build solutions that could actually make a difference in fostering a "happy, health and just classroom" (Ms. B). Students were given the challenge of designing for a sustainable classroom in ways that leveraged their developing STEM knowledge (energy transformation, sources, and environmental impacts), community knowledge (issues that matter, to whom, how and why). The class spent 3 weeks on the design investigations, prototyping, testing and refining process.

During the design process, students used community ethnography to identify several key challenges to sustainability they felt their classroom faced, including students being tired and cranky in school, the need for more opportunities to celebrate and value each other, and a need for more fun and joy in learning. Student groups designed a wide-range of solutions that could be integrated into the routines of their classroom: a light-up interactive art board, where students could draw and pin their art for others to enjoy, light-up games to be used during free time or when the class is feeling stressed, and a light-up joy box group to be used in the school's social workers office as another tool to support students navigating hard emotional times, and Marble Drop engineering design, an innovative one-person game that supported players in completing a marble maze and lighting up the board to celebrate. All projects used either handcrank generators or solar panels to power them.

By several key accounts, the implementation was successful. Students expressed enjoyment. Authentic projects were successfully completed. Students exhibited mastery of the science and engineering learning goals (Tan, Calabrese Barton & Benavides, 2019). However, several weeks after implementing this unit, Ms. B discovered that some of her students were frustrated that their designs were not actually being used to address their community concerns. Students' designs were meant to make their school happier, healthier and more just, while also leveraging green technologies in support of the environment. Mrs. B was an expert in teaching this unit she helped co-develop, and had taught it during three consecutive academic years.

Consider for example, two groups who shared with Mrs. B and their classmates that their designs were not being used as they hoped. The Joy Box group created their original design to be used in the school's social workers office as tool to support students navigating hard emotional times. The students worried their design was "useless" when they realized the school social worker could not use it because her office was too small. Another group wanted to support other students in having chances to have more ways to calm down when they created the Marble Drop game. This design was an innovative one-person game that supported players in completing a marble maze and lighting up the board to celebrate. The boys who made this design knew that having opportunities to take their mind off whatever was triggering their anger was a calming coping mechanism for them. However, the students noticed that it was not kept in the common library space like they imagined but was in a closet instead.

While Ms. B could have considered the engineering design unit a success if she only evaluated the designs based on the required STEM goals, she instead gave critical witness to their concerns. She hosted a conversation in STEM class on why the projects were not working, and what they students wanted to do about that. Bringing ideas back to the RPP, she worked with researchers, partner teachers, and school personnel, to design and enact new structures to support students in further optimizing their designs to better meet their goals for classroom sustainability. First, she supported students in defining *what the success criteria would be* for their engineering designs by asking questions such as: "How can you tell if your engineering design is meeting your goal?", "Who should be using the design?", and "How often should the engineering design be used?". She then supported students in using tools such as *observations and community interviews to evaluate their engineering design's success and make plans to improve their designs to address the issues that mattered to them*. Ms. B extended the unit so that students could refine their goals and designs. She also engaged students in considering the social contracts that might be required to organize for new school routines around their designs.

Ms. B also created space for students to connect with a range of stakeholders to discuss ideas on why their projects were not working and possibilities for revision. The creators of the Marble Drop game interviewed the school's administrative assistant to get permission to store the game next to her desk and encourage students who were sent out of their classrooms for "disrupting" class to play the game as a way to calm down. In response to their conversations, they created written directions for students to follow which included these two tips: "Fact: Hand crank can go both ways." and "Fact: Do not take marbles."

For the Joy Box, Mrs. B supported the group to collaborate with school personnel to better address their goals. Students worked with the social worker to develop a social contract on how and when the joy box would be used. The students sent letters to each teacher in the school explaining how the Joy Box works. They went to each classroom to present the Joy Box and answer questions. The school community put the Joy Box to use as a result. Both students and staff placed positive messages in the hand crank-powered light-up Joy box weekly. While in use, the group delivered the messages to each classroom while lighting the Joy Box. Students described having their "hearts feel warm" as the schoolwide positive message delivery system was used by the community.

Ms. B. recognized students' assessment of their under-utilized engineering designs as a bid for rightful presence. As Ms. B described, it was that the youth were disappointed that their initial designs to address issues that mattered to their school communities fell short of *their* desired outcomes, which were to feel joy, to warm hearts, and to care for each other, although this was important to her. It was also that she began to question what authentic designs really were: "We actually had to change things. To say, you know, this isn't working here. There is something wrong. If school has taken away the joy because you can't get recognized or whatever a kid might be feeling, then there is something deeper that needs to change. More than just the project itself." The tools and approaches to following up on students' experiences with designs became a part of the unit moving forward.

Infrastructuring efforts caused friction when students expressed disappointment their designs did not work. Ms. B engaged the friction as a productive space of learning, not just for herself, but for her RPP and her students. She created space to give witness to students' frustrations with the sociopolitics of school life as an act of allied political struggle. Her acts humanized the youths' participation and valued them as cultural and whole people. They also opened up opportunities for new forms of science learning, reframing what counts as just, learning outcomes and who, beyond the science teacher and students of this class, are involved in realizing such.

Ms. B, along with members of her RPP and school community, furthered the goals of infrastructuring for justice – continuing to foster new modes of being, new relationalities that disrupt established power-dynamics between who are experts, who are novices, whose ideas matter, why and for whom, ultimately reflecting what the RPP values in a) the classroom enactments, b) the RPP efforts, and c) the tool/products produced. This example points towards new orientations for what sustainability in reform may mean. Insights and processes, as well as design results, may be continually activated and expanded across scales of activity – time, settings (horizontal) and levels of power (vertical) – as seen in: Tracing multiple pathways, new metrics for success, new spaces of engagement of reform. This kind of infrastructuring is not just infrastructuring for educational innovation, but also for just, happy and healthy communities.

Discussion

Engaging in longitudinal, community-based RPP work has led us to three insights on infrastructuring for justice, imbricated with one another, and anchored in and contingent upon allied political struggles as core practices.

First, we suggest there is a need to reconsider the nature of infrastructure connectivity. Western schooling practices have artificially siloed what counts as legitimate school epistemologies and ontologies, reflecting White male, heteropatriarchal axiologies. Even when positively regarded by the field of STEM education, community-based STEM experiences are positioned as adjacent to school STEM teaching and learning, in a supportive role to students where positive outcomes from these out-of-school experiences might be "supplementary" to students of color but the gains from such out-of-school STEM experiences, whether epistemological or axiological, fail to accrue mobility between the out of school infrastructure into the school STEM infrastructure because of conflicting axiologies. While "alternative" infrastructures, such as out-of-school STEM programs housed in community clubs, are necessary for seeding new relationalities between youth, STEM and communities, infrastructuring symbiotic connections between youths' STEM experiences out of school and in school itself, requires allied political struggle. Ms. D and Ms. L were compelled by the expansive STEM epistemologies and ontologies they witnessed at the community STEM program. They were simultaneously concerned about how differently school STEM is set up. What was most apparent to the teachers were the incommensurability, as they perceived, between in school and out of school STEM. This calls into question the nature of STEM education infrastructure pertaining to what is valued and sanctioned in which activity systems that youth engage in STEM; and discerning the kinds of allied political struggles, involving which stakeholders, where and when, need to take place to support mobilities of resources and gains made between in school and out of school STEM infrastructure.

Second, friction serves as indicators of progress when infrastructuring for justice. Aligning with the rightful presence framework, infrastructuring for justice through allied political struggles is necessarily disruptive. When students are reauthoring rights with the support of more powerful allies like teachers, they are disrupting normalized practices, replacing them with new ones that shift the epistemological, ontological and axiological nature of school STEM. As described earlier, dissatisfied with the mere completion and tested functionality of their engineering prototypes, students' insistence on buy in from the school to put their prototypes to use as they intended necessitated Ms. B's recognition that she needed to do more to advocate for students' hoped-for outcomes with their projects. Such friction made visible the limitations of redesign, since "infrastructuring efforts must always wrestle with what is already there in place in systems—that is, existing infrastructures and practices that are products of past design efforts and that persist in their influence on practice" (Penuel, 2019, p. 662). At Ms. B's school, none of the prior reform efforts were concerned with student projects that impact community identified problems, nor prioritized the potential of shifting social interactions as a result of the afterlife of these projects, as an important STEM learning outcome. The friction manifested in students' frustrations to Ms. B, made

visible such limitations and lent directionality and impetus to Ms. B to engage in further allied political struggle with the students that involved other adult stakeholders in the school and her RPP.

Understanding that systemic oppressions in schools operate through local practices calls into question the feasibility of scaling context-independent products. Traditional notions of scaling such supposedly applicable and thus highly mobile products therefore becomes antithetical to the justice reform agenda and in fact, most likely works to reproduce injustices. Infrastructuring for justice flips the script on scale in its grassroots origins – when local, unjust, normalized practices are collectively identified and interrogated via allied political struggle through new activity systems as inherent to reform, the possibilities of enacting new, more just practices are higher and become an accountability measure of justice-oriented scale. Such a grassroots mechanism of scale has a higher and more authentic potential to "build in" ownership and therefore, sustainability.

Conclusions

Infrastructuring work takes place in the complex interactions arising from resistance and accommodation, disruption and revision that make up the relational work of design. This relational work does not focus on the design of the intervention itself, but on the conditions that make possible the sustainability of outcomes tied to the intervention, such as the very kinds of transformations of institutional relations and practices mentioned above. Time spent, in both quality and quantity, building new foundations is necessary for the political clarity needed for the relational work of sustained reform. Our stance on justice-oriented infrastructuring with communities described here is informed by our decades of entrenched, empirical participatory design work. Being embedded thickly in context across time is a robust and ethical way of making sense of the necessary infrastructuring work at the different vertical and horizontal levels of power/political authority in schools/communities.

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Abstract: In this paper, we study students' epistemic engagement in a learning environment that uses Emergent Systems Microworlds (ESMs). ESMs are agent-based computational models that are designed as constructionist microworlds. We use Engeström's theory of expansive learning for analyzing how agent-based restructurations and constructionist design features of a learning environment facilitate the epistemic expansion of an activity system in a science classroom. We analyze three design features of an ESM-based learning environment that created generative contradictions, which allowed students to devise epistemically expansive ways using the same features to address those contradictions. We discuss how these features facilitated student learning as the students used the ESM as a computational experimental system to test and establish evidence-based claims and collectively shape epistemic practices. This work provides an approach for designing learning environments that foreground students' epistemic engagement in shaping science practices to learn about disciplinary ideas.

Introduction

In his 1991 paper, Engeström discussed approaches to overcome the encapsulation of schooling, which he defined as the artificial separation of school learning from experience, cognition, practices, and values from outside the school (Engeström, 1991). Engeström's framing of this issue goes beyond the concerns regarding designing for out-of-school learning experiences. He draws attention to the lack of direct connections between ideas that one learns in school and their relevance to everyday learning and lived experiences out of school including potential disciplinary practices. From the communities of practice (CoP) standpoint (Lave & Wenger, 1991), which Engeström discusses as one of the approaches to overcome this separation, learning is defined as the legitimate peripheral participation in a community of practice. So, what would such legitimate peripheral participation be for science students in a school?

Science educators and researchers have advocated for decades that science learning should involve meaningful participation in scientific inquiry or sense-making practices to learn about disciplinary ideas (Abd-El-Khalick et al., 2004; Duschl, 2008; Schwarz et al., 2017). Such participation in science practices is intended to serve two purposes – (1) when students construct knowledge by experiencing and investigating natural phenomena in the world, they learn deeply about the science content, and (2) the engagement in the practices of scientific knowledge construction also allows students to learn about the practices themselves. Such meaningful participation in science practices requires reimagining the roles of students and teachers in the science classroom such that students become *doers of science* and not *receivers of facts* (Miller et al., 2018; Schwartz et al., 2004). For example, biology students can participate in the same practices as professional biologists, such as using agent-based computational models to investigate a biological phenomenon such as prey-predation population fluctuations or synchronization of flashing of fireflies (e.g., Wilensky & Reisman, 2006).

Having agency in shaping the community's shared knowledge construction work is an important aspect of science researcher practice (Latour, 1987). Engaging students in similar ways in knowledge construction processes requires designing learning environments that support students' epistemic agency. The term epistemic agency was introduced into education literature in relation to the research on knowledge-building communities conducted by Scardamalia and Bereiter (1991). Epistemic agency refers to students' ability to shape and evaluate knowledge and knowledge-building practices in the classroom (Scardamalia & Bereiter, 1991; Stroupe, 2014). The Next Generation Science Standards (NGSS) has recommended a set of science practices that are epistemically equivalent to those practices of scientists (NGSS Lead States, 2013). However, this framing of epistemic equivalence creates a contradiction for *doing science* using the NGSS framework (Miller et al., 2018) because encouraging students to appropriate a set of practices chosen by others does not position students with epistemic agency: the power to shape the knowledge production and practices of a community. In a classroom setting there is often a tension between teaching established disciplinary ideas and authentically participating in practices to construct knowledge (Russ & Berland, 2019; Schwarz et al., 2017). What Russ & Beland (2019) refer to as a problem of practice arises because of this tension between learning established ideas and constructing one's own ideas. The authors highlight a dichotomy between two intended objects or goals of students' activity in a science classroom using the activity theory framework (See Figure 1). This dichotomy is between "Figuring it out" vs

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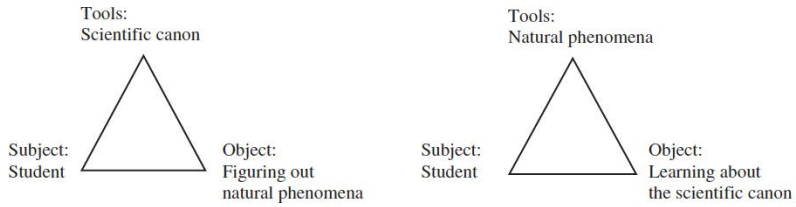
"Learning about" activity systems, where the former is focused on using the scientific canon to figure out a natural phenomenon and the latter is focused on using a natural phenomenon as a tool to learn about the scientific cannon.

Figure 1

Mediational activity triangles in a science classroom (From: Russ & Berland, 2019, p. 286)



a. "Figuring It Out" activity system b. "Learning About" activity system

In this paper, we propose a different way, an epistemically expansive way, to frame students' classroom participation based on Engeström's framework of expansive learning (Engeström, 1991, 2001) to address the problem of practice. We use expansive learning framework because it is intended to promote and capture participation in constructing a new activity system, which is what students do when they, like scientists, identify the questions that will guide their work, and the methods that will help them answer those questions most efficaciously. Using this framework, we analyze student learning in a classroom learning environment which was designed to support students' agentic participation by providing them with tools to engage in epistemic practices. We refer to this learning environment as Emergent Systems Microworld (ESM)-based learning environment. An ESM is a computational microworld designed using constructionist and agent-based modeling principles (Dabholkar et al., 2018; Dabholkar & Wilensky, 2019). Our goal in developing this curriculum was to not simply have students use the model, but to have them refine their own practice so that the kinds of agent-based computational models we provided would have value in helping them pursue their own epistemic goals. Thus, we wanted to support and guide them in engaging in epistemically expansive learning. We used the term guided because in contrast with traditional approaches to expansive learning where participants solely identify their need for and direction of change, our goal was to help encourage a specific new direction of socially constructing knowledge using scientific inquiry practices. We investigate the following research questions in this paper:

What design features of an ESM supported a guided epistemic expansion? How did these features mediate students' epistemically expansive learning?

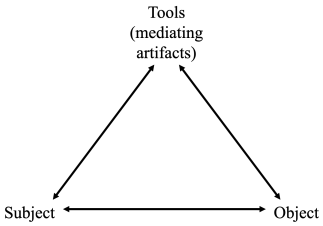
Theoretical Framework

Activity theory and expansive learning

In this paper, we analyze how an ESM-based curriculum supports the transformation of a classroom activity such that students take more agentic roles as they construct and evaluate knowledge using Cultural Historical Activity Theory (CHAT) and its extension, the theory of expansive learning by Engeström (2001). Activity theory provides a lens to design and investigate learning environments that support student engagement in social knowledge-building activities in specific domain areas such as complex systems (e.g., Danish, 2013, 2014; DeLiema, Enyedy, & Danish, 2019). The focus of such analysis is to investigate how different *tools* in a learning environment mediate individual and social transformation (Engeström, 1999).

Figure 2

Vygotsky's mediational triangle (from (Cole, 1998), p. 119)



The original activity triangle or mediational triangle, proposed by Vygotsky, explains the relationships between subject, object, and a mediating tool (Vygotsky, 1978) (Figure 2). The mediational triangle helps in understanding the object-directed nature of human action. While Engeström has since expanded the triangle to include the community, rules, and division of labor (Engeström, 2001), we find that focusing primarily on the designed mediational tools can provide clarity in our design efforts and avoid some of the challenges that arise

from attempting to categorize all of the mediators in play (Witte, 2005). In a classroom setting, an object for a student is not necessarily the same as the object that is intended by a teacher for the student. The intended object is the purpose for which the activity is designed, and the enacted object is the object that a subject (student) uses a tool to achieve. This distinction becomes even more crucial when one intends to use activity theory to design and analyze a learning environment. For example, when an ESM-based learning environment is designed for students to socially construct knowledge, the object 'to socially construct knowledge' is an intended object for the students by the designer of the ESM-based curriculum. So, how can designers' intended object for students become the enacted object in a classroom activity system?

In the theory of expansive learning, Engeström (2001) discusses the possibility of expansive transformation of an activity system, in which the Object (goal/purpose) of Activity gets reimagined as subjects engage with a mediational tool. In the context of science education, such expansive transformations mean a shift in the role of students in a science class from listening and understanding to actively engaging in knowledge-building practices. In this paper, we analyze how design features of a learning environment guide such epistemic expansion such that designers' intended object becomes the enacted object.

Design Framework

ESMs and ESM-based curricula

Over the years, scientific communities across the globe have developed experimental model systems that have affordances to investigate specific aspects of natural phenomena. For example, fruitflies' (*Drosophila*) chromosomal organization and their short life span have made them a model system to study genetics. We argue that using principles of Learning Sciences computational models can be designed to be pedagogically effective model systems that support students' self-driven investigations and therefore their epistemically agentic learning within the constraints of a classroom. In this work, we designed Emergent Systems Microworlds (ESMs) as computational model systems embedded in ESM-based curricula for students to investigate a modeled emergent phenomenon in agentic ways.

ESM design combines two design approaches in Learning Sciences, namely agent-based modeling of emergent systems and constructionism (Papert, 1980; Wilensky, 2001). Agent-based representations in ESMs create affordances for learners to engage deeply with a complex emergent phenomenon (Goldstone & Wilensky, 2008; Wilensky & Reisman, 2006). An ESM is designed as a microworld using constructionist design principles to mediate students' self-driven explorations to investigate various aspects of the represented disciplinary ideas (Edwards, 1995; Papert, 1980). An ESM-based curriculum and accompanying pedagogical practices are intended facilitate such student engagement in self-directed, interest-driven explorations and investigations using an ESM. Students are encouraged to share their findings and participate in teacher-guided reflections to collaboratively construct knowledge about the modeled complex phenomenon in an ESM. Our design goal for the ESM-based learning environment was to support students in seeing their participation in epistemically agentic ways – as producers, consumers and evaluators of knowledge.

ESM-mediated Guided Epistemic Expansion

As we discussed before in a learning environment designed for epistemically expansive learning, the intended object 'social construction of disciplinary knowledge' must become the enacted object of classroom activity. Though this framing is inspired by Engeström's theory of expansive learning, there is an important distinction in our framing and Engeström's. Engeström focuses on inherent contradictions creating a driving force for change such that new cultural patterns are produced in the activity system, which are often previously unimagined (Engeström, 1991, 1999); whereas an ESM-based curriculum is designed to *guide* a transformation of an activity system to make its enacted object to be 'social construction of disciplinary knowledge'. To underscore this distinction, we use the term *guided epistemic expansion* to refer to the ESM-mediated transformation of a classroom activity system.

Cole (1998) expanded the concept of mediational tools to include representations that communicate the community's norms, beliefs, and understandings, as well as cognitive structures that guide action and thought (Cole, 1998). This extended concept of mediational tools becomes important in the context of designing a learning environment. Different features of a learning environment can be considered as tools to analyze how they support different intermediate activities that build towards change in an activity system. These features can act as tools to mediate student activity by supporting or constraining an action. Analysis of these features as mediational tools allows deeper insights into learning activities in an environment designed to support certain forms of learning. The mediational tools in our work are the design features of an ESM, which is a constructionist agent-based computational model. The theory of constructionism has always foregrounded such students' epistemically

meaningful participation in constructing knowledge (Papert, 1980; Turkle & Papert, 1992; Wilensky, 2003; Wagh et al., 2017).

This kind of intended epistemic expansive learning in a science classroom addresses the *problem of practice* (Russ & Berland, 2019) by building on the idea of Invented Science. The authors argue that children invent 'science' to satisfy their curiosity about why and how a phenomenon occurs. However, to achieve the object of satisfying curiosity, children need to have the appropriate cognitive resources to act as mediational tools (Elby & Hammer, 2010; Piaget, 1970; Smith III et al., 1994). In a classroom setting where teachers try to balance their time between "Figuring it out" vs "Learning about" activity systems, external tools that would provide students objects-to-think-with can serve to engage in epistemic pursuits to 'invent science' (Papert, 1980; Turkle & Papert, 1992). Analysis of such mediational tools in a learning environment using activity theory can provide insights into how students socially construct knowledge of a complex phenomenon (Danish, 2013, 2014). In this paper, we discuss how a computational model system in the form of an ESM provides students with such tools to collectively support the social construction of knowledge of the modeled phenomenon.

Methods

Participants and Setting

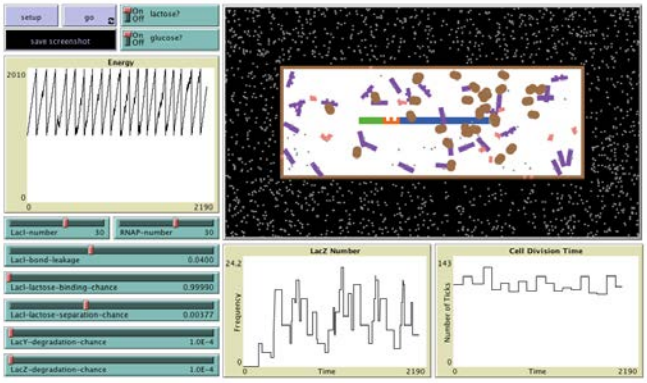
The first author was the lead designer and the lead teacher of the ESM, and the ESM-based curriculum discussed in this paper. From the methodological perspective, this made him an "unusually observant participant" and a designer (Erickson, 2006). The first author conducted these courses in two locations: twice during a weekend extra-school program for middle school students conducted by a talent-development center in a midwestern university in the United States, and twice in residential summer camps in a western city in India. The data presented in this paper is from the fourth iteration in India in which 12 students participated, of which 5 were female and 7 were male. All the students were of Asian Indian origin. We collected data in various forms, namely videos of student discussions (around 150 hours), fieldnotes, workbooks in which students wrote their observations and explanations, the computational artifacts (models, screenshots, and presentations) that students created, pre- and post-tests, and pre- and post-interviews.

GenEvo an ESM based curriculum

To engage students in constructing knowledge of disciplinary ideas regarding gene-regulatory mechanisms and evolution, we created an ESM-based curriculum, GenEvo (Dabholkar et al., 2018; Dabholkar & Wilensky, 2016). In this paper, we study students' epistemically expansive learning with the GenEvo curriculum (Dabholkar & Wilensky, 2016). This curriculum incorporates a series of four interconnected computational models designed using Wilensky's agent-based programmable modeling environment NetLogo (Wilensky, 1999). NetLogo was designed for both constructionist learning experiences and for use in scientific research. Since these four NetLogo models are strongly interconnected, they form an ESM because the underlying rules for agent behavior are consistent across the models. Using this curriculum, students can investigate the emergent properties of biological systems, including gene regulation, carrying capacity, genetic drift, and natural selection.

Figure 3

A screenshot of the first model (Genetic Switch) of the GenEvo ESM which allows students to manipulate and observe molecular interactions inside a bacterial cell



The curricular activities were designed to guide student investigations and engage students in discussing and evolving epistemic practices to establish and evaluate knowledge claims. These discussions included topics such as - *What counts evidence for a particular claim*? *What are various ways to collect, analyze and present*

evidence? *How does one establish a claim using evidence*? Since students were using an ESM to investigate specific aspects of a phenomenon, these discussions were strongly grounded in concrete aspects regarding the biological system under investigation. Throughout the curriculum, students iteratively explored specific aspects of the phenomenon, investigated specific questions, collected evidence, and presented how their evidence supported their claims regarding the research questions.

Microethnographic analysis

To investigate students learning using the ESM-based curriculum, we conducted microethnographic analysis (Erickson, 1986, 2006) of classroom videos, specifically focusing on the dynamics of students' shifting participation in the activity and their shaping of the sociocultural practices of knowledge construction and evaluation in the classroom. Using a top-down approach, we identified instances in the field notes that indicated student engagement in knowledge construction. We performed a micro-ethnographic analysis of videos of these instances to investigate how restructuration properties of the ESM instantiated through ESM design features (mediators) and how complementing pedagogical moves by the teacher (mediation) supported student engagement in knowledge construction.

All episodes related to knowledge construction and evaluation (n = 92) were further coded using a bottom-up approach to identify the objects (the intended goals of the activity), the design features as mediating tools (mediators), and accompanying pedagogical moves (mediation). Even though the ESM is a primary mediating tool for all the activities, we coded for specific design features of the ESM to further investigate how those design features mediated different aspects of knowledge construction. We identified how these design features mediated specific intermediate objects as the activity system underwent transformation.

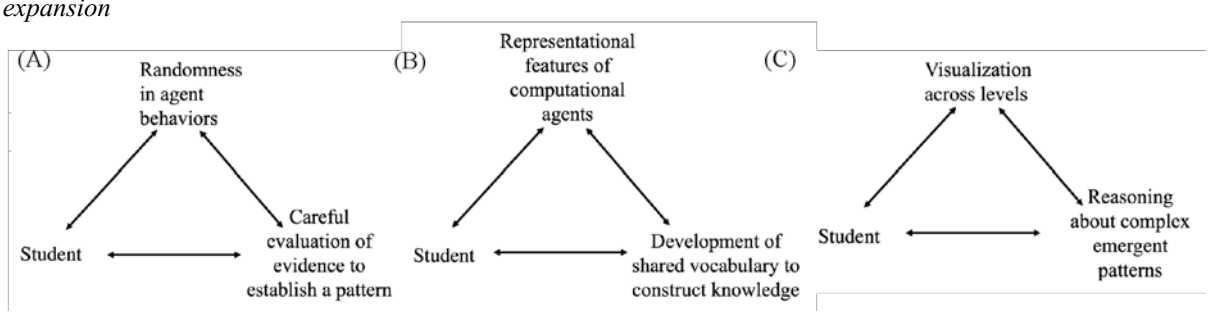
Findings

In the previous work, we have demonstrated students' learning gains regarding disciplinary ideas and shifts in their perceptions regarding their roles in a science classroom from the perspective of epistemic agency (Dabholkar et al., 2018; Dabholkar & Wilensky, 2019). In this paper, we focus on identifying and analyzing design features that mediated students' epistemically learning expansive learning. In the GenEvo ESM-based learning environment, students constructed their shared knowledge about how genetic regulation takes place in a bacterial cell as an emergent phenomenon by conducting experiments with the ESM, developing, and evaluating evidence-based claims and establishing practices to evaluate the claims.

Internal contradictions in an activity system act as a driving force for change as it undergoes expansive transformation (Engeström, 2001). We microethnographically analyzed three design features focusing on how contradictions arose because of those design features of the ESM and how the same features allowed students to find ways to address those contradictions. Our analysis helps in understanding how these internal contradictions acted as a driving force for epistemic expansion in the classroom. These design features mediated students' engagement in intermediate objects in the activity systems as they progressed with constructing knowledge of disciplinary ideas and evolving scientific practices (see Figure 3). The three objects of intermediate activity systems were (1) careful evaluation of evidence to establish a pattern, (2) development of shared vocabulary to construct knowledge, and (3) reasoning about complex emergent patterns. These objects are intermediate steps that are essential to construct knowledge about the complex phenomenon modeled in the ESM. Student enactment towards achieving these objects, in turn, mediated the transformation of the classroom activity system. The object of the classroom activity system became the social construction of knowledge about complex disciplinary ideas.

Figure 4

Intermediate activity systems in an ESM-based learning environment as the activity system underwent epistemic expansion



Randomness in encoded agent behaviors in the ESM caused slight differences in experimental outcomes, even when an experiment was repeated with identical conditions (Figure 4A). This design feature of the ESM

makes the behavior of the ESM as a system close to the behavior of the real-world system (a bacterial cell, in this case) it models. Despite such stochasticity in agent behaviors, those behaviors produce consistent emergent patterns at the system level. This feature created contradictions when students tried to evaluate each other's claims. When asked for their conclusions after a curricular activity, a student, Shaurin said, "*Even with the same parameters, you won't get the same results every single time…But there is some pattern*". This was after students had investigated the effects of sugar availability in the environment on the energy of a bacterial cell. When asked further about the pattern, Shaurin and other students shared their observations and concluded that cell division time was shorter when glucose is present than other conditions, even though the observed cell division times were slightly different for all the students. In this exercise, students collectively developed an important insight regarding a practice of science, which is that there can be variability in observed data within the same experimental conditions and multiple trials need to be conducted to verify the validity of observed patterns. This led to the classroom community evolving two practices for carefully evaluating evidence: conducting multiple trials and carefully observing the mechanistic details by slowing down a model. More rigorous forms of these practices are prevalent in modern biological research: statistical analysis and time-lapse microscopy.

Another set of contradicting observations arose when students attempted to establish claims regarding the properties of specific agents and their interactions with each other because of the lack of established identities for computational agents (proteins and parts of DNA) in the microworld. These contradictions required students to develop shared vocabulary to construct knowledge (Figure 4B). While in a traditional model, a teacher might give a key or legend for the biological names of proteins and parts of DNA, in this classroom the teacher encouraged students to develop and use their naming conventions for identifying agents in the model. Students used representational features (shapes and colors) to develop a shared vocabulary for creating naming conventions for computational agents. This vocabulary evolved from "pink and purple stuff" to "pink triangles, pink rectangles, purple keys, and potato-shaped things". This incidental design feature served to engage students in an important scientific practice. Since students were investigating how molecular interactions resulted in genetic regulation at the cellular level, establishing the clarity about the identities of computational agents, their properties, and their interactions with each other was crucial. Such development of shared vocabulary is an important aspect of science practice. For example, naming conventions of organisms such as SARS-CoV-2, allows scientists across the world to easily share their findings. Representational features of computational agents in the ESM, though initially created contractions, also allowed students to devise ways to address those contradictions.

The GenEvo ESM was designed for students to visualize agent behaviors at the level of biomolecules and reason about how genetic regulation takes place at the cellular level. Students could visualize properties and interactions between biomolecules and system-level parameters such as the energy of the cell and cell division time. Discussions based on these visualizations created contradictions regarding a fundamental aspect of emergent systems: who is controlling all this – the cell, specific control molecules in the cell, or the genetic control is an emergent property of a cell. These contradictions served as a driving force for students to reason about how behaviors and interactions at micro-level result into emergent patterns at the system level (Figure 4C). Since students had designed and conducted various experiments to investigate agent-level properties, and interactions of biomolecules in different environmental conditions (presence or absence of specific sugars, glucose, and lactose) and system-level outcomes, they argued using the mechanistic details of molecular interactions to address the contradiction by reasoning how this emergent behavior at the cellular level can be manifested through interactions of biomolecules.

Discussion

In this paper, we developed a theoretical construct, *guided epistemic expansion* to name a design outcome that is intended to address the problem of practice. Our analysis of an ESM-based learning environment demonstrates how design features of an ESM mediated the *guided epistemic expansion* in the GenEvo learning environment. The findings show that three design features supported shifts towards student engagement in the social construction of knowledge about a complex phenomenon. The learning outcomes for the students were three-fold, (a) they developed knowledge about disciplinary ideas about genetics and evolution, (b) they developed knowledge about *doing science* by evolving practices to investigate a phenomenon, (c) they shifted their perceptions about their agency in the process of knowledge construction. The third learning outcome is about their *epistemic consciousness,* the realization that they can participate in constructing knowledge and devising ways to construct knowledge. One student reflected on her learning in post-interview, "*We sort of learned like how scientists would learn about the world. We do not have as much knowledge as scientists do. We formed groups, we shared ideas, we got ideas, we combined them*."

The three analyzed design features - (1) randomness in agent behaviors, (2) representational features of computational agents, and (3) visualization across levels of the ESM mediated students' engagement in specific

intermediate learning goals (objects of the activity system) as they progressed with constructing knowledge of disciplinary ideas and evolving scientific practices. These three design features created contradictions as students tried to make sense of the modeled phenomenon in the ESM. These contradictions served as a driving force for the classroom community, guided by the teacher, to use the same features for addressing those contradictions. Students' enactment towards achieving these objects, in turn, mediated the transformation of the classroom activity system through epistemic expansion. The object of the classroom activity system became the social construction of knowledge about complex disciplinary ideas, which resulted in the outcome of students' expanded ideas about their participation in learning science in the classroom in epistemically agentic ways.

This work demonstrates how the design of learning environments and allied pedagogical practices to support students' epistemic agency in a science classroom can result in epistemically expansive learning. Through this work, we provide a way to address the problem of practice by providing students a computational experimental system or a playground to test and establish evidence-based claims and collectively shape practices for doing so. As students use such computational microworlds to make sense of a modeled phenomenon, contradictions created by certain design features of the ESM-based learning environment led to guided epistemic expansive learning. In the future, we would like to investigate how students make sense of their learning trajectories in such learning environments and whether they see shifts in their epistemic agency as the classroom activity systems undergo epistemic expansion.

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Zoom School Diaries: Caregiver Insights from Listening In on Synchronous Instruction

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Abstract: Continuing schooling during the Covid-19 pandemic dramatically changed the way students, families, and teachers engaged with school and academic content. Remote instructional methods utilized by schools to reach students in their homes often relied on internet-based communication tools and individualized learning platforms, and divided instructional time into two categories: synchronous and asynchronous. We consider how synchronous learning moments, defined as live interaction between the focal children and their teachers via video or phone calls, were experienced by 109 families of elementary school children across the U.S. Specifically, we examine who had access to synchronous lessons, what happened during those lessons, and what parents and other caregivers noticed given their proximity and ability to observe the lessons first hand. We discuss how the sense of connection to peers and teachers that the synchronous interactions provided was critical to engaging students with school during the transition to distance learning.

Introduction

Few events have shocked the U.S. education system as much as the sudden shift to distance learning during the onset of the Covid-19 pandemic in the spring of 2020. The situation presented challenges for educators and caregivers for which there was little guidance. School personnel did their best to sustain learning and provide for students' basic needs, leading to a patchwork of approaches that depended on the resources of each family, school, and district (Anderson & Hirra, 2020; Reich et al., 2020). Caregivers were expected to help their children keep up their academics, motivation, and social-emotional learning, as well as balance competing demands from work and existing responsibilities (Fontenelle-Tereshchuk, 2021; Garbe et al., 2021). Across the developed world, caregivers struggled to access distance learning due to a lack of digital resources, lack of communication with the teachers, child learning differences, and limits of their own content and pedagogical knowledge (Bhamani et al., 2020; Dong et al., 2020). Large scale data from the Household Pulse survey indicates that overall in the U.S., parents were doing what they could to help their children continue with their academics during distance learning and that the number of "live" contact hours with teachers correlated with the amount of time children spent on schoolwork (Bansak & Star, 2021). However, low-income families were less likely to have regular, synchronous contact with their teachers during remote learning in addition to less access to computers and high-speed internet, critically impacting the quality and quantity of instruction these students were able to receive (Bansak & Star, 2021; Katz & Rideout, 2021). Although analyses based on large scale data are critical for beginning to specify the resources that contributed to resilience, to understand how and why synchronous sessions supported learning we need documentation of the interactions that took place. Qualitative work has begun to explore how caregivers supported their children's learning (e.g., Barron et al, 2021; Bhamani et al., 2020; Sonnenschein et al, 2021). This paper contributes to that line of work.

We present findings from a remote diary study conducted with families across the U.S. focused on understanding how families were adapting to remote learning. Our analysis explores examples of synchronous moments that caregivers reported. We examine what happened in these learning moments (e.g., content, structure, engagement) and what caregivers noticed through observing their children engaged in synchronous learning. We define a "synchronous activity" as a learning moment that includes live interaction between the focal children and their school teachers facilitated via video conferencing or phone calls. While many other kinds of synchronous learning took place in the moments that caregivers described in the study (e.g., reading to younger cousins over FaceTime), we have deliberately limited the scope of the activities in this analysis because of the novelty of the medium of instruction at this scale, weight placed on synchronous instruction for students during the pandemic, and the lack of equity of access. Our findings complicate the story of synchronous school-based remote learning during the pandemic, highlighting the social and emotional benefits the live communication with their teachers and peers provided for the children during a time when social activity was restricted. We also describe how caregivers and teachers played complimentary roles in fostering a sense of connection between home and school for the children through synchronous learning moments.

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Theoretical framing

Coordination across spaces in children's learning ecologies (Barron, 2006) and the creation of systems of support for children's social, emotional, academic, cognitive, and physical wellbeing (Darling-Hammond et al., 2019) are critical for healthy child development. One aspect of that is caregiver involvement with schooling, which is known to be positively associated with children's academic success in the U.S., both for in-person schooling (Smith et al., 2020) and virtual school environments (Garbe et al., 2021). Positive home-school relationships shape children's sense of belonging in school environments. Yet crossing the boundary between home and school to advocate for their children's individual needs requires caregivers to develop and maintain working relationships with their children's teachers (Lawrence-Lightfoot, 2004). This amount of time and effort is often out of reach for caregivers who do not have work flexibility or may face a language barrier (Valdez, 1996). When the pandemic forced home and school to be co-located, although many of these factors remained challenging, new opportunities emerged for caregivers and teachers to cooperate and establish multifaceted systems of support to foster healthy learning environments for the children under adverse circumstances.

During synchronous sessions caregivers were often actively engaged, providing technical assistance, supervising or simply keeping their child company, and taking the opportunity to observe interactions and listen in on classroom discussions. Observing and listening in on activities and events are modes of active learning that Rogoff et al (2003) describe as learning through "intent participation." Much of the previous research on intent participation has come from examining how children learn to participate in everyday practice that shapes community life (Rogoff et al, 2003; Rogoff, 2014) as well as in more structured learning environments (e.g., Jocuns, 2008). However, intent participation could also be used to describe how caregivers of young children learn to shape their interactions with their children based on their noticings of their children in different settings. Caregivers regularly take on new responsibilities and roles to meet the needs of their children (Barron et al., 2009), gathering information on how to do so through formal and informal sources (e.g., family networks or child-rearing classes; Radey & Randolph, 2009). Rarely do they need to do so under such unusual conditions as a global pandemic. Given the enormous challenge for maintaining motivation during school closures, we focus on what parents noticed about what facilitated their child's positive engagement with school during video-mediated classroom interactions. Our analysis draws on situated views of learning that conceptualizes engagement as dynamic, multidimensional, and often connected to idiosyncratic social or activity-based preferences (Azevedo, 2013). We foreground how caregivers described the relational, material, participatory, and content-related resources that contributed to their children's enjoyment of synchronous sessions.

Methods

In May and June 2020, we collected over 700 reflections, including 668 diary entries of learning moments, from 109 families with children aged 5-10 using *dscout*, a smartphone-based remote qualitative research platform (Barron et al., 2021). Using a smartphone-based app allowed us to collect multimodal in-the-moment data from busy caregivers as they went through their days and observed their children learning. Our method foregrounds the perspectives of caregivers which gives us unique insights into the roles caregivers were playing during the stressful months early in the pandemic where they were forced to balance competing priorities of work, child care, and schooling. We recruited from *dscout's* participant panel. Our criteria for participation were: (a) having a child between ages of 5-10 living at home, (b) the child's school had moved to remote instruction and was in session for the entire duration of the study, and (c) the applicant had given consent for their responses to be used for research. Over 1,000 people applied to be part of the study. We sorted applicants into low ($0-49K), middle ($50-99K), and high ($100K+) income groups and randomly selected 37 participants from each group to ensure a diversity of socioeconomic status in the sample. In total 109 caregivers completed the study. They were from 28 states and were mostly women (67%) with children in public elementary schools (84%). Racially, 55% self-identified as white, 16% as Black, and 15% as Latinx, 9% as Asian, and 4% as Middle Eastern or North African. Slightly over half (55%) of the caregivers reported an annual household income of at or above the national median income of $75k. Participants were paid $75 at the end of the study.

Data collection was organized around five themes: (1) relationship to school pre-pandemic, (2) relationship to school during distance learning, (3) daily learning moments, (4) how the family learned about Covid-19, and (5) reflections. For each theme, participants answered a series of questions using short videos, photographs, survey questions, and direct messages to the researchers. Theme #3, daily learning moments, is where we draw data for this analysis. Data for these moments included a 2-minute video, transcribed, of the caregiver explaining and reflecting on a learning moment they observed that day, a photo of the activity, as well as multiple-choice survey style items where the caregivers reported the subject of the activity (e.g., art, writing, math), how much learning they perceived to be happening in the moment, and how engaged the child was with the activity (e.g., how much fun they were having.) For this part of the study, we asked caregivers to share six

learning moments they observed over the course of a week. Of the 668 learning moments we received, 128 (18%) were identified as examples of synchronous video or phone-enabled interactions with teachers through multiple rounds of qualitative coding.

Next, we employed a mixed-methods analysis to explore the following questions: (1) Across the whole sample, how did access to and the content of synchronous learning experiences vary by family demographics? (2) How engaging were synchronous learning moments for the children and what did they look like? (3) What do caregivers learn about their children's experience in distance learning as a result of listening in, observing, supervising, and assisting with instruction? To understand the distribution of synchronous moments across our sample, we used statistics to analyze caregiver responses to survey items about what their child's school provided for remote instruction, including communication channels with the teacher. Next, using iterative rounds of inductive and deductive coding, our team developed a codebook for a thematic analysis of the structure, challenges, benefits, and caregiver insights present in the caregiver descriptions of the events (Saldaña, 2011) and applied the codebook to the sample. Additionally, to deepen our interpretation of what was happening in the learning moments and what caregivers were attending to, we looked at our coding of the synchronous activities in relation to the standardized data the caregivers reported about the details of the learning moments, including child engagement.

Findings

In the sections below, we utilize descriptive statistics to explore the question of equitable access (research question #1) and show the variety of content and structure of the synchronous activities (research question #2). We further illustrate the aspects of synchronous learning moments that facilitated positive student engagement (research question #2) and how caregivers acted as partners in supporting that engagement (research question #3) with representative qualitative examples.

Access to synchronous lessons

In the overall sample of participants (n=109) higher-income families (annual incomes above the national median of $75k) were more likely than lower-income families (annual incomes less than $75k) to indicate having access to synchronous classes, other types of family-teacher communication such as individualized messages from teachers, and access to teacher-recorded video content (Table 1).

Table 1. Reported access to synchronous opportunities by income group

		Median income groups			
	N	Higher	Lower	X^2	p
Synchronous classes	109	92%	72%	6.48	0.01
Individualized messages from teachers	109	90%	67%	8.6	.003
Teacher-recorded video content	109	68%	47%	5.1	0.02

The sub-set of 128 examples of synchronous learning we identified through iterative rounds of coding came from 71 families (65.1%). The caregivers who submitted these moments did not differ significantly from the rest of the whole sample (n=109) by income (54% above $75k annual income).

Positive engagement in synchronous lessons

In the diary entries of learning moments, caregivers reported their children's positive engagement on a Likert scale item with rating options from 0-10. A one-way ANOVA revealed a significant difference in caregiver perceptions of synchronous and non-synchronous moments ($F(1,666) = 9.49$, $p = .002$). Overall, caregivers rated synchronous learning moments as more engaging ($M = 7.73$, $SE = .240$) than non-synchronous moments ($M=6.90$, $SE = .117$). About 60% of synchronous moments (77 of the 128) were rated as highly engaging , meaning they were higher than the median engagement score across all learning activities documented. Through parent ratings and descriptions of the moments, we were able to explore what caregivers noticed that might have made these synchronous learning moments engaging.

Structure and content of engaging lessons

Whole class meetings were the most common (55%) of several ways that caregivers reported their children participating in synchronous lessons. Children also participated in small groups (12%), had one-on-one meetings

with teachers (9%), and received special education pull-out instruction (4%). Over three quarters of these meetings were structured in some way (82%) while a minority were unstructured (9%). There were no meaningful differences in caregiver ratings of engagement by the structure of the synchronous moments.

The most commonly covered academic content in synchronous lessons was reading (32%), followed by mathematics (27%), science (15%), and writing (15%). The activities that were more likely to be rated as highly engaging, however, were either art or music (X^2 = 5.7, p=0.02), and the ones less likely to be highly engaging were math lessons (X^2 = 8.17, p= 0.004) and writing lessons (X^2 = 10.66, p = 0.001). Alice described how her kindergartener's weekly Zoom music class provides "A little bit of normalcy and all this crazy times":

> Her music teacher comes on and then she can see her teacher as well as all the other children in her class. So it lasts about a half an hour and my daughter absolutely loves it. She loves doing it. She loves music. They play games, they play songs, and do little dance moves and everything like that. [...]The teacher is able to mute them and unmute them and sing along and call on people and things like that. So my daughter really enjoys it.

Alice's attention to the positive experience her daughter has in music class encourages her to keep logging on to the class each week. Indeed, this attention to the importance of social, emotional, and content-related interactions emerged across the synchronous sample as was made evident by what aspects of the synchronous moments caregivers highlighted in their documentation.

Engagement fostered through teachers caring and connecting

Caregivers noted the importance of synchronous sessions for supporting a sense of connection to peers and for providing opportunities for teachers to communicate their caring for students' well-being. For example, Dillon reflected, "this one was pretty cool for the teacher to make the time to keep my child feeling cared for. [...] my daughter was doing a one-on-one check-in with her teacher and they were just talking about various things catching up on what was going on in her life and a few other things." The emotional benefit for his fourth-grade daughter of having a one-on-one check-in with her teacher was great since she had liked her teacher and "was sad when the school year got cut drastically short. [...] The interaction went really well and she was pretty happy to get that one-on-one attention which my child tends to thrive on."

In another example, Ida, mother to second-grader Lani shared her observations of a whole class Zoom:

> [I]t's a good thing that they do this [...] twice a week, to kind of like you know, talk about the book they're reading, learning about vocabularies, or either you know, just kind of keep track of what they are working on this week. And I like the idea of doing this because they get to see their friends, their classmates and their teacher and say hi, and what have they been doing for the past few days or weeks. And it's very engaging, and I like when my daughter is able to share her... whatever she's been doing for the past few days, and [...] check in. So they [are] kind of like, slowly, [...] making sure that the kids stay on track as far as their grade level.

Ida describes a Zoom meeting in which the class is reviewing the content they have been working on and has an opportunity to connect face-to-face. The purpose of the time together is not necessarily to learn new content or complete an assignment. However, these twice-weekly meetings keep Lani engaged with her class and reflect care and attention from her teacher.

Engagement fostered through teachers welcoming children's interests and identities

Caregivers also noticed their children enjoying synchronous lessons when they had the opportunity to share their interests and aspects of their identities with their classmates. Being given more agency over what they brought to class was motivating for the students. Some examples caregivers shared were times where the children brought items to Show and Tell, dressed up as superheroes, or had open sharing time to talk about things on their minds. Other moments tied more directly to the content of the class. For example, Billy's second-grade son was disappointed when schools closed, and "he could not have science class in person anymore." However, his teacher organized a virtual lab for the class, and "when he learned he was going to have a virtual lab he became really excited." Billy commented on how his son was "intrigued the whole time. And he was telling me about the different stages of a scientific experiment, and how he was making observations about what he was seeing. So overall, it went really well, and he seemed to love it."

School routines that were transferred to Zoom were also opportunities for student agency in some schools. Layla shared how her kindergarten daughter "was glowing" when she was chosen by the school principal to

display the Israeli flag and lead the school in the Israeli national anthem. She explained, “ever since Israel had its 72nd birthday [...] my daughter wanted to make a flag for that country”. She went on to describe how the school met every morning to say the pledge of allegiance to the US flag, but then also included flags and anthems from different countries when students express interest in sharing their own.

Caregivers as partners in supporting positive engagement

Through leading synchronous sessions for their students to be together virtually, or connect one-on-one with students, teachers enabled opportunities for social and emotional connections that would not have been possible otherwise under the shelter-in-place orders and social distancing guidance. Teachers facilitating these learning moments for students provided an opportunity for caregivers to take a step back and watch how their children reacted to the sessions, and come up with strategies to support their children from home.

Synchronous lessons reveal complicated emotions

Throughout the reflections from caregivers on their children’s positive engagement in synchronous lessons, caregivers highlight the value of maintaining a social connection to peers and teachers for their children’s emotional well-being. During a difficult time filled with fear and uncertainty, synchronous class meetings and activities provided caregivers insights into how their children were handling the situation. For Maggie, a poetry assignment helped her understand what her fourth-grade son was thinking and feeling:

> So I'd say it was successful but not necessarily for the academic purpose of it. But we're not really using Zoom at the elementary level for instructional purposes anyway so it was just kind of a bonus educational activity today that a couple of kids shared poems but was far more social and importantly so. [...] I think it was a really good activity just because you know it kind of let me see the things that were on his mind that he hasn't necessarily been expressing [...] I think it was you know it's definitely something I'm going to save to kind of earmark this time in his life. So I'm glad it was an assignment we had. [...] I do think it proved a good exercise in emotional wellness.

The poem Maggie’s son wrote was titled, “Empty Soccer Field,” and expressed the sadness he felt not being able to play soccer with his friends at the time.

When teachers provided forums for students to share and express their identities, parents noticed engagement but that engagement was often complex. Brie gave an example of how her first-grade son’s teacher opened their thrice-weekly morning meetings with “Does anybody want to share?” Students would read to each other and show off their pets, and Brie’s son “enjoyed showing his ladybugs and his roly-polys [laughs] and his other bug pets.” While Brie notes that “when he goes, he’s always wanting to share, and listening to his friends share,” she also says that he reports that he does not like the class meetings. She reflects, “So, it's kind of funny to me that he doesn't like them. I just think he doesn't really like the online-- He has not enjoyed like, online play dates or any of the online interactions with friends. It's been really difficult for him. He misses actually being with friends and really playing.” Through listening in on her son’s class meetings, Brie was able to see her son’s continued reticence to socialize online, even if there are aspects of it that he did enjoy.

Caregiver strategies for supporting positive engagement in synchronous lessons

From the other side of the camera from the teachers, caregivers took up multiple roles for supporting their children’s engagement during the synchronous lessons. Some encouraged hesitant children to attend, such as Connie who reports she and her husband encourage their fifth-grade daughter to participate so that she “stays connected with her teacher and classmates. I think it helps keep her engaged in doing the online E-learning classwork.” While children were logged on to their video classes, caregivers were often close by listening in on what was happening (e.g., actively attending to the child’s actions or interactions with the teacher or their peers), actively supervising (e.g., assisting in time and task management), or taking on a teaching role to modify instruction live to meet their children’s needs.

Modifying instruction often occurred when the children were confused during the lesson and did not have a good way to get their questions answered by the teacher. For example, Arielle’s fourth-grade daughter Cami got lost during a math lesson, and Arielle, who was listening in next to her, stepped in to help Cami get back on track. She explained:

> So [Cami’s] teacher was going a little fast, because they are learning-- they're learning at a fast pace, because school is now wrapping up, so she's trying to squeeze a lot of stuff in. So [Cami]

> was getting very, very confused, and I had to mute her and turn off the camera and kind of re-explain the concepts to her. I also did it in the traditional math way instead of the Common Core, which has 10 steps. And she got that way better, so I would like to think that I am a secondary teacher for her.

In this moment, Arielle was supervising Cami because after the previous class was over, "she turned her camera off and muted herself. So she had thought that she could just hang out on her phone. So I just sit there, do my work right next to her, and make sure that she took notes and did the assignment and asked questions and just participated." Arielle's insistence that Cami participate fully in the synchronous lesson ended up not being fully realized in that she effectively pulled Cami out of the classroom for private instruction using different pedagogical strategies than the teacher. However, by engaging with the content, they did surface an area of confusion for Cami and addressed it immediately.

Jade also kept a careful eye on her fifth-grade grandson Henry, who had an IEP, and stepped in to advocate for his learning and help manage social interactions. For example, when Henry was put in a small group with classmates to write a collaborative report on the U.S. "Founding Fathers," his classmates ignored him. Jade noticed the negative dynamic and shared that, "I'm not gonna have the other kids close him out and him trying to work on it on its own. I'm trying to figure out a way if maybe he can do a report on a founding father on his own, and I need to check with the teacher maybe do it that way." Synchronous classes were hard for Henry to keep up with, and sometimes he would switch to listening to audiobooks or working on a personalized learning platform instead of following along with the class. Jade supported these activities and ran interference to try to make Henry's live interactions with teachers and peers a positive experience.

Helping children manage their emotions, stress, and anxiety was also a responsibility that some caregivers took up explicitly. Ramira, for example, shared how her fifth-grade daughter came to her to ask questions instead of asking the teacher because she wanted to finish her work before the end of the lesson since it was the start of a holiday weekend. "During the event she Was getting anxious about finishing her Work due the holiday weekend" shared Ramira, "She was engaged by asking me questions and muting and not wanting to finish, and finally after some coaching, she was able to focus and concentrate."

Caregivers also attended to the physical arrangements that their children set up for themselves to be comfortable during synchronous lessons. This view into their children's preferred working environment was possible due to the caregiver's observing and supporting their children to experience synchronous instruction as positively as possible given the constraints of the time. For example, Matt, caregiver of third-grade Oliver, noted that Oliver "likes to snuggle up with the dog and blankets. Been doing it, and I think it gives him comfort when he's online with his classmates." One day during the morning meeting the class was sharing who they admire most and Oliver said he admired the dog. Matt reflected "it is true because that dog does give him comfort, and he likes to be the class clown- [...] teacher didn't yell at him. I don't know that I thought it was super appropriate, but it seemed to work for him." Mariah also noted where her fifth-grade daughter was comfortable taking calls: from her bed but dressed up "so she can kind of show off her classmates and to make sure she looks the best :-)." Mariah takes a hands off approach to give her daughter space to connect with the teacher and classmates on her own. "When she does her zoom calls I pretty much kind of stay out of it," Mariah shared, "I want her to have that time away from me to be with her teachers and to be with her classmates so that she can have the slightest bit of normalcy."

Discussion

Given the rapid transition to remote learning, the varied responses and capacity by districts across the US, and the widespread utilization of technology tools for school-to-student communication and lesson delivery, we set out to understand how families experienced school-driven synchronous moments. We found that caregivers whose household income was below the national average reported less access to synchronous classes as well as other family-teacher technology-mediated interactions, and shared fewer synchronous moments in their learning diaries. This is especially critical in light of our other findings that highlight the benefits of synchronous moments that reach far beyond just being academic content delivery mechanisms. Synchronous sessions tended to be recognized by caregivers as highly engaging for their children. Encountering and fostering positive social interactions and emotional connections to school during the difficult transition to distance learning was important to caregivers. Our finding aligns with Katz and Rideout (2021) who conducted a nationally representative study of underconnected, lower-income families (less than $75k annual income) and found that top priorities for their children upon returning to school in the fall of 2020 were social or emotional (50%). Their study also underscores the inequity of lower-income families not having access to synchronous opportunities which we found to provide generative moments of social and emotional support.

Additionally, we found that as caregivers attended to their children's reactions and engagement with synchronous lessons, they reflected on how the content, structure, and relational components of the sessions contributed to their children's experiences. These findings also align with Katz and Rideout (2021) who found that parents of 3-13 year-olds felt that they knew more about their child as a learner (66%) and more about the content and structure of school (62%). In some cases, especially when student engagement or focus was a challenge, caregivers used what they knew about the activity and their child and took an active role in mediating their children's engagement with the lessons to support a positive outcome for them. This action was typically not possible before the pandemic. While teachers and schools scaffolded synchronous opportunities, parents were on the other side of the camera with their kids providing a supporting role using a variety of strategies. They mediated moments of potential meltdown by stepping in to turn off the camera and providing extra coaching about the material or letting them skip a session altogether, they gave reassurance and coaching for anxious learners, and they helped create the physical conditions that offered comfort and security for engaging in synchronous learning moments.

Together, these findings suggest a more complex picture of online learning during the pandemic. Synchronous sessions were not always just a re-creation of school lessons; many engaged young people through supporting peer-to-peer and student-to-teacher connections and opportunities for personal expression and agency. The live interaction with teachers and peers provided by synchronous learning moments fostered a sense of connection and stability that was critical for well-being during the uncertainty that marked the beginning of the pandemic. Yet in our data, the incidental partnership between teachers and caregivers made it clear how caregivers were playing a supporting role for their children during these synchronous moments, adapting and reacting in the moment depending on what they noticed, often bolstering engagement. More research is needed to understand how a sense of connection with peers and teachers was maintained for the families who did not have that live interaction with school during critical points in the pandemic. In our sample, caregivers who worked during the day did find ways to connect with schools, despite being unable to connect synchronously. These included caregivers who watched previously recorded zoom sessions with their children and others who found other ways to communicate with teachers and peers

Further, our qualitative findings are consistent with larger studies showing relationships between online synchronous connections and metrics of engagement in learning (e.g., Aguilar et al., 2021). This convergence between studies warrants future research that can offer deeper explanations for how and why synchronous connections may support engagement in the moment and over time. Experiments and broader ethnographic studies that include a more diverse set of family situations can offer theoretically rich and design-relevant data. In addition to new research designs, multiple measures of engagement will be useful in advancing this work. Our parent rating of engagement in activities is novel and future work can be designed to validate such ratings through designs that include children's views or interactional metrics of participation in learning moments.

Conclusion

Nearly two years later, Covid-19 continues to have a lasting impact on families and schools. Large-scale reports detailing the "learning loss" shown through standardized testing data devalue the efforts by teachers and caregivers to attend to children's well-being during the pandemic, and the learning partnerships that emerged in response to the disruption of the pandemic. Findings from our analysis have implications for emerging models of schooling for the rest of the pandemic and beyond, fostering positive engagement with school and child well-being, as well as for future educational research centered on families. With regards to the former, the experiences of our families in this study highlight the importance of having real-time interactions with peers and teachers for academic and social purposes. Future models of home-based learning in the "new normal" must capture those benefits while also taking into account the additional burden placed on caregivers by the technical and pedagogical challenges introduced by synchronous remote learning. However, our results point to promising directions for increased communication and coordination between teachers and caregivers allowing for students to engage in more personalized and interest-driven learning as part of academic instruction. Additionally, the data suggest that having synchronous interactions within a virtual school context helps learners and caregivers feel connected to teachers and peers. Synchronous connections may be an important source of educational resilience, allowing parents and children to cope with the challenges presented by distance learning and sustain or increase their enjoyment while learning.

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"Keep it in the Village": A 25-Year Journey of Collective Concept Formation Transforming Financial Practices in a Rural Thai Village

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Abstract: Community-generated concepts, namely "germ cells," can be productive to address problem situations. Yet most literature on germ cells accounts for the initial development of concepts and how these create opportunities for learning and concrete application. This taps into only a small part of the potential power of a germ cell to be generative. In this paper we consider the ongoing development and application of a germ cell in a rural Thai village over 24 years, showing how through a series of learning intraventions, each involving self-analysis and reflection alongside concrete community actions, a germ cell slowly evolved, continuing to orient the village's transformative work. In this process, the villagers' family and community financial practices underwent dramatic, productive change. The ongoing unfolding and expanding concrete manifestations of the germ cell shed light on their generative capacity in community learning and transformation.
Keywords: germ cell, formative intervention, intravention, activity theory, concept formation

Introduction

Supporting collective community learning through concrete changes in practice is an underlying challenge in the learning sciences (Gutiérrez & Vossoughi, 2010) that requires forming collective concepts that catalyze change. One way to approach concept formation is through the analysis of germ cells: powerful, underlying ideas (i.e., abstract concepts) developed through experimentation and self-analysis by a group of people to orient their actions toward productive, collective learning. In other words, a germ cell is a simple explanatory concept that people construct to transform their community practices in concrete ways to learn expansively (Engeström & Sannino, 2012; Gutiérrez & Penuel, 2014). In this paper we explore the community development of a germ cell that helped to orient dramatic improvement in community financial practices in one rural Thai village over 24 years.

In the late 1990's, like many subsistence agricultural villages, the northern Thai village of Ban Samkha faced crippling financial conditions that threatened its survival. They were collectively buried under unsustainable debt at high interest rates and, according to their own descriptions, had no understanding of the mathematics of compound interest (or its influence on their debt) or how they accumulated such debt in the first place. Problematic practices added to their expenses, for instance, selling all their crops at low prices and purchasing food from outside vendors at higher costs. While various government and nonprofit organizations initiated development programs in prior years to help Ban Samkha and other villages, for instance providing an influx of cash with a "village fund" or group lending initiative (Coleman, 1999), without a means to comprehend the underlying issues behind their financial problems these interventions worsened the village's problems. Villagers expressed feeling incapable of understanding, much less tackling the concerns that overwhelmed them.

The challenges Ban Samkha faced were not unique; they were (and are) common in villages throughout Thailand and the world (Chichaibelu, 2018). Although transformative social change in villages and rural communities is a valued ideal, supporting it is nontrivial. Villages face multiple, interrelated obstacles, from a lack of financial literacy to unsustainable agricultural practices, to local ecologies actively being reshaped by climate change (e.g., Sayizonga et al., 2016). In the face of these challenges, community participation and leadership are necessary for initiatives to succeed, yet most development initiatives in Thailand and across the world are designed with scant understanding of local contexts, community interests, or the histories and power structures in which problems are rooted (Gutiérrez & Vossoughi, 2010; Nuttavuthisit, 2014). Further, the participatory practices necessary for community empowerment and transformation (Freire & Macedo, 1987), as well as the understanding of larger schemes of exploitation (Freire, 1974), are usually absent from financial literacy education programs (Blue & Pinto, 2017). However, the development of local agency is essential for community members to become "agents of change" and take action together (e.g., Gutiérrez & Jurow, 2016). Such agency requires conceptual development on the part of communities: the ability to analyze their specific, local challenges and develop means of organizing and acting toward transformation (Vossoughi & Gutiérrez, 2016). In these contexts, community formative interventions, which include the development of germ cells, can provide a means for expansive learning and transformative agency (Sannino et al., 2016). Yet most literature on germ cells addresses only their initial development and application over the first few years of an intervention (e.g.,

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Ivaldi & Scaratti, 2016), tapping merely a small bit of the potential power of germ cells to be generative for years and across multiple areas of community life.

In this paper we consider how Ban Samkha developed a germ cell— "keeping it in the village"—and how this germ cell helped spur the village's learning through a truly remarkable series of intraventions over 24 years. The germ cell emerged through collective analysis of their financial problems and supported the development of many concrete actions in the village. Further, what began in the financial domain slowly expanded to other domains as the germ cell was incrementally developed over time. To study this, we drew on 37 hours of interviews across four visits over as many years in addition to over 350 pages of documentation by the village and a supporting foundation. We employ an iterative case study approach, using chronological sequencing and thematic analysis, and apply Engeström and colleagues' (2012) framework of learning actions for ascending from the abstract to the concrete to address the following research questions: (1) How did the village develop a germ cell? and (2) How did that germ cell evolve over time through multiple, concrete village-led intraventions? In the discussion we consider implications of this work for community development alongside theoretical insights from the village's markedly longitudinal and generative development of the germ cell.

Background

Village learning, like other community learning, can be observed in changes in practices, as conceptual thinking occurs in action (Davydov, 1990). Davydov (2008) proposes that when learners engage on a particular task, they "complete a sort of microcycle of the ascent from the abstract to the concrete" (p. 124) in order to assimilate, in a Vygotskian sense, theoretical knowledge and form concepts. In these sequences of learning actions, which consist of operations that occur within the context of a learning task, germ cells emerge as general concepts or activity units. Germ cells are abstract concepts created through iterative experimental and analytical examination of one's own community's practices (Gutiérrez & Penuel, 2014). The abstraction of the germ cell is developed in the process of modeling a solution to a problem situation and captures the genetic unit capable of creating new and concrete change (Falmagne, 1995; Davydov, 1990). For Davydov, the proponent of the term, these conceptual cells work like biological cells in the sense that "a cell is what everything stems from and is reduced to" (Davydov, 1999, p.47). To wit, germ cells reproduce like biological cells, generating new implementations and extensions of a concept as learners "ascend to the concrete" (Falmagne, 1995; Davydov, 1990) of concept formation by mastering conceptual understanding through concrete changes in practices—further constructing the abstract idea by applying it in everyday situations.

Engeström and colleagues (2012) have a long history of studying the development of germ cells in formative interventions where communities address challenges with the support of researchers. Building on Davydov, they argue that concepts are formed as learners ascend from the abstract to the concrete where, starting with a problem situation, they model an abstract concept that is developed and becomes concrete when applied in practice. This process occurs in a sequence of epistemic actions that include (1) questioning, (2) analyzing, (3) modeling, (4) examining, (5) implementing, (6) reflecting, and (7) evaluating. In such a sequence, the germ cell itself is discovered, modeled, and examined experimentally and analytically by learners as they investigate and transform their activities. Germ cells play an important role as the smallest unit of the complex totality of all the analysis and changes in practice, they carry the contradictions of the whole, and in practice can be ubiquitous to a point that they may go unnoticed (*Ibid.*). More importantly, germ cells are generative and can be extended in multiple applications and future developments. Yet while the generativity of germ cells is well argued for, most research on germ cells takes place in researcher-led formative interventions where the time limitations of research projects (i.e., 3-5 years) often curtail the evidence for the longevity and "multiple applications" of germ cells.

In the learning sciences, most research on germ cells has focused on single learning sequences to study how germ cells are formed. For instance, Engeström and colleagues (2012) studied how care workers at an elderly home alongside elderly people at risk of losing physical mobility collectively formed a new concept of mobility over a period of two years. Through the simple idea of "standing up" they included regular mobility exercises in home visits and daily life. This was generative in framing physical mobility in terms of sustainability and in generating innovative ways of using household objects to support mobility and autonomy. Other work has addressed the emergence of the "walk the talk" germ cell in a formative intervention among volunteers at a nonprofit as a concept that in practice can help align volunteer work with organizational values (Ivaldi & Scaratti, 2016) or the "tighten knots" germ cell as a concept that through concrete practices helped an interdisciplinary health promotion team come together and work towards common goals when providing health services from complementary disciplines (*Ibid.*). These examples focus on germ cell emergence without addressing germ cell generativity over time and domains.

This is not to say that there is no research that has focused on generativity beyond the initial conception and application of a germ cell. As an example, Sannino and colleagues (2016) describe how in a *series* of learning

sequences over many years, a community in an urban Brazilian informal settlement developed, sustained and expanded a germ cell. The germ cell, that trash has value and "trash is life," emerged as the community was dealing with flooding where trash in the river affected its members' health and safety. The community's questioning and analysis led to an *intra*vention on waste management, where the germ cell "trash is life" emerged. Yet the generativity of the idea continued far beyond this initial development, and the community continued to learn, as evidenced in their changing practices over 3 years in related areas: waste management and policies, flooding prevention, community safety, and even policy advocacy at a city level. Further, through the concept of "trash is life", the community became aware of its rights and its power to transform and improve itself (Sannino et al., 2016). We find this work particularly inspiring because it was not researcher-driven, but primarily community-driven (illustrated with the term *intra*ventions), in a sense a social design experiment (Gutiérrez & Jurow, 2016) generated by and iterated on by the community itself. This is also a provocative example of a germ cell that the community applied in multiple ways, providing evidence of the promised generativity of germ cells. Building on this work, we analyze the community-led formation and generativity of a germ cell in Ban Samkha across a series of learning sequences in community-led financial intraventions over a period of 24 years. We consider how the germ cell developed over time—evolving through iterative experimentation, practice, analysis, and reflection—and briefly describe how it became generative in other domains of village life through environmental, health, and educational initiatives.

Methods

Context

Ban Samkha is a rural village in northern Thailand (~600 people) that today is known as a "model village" in the country (Bruneau, 2009) for its financial, environmental, and agricultural sustainability initiatives, including a community bank, a successful homestay program (~3000 tourists a year), and a ban against herbicides and pesticides. By internalizing the learning philosophy of Thai Constructionism (see Blikstein & Fields, 2021; Fields & Blikstein, under review), the village developed an established sense of agency with a learning process they applied iteratively with perseverance. This paper is part of a larger study on the development and pursuit of a unique implementation of Papert's constructionism (1980) in Thailand (see also Cavallo, 2000), which over two decades was reshaped through local internalization into Thai Constructionism (Fields & Blikstein, under review). Elsewhere we have documented the transformative story of Ban Samkha's journey to become "a village that learns" (Fields et al., under review). Here we focus on the development and role of the germ cell—"keeping it in the village"—that helped drive their communal work in finances.

Participants, data collection and analysis

We collected data during four research visits to Thailand from 2017-2020, including three extended research visits to the village. We interviewed 14 villagers and 6 people from other institutions that mentored and/or learned from villagers, totaling more than 37 hours of interviews, in addition to gathering over 350 pages of scanned project documentation, including a book published by the village (Ban Samkha, 2005). Interviews focused on participants' personal and collective narratives of struggle and change, as well as experiences learning with constructionism (the original topic of the broader study). Later interviews built on early analysis, soliciting specific details about what led to significant events and projects. Overall, we spent 1-5 hours with each participant, individually and/or in focus groups. Further, to develop a common understanding of research interests and IRB concepts of privacy and research protections, we spoke with translators extensively before interviews to support more meaningful translation and interpretation. Of note, the native language of Ban Samkha villagers is Lanna, and interviews were conducted in Thai, English, or a blend, depending on villager preference. We clarified meanings whenever greater understanding was needed.

The 14 participants interviewed, while a small sample, represented a range of people who participated in the constructionist efforts over the course of 24 years in different ways. Some were children at the time of the first intraventions and as of our last visit led various village committees. Others joined in very peripheral ways in the early years and became more involved 5-10 years later but are not considered core leaders of initiatives. Still others did not even begin to be involved until 10 years after early intraventions in the village. Some were the original core leaders. The villagers chose who we interviewed. We began with a few contacts in the village, networked through a foundation that worked with them since 2001. We requested to meet a range of people involved in different ways, and our contacts chose people from a variety of ages, professions, and gender, including local farmers, teachers, parents, homestay hosts, local monks, village committee leaders, etc. We were invited into homes as well as the village meeting hall and participants showed us their accounting forms, reflective documents, farm products, crops, fruit trees, check dams, etc. The villagers we interviewed represent only a

fraction of those involved in constructionist efforts in Ban Samkha and of the village population at large (~600 people). While interviews were primarily based on memories, some 20+ years old, these were checked by villagers' meticulous written records and reflections, for instance of every visit by mentors over 24 years (into the hundreds), records of village and family farm finances, and contributions (knowledge and monetary) by outside organizations. Most notable is a publicly available, village-authored book covering 1999-2003, including detailed explanations of the historical origins of village problems and sequences of early intraventions (Ban Samkha, 2005). To honor and reference Ban Samkha's own written history as well as other native Thai authors who have researched the village (e.g., Koanantakool, 2004; Sipitakiat, 2020), we identify the village by name. Consequently, we seek to protect the identity of participants by keeping names and identifiers of individuals as anonymous as possible. This serves to protect villagers who could be easily identified by gender, age, or profession.

In developing the case study, we conducted chronological sequencing, and thematic analysis (Merriam, 1988) to organize villagers' accounts of events. Before our third data collection visit to the village, we created a comprehensive timeline of key events. Then, during this visit, using an 8-foot-long version of the timeline with movable post-it notes for events, we invited villagers in four different focus groups to help fill in missing events and confirm the order. Villagers checked each other's accounts, and together we created a firm order of key events important to villagers which further prompted reflective, insightful conversations. Once we had a clear understanding of the intraventions conducted in the village we conducted thematic analysis (Yin, 2018) of initiatives in five key domains of village life (financial, environmental, educational, agricultural, entrepreneurial) across all interviews. Through this process we recognized that villagers engaged with a germ cell that we summarize in English as "keeping it in the village". Further the meaning of this germ cell changed over time—evident in villagers' explanations of their initiatives, reflections, and changed thinking. Following this insight, we applied Engeström and colleagues' (2012) framework of learning actions for ascending from the abstract to the concrete as an analytical grid to investigate how the germ cell was developed and identify the sequence of learning actions within each intravention. Then we compared how the model of the germ cell changed and evolved in practice to analyze its development and generativity over time.

For external validity we engaged in "member checking" with feedback sessions at several stages of analysis and writing, including follow-up interviews, focus group interviews, and the timeline construction. In addition, two long-term Thai Constructionists with 15-20 years of experience with the village provided feedback on our findings to support analytical rigor as well as political and cultural sensitivity.

Findings

To situate Ban Samkha's challenges historically (Gutiérrez & Vossoughi, 2010), we begin where the village itself placed the origins of its current financial struggles. In the mid-1900's, as modern farming technologies were advertised and better roads connected the village to the provincial capital, farmers bought "iron buffalos" or walking tractors, started selling rice and produce to middle-people from outside the village, and began utilizing chemical fertilizers, pesticides, and herbicides (Ban Sam Kha, 2005). Villagers took out high-interest loans for farming, vehicles, and secondary education for children (*Ibid.*). But it was the 2540/1997 crash of Asian markets, which started in Thailand, that took village debt to unprecedented levels. That year, the country's economy contracted 11%, and the cost of living increased by 40% (Hewison, 2000). Villagers returned from the cities looking for work and the collective debt of all families summed more than 18 million baht (31 million baht or 1 million USD adjusted for inflation, ~12,000,000 USD converted per purchasing power parity) gathering interest at high rates (Koanantakool, 2004). Something had to be done. As one villager explained, they had to find ways to survive because "the entire village was in bad debt" (interview, 2018). Debt was a common problem across Thailand, as were government interventions to try to resolve it, including the 2512/1969 "village fund" (Coleman, 1999). However, in Ban Samkha and other villages, this initiative failed. As a villager explained, "because of our lack of knowledge, we used [the] money the wrong way… we actually used it for our daily expenses" (interview, 2020). However, in 2540/1997, the villagers approached their financial issues with a new and different resolve: to understand them and seek knowledge. Thus began a series of initiatives—or intraventions—by the villagers to learn ways to address their financial problems, a process that led to rich financial literacy and further developments that the village could not have predicted at the time.

Keeping it in the Village: Forming the Germ Cell

In pursuing financial health, villagers eventually created a new concept: "keeping it in the village." This germ cell developed across successive and iterative intraventions. Here, we analyze how the germ cell was formed through a sequence of learning actions taken by the village. In 2540/1997, villagers began by **questioning** the nature of their debt. Unlike prior efforts, they rejected the idea that they could not understand their finances, sought help to learn about debt and organized to find solutions. In a second learning action, with the support of a Japanese

nonprofit, "fourteen smart people studied debt in depth" (interview, 2020), spending 3-4 hours daily over an entire year to inquire into the origin of villagers' debt and **analyzed** it using spreadsheets to keep track of income, payments and debt owed. A village leader explained:

> We looked back to try to figure out how all the debt was accumulated and how the problem might be solved. We realized that the villagers didn't have savings, only debt. Saving is hard if the amount of money is small, it's difficult to deposit it to the bank (interview, 2020).

This initiative, which they called the Debt Research Group, was not a complete sequence of ascension to the concrete as described by Engeström and colleagues (2012) and did not yet model a new concept or germ cell. However, after the debt analysis villagers realized they needed to find a way of "creating savings within the village" (interview, 2020). The questioning and analysis conducted during this intravention led to the first model of a plausible solution that same year (2540/1997), an intravention they called the Honesty Savings Group.

The village council decided to mandate participation in the Honesty Savings Group, with 40 families each contributing 30 baht/month (~1 USD/month in 2021 rates) to a collective fund that was then used to make payments on the most urgent loans (like that described by Martin, Goldman & Jiménez, 2009). It was here that the first iteration of the idea of "keeping money in the village" appeared: villagers engaged in **modeling** the new idea, or germ cell, which provided the beginnings of a plausible solution to their financial problems—saving money, paying off debt and working collectively. They **reflected** and **evaluated** their work looking for possibilities to expand it: "we learned from creating the savings group. When we took out loans, the interest was high. So, we said to each other, let's stop getting loans from the bank. Let's use our own savings for the loans" (interview, 2020). In other words, villagers began to conceptualize the need to save money, pay off debt (even a little), and not take out further loans to pay off earlier loans. Villagers' learning actions in these two initiatives set the stage for later work that evolved around the emergent germ cell "keeping it in the village".

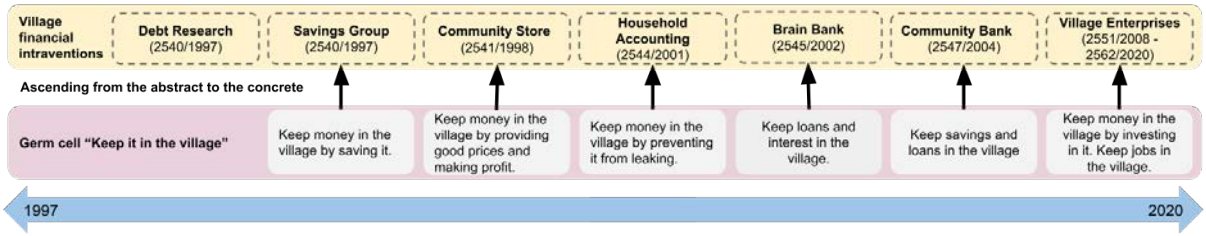
Generativity of the germ cell

The germ cell of "keeping it in the village" was core in the development of several more concrete financial initiatives that also helped to further refine the idea, leading to a cycle of generativity (see Figure 1) where the village went from saving money with the Honesty Savings Group, to keeping it from "leaking", to investing it.

In 2544/2001, villagers extended their research into the nature of their debt in the Household Accounting Program, shifting from a village-level analysis of how much debt existed to family-level analysis of how debt was created. Support came from a Thai foundation that invited a janitor from a nearby industrial plant to share how he kept track of his finances using a simple spreadsheet that laid out income and expenses. After formal discussion, including opposition from some villagers, the village council decided to make the Household Accounting Program mandatory. Small groups of 6 households, each with a leader (usually a woman) completed household spreadsheets and met monthly to share insights from their accounting and identify how their debt was created. The village decided to use the funding the foundation provided for snacks to pay each household leader (30 baht/month, ~1 USD in 2021 rates) for the effort of accounting, adding to the potential to save money. Thus, research on village debt evolved into research on family debt, which led to insights about over-expenditures that allowed for changes in family financial practices, namely, to keep money from "leaking" out and encourage saving within families. The Household Accounting Program was credited for many behavioral changes in people's lives. For example, one man, who had been contemplating suicide because he did not understand why his debt grew the more and harder he worked, learned through his analysis of daily expenses that instant coffee purchases were beyond his means; further, the more he worked, the more he spent on coffee packets (interview, 2017). Understanding his income and expenses helped him change his habits and decrease coffee consumption (*Ibid.*). Villagers shared many other stories of how the insights from accounting research helped change their spending habits. The Household Accounting Program provides the first example of how the germ cell "keeping it in the village" began to expand beyond its initial conception to include preventing money from "leaking out," made concrete through the new layers of self-research and changed family practices.

Figure 1

Visualization of the generativity of the germ cell and its development over time.



Other intraventions further developed the germ cell by creating a cooperative store and banking systems within the village that could keep profits, financial transactions, debt, interest, and savings in the village. The cooperative community store, opened in 2541/1998, provided reasonable prices for villagers, creating beneficial competition with the other stores in the village and allowing families to save more. At the same time a portion of revenue from the store went directly into village coffers, enabling the village itself to invest in community initiatives and infrastructure. Here, "keeping it in the village" included price competition and profits. A second intravention was the Brain Bank, a youth-led bank that issued loans to villagers. It started in 2545/2002 when children used savings from a fundraising event at an English language camp to provide a small loan to a cherished elder. In this bank individual villagers themselves chose what interest they could pay, including unusual forms such as providing expertise on raising crops or animals. Not all loans were paid back in a timely manner, leading to some difficult learning, but slowly profits built up. This was the first time that interest from loans (even in the form of animals or expertise) was kept in the village rather than paid to an outside financial institution. This success, along with a growing understanding of interest and loans, led to the later development of a Community Bank (2545/2004) in partnership with a commercial bank in the provincial capital. One villager reflected on how one initiative led to another and to the creation of the community bank:

> Every family had debt and paid interest. We never talked about it, villagers just paid whatever interest the outside banks calculated. We saw the data, and the bigger picture: we were really getting taken advantage of. We told the villagers that we were going to build our own bank. We created our dream. (interview, 2020)

Some villagers attended a year of classes to learn how to manage the bank. Now, villagers earned more interest on their savings, paid less interest on loans, and the village itself benefited from loan payments.

Other financial initiatives over the past 15 years focused on keeping money in the village by investing in small enterprises (see Figure 1). A younger generation of villagers, that were children and teens while the germ cell emerged, have recently started several enterprises including a rice paper plant, a dried mushroom factory, and a local tourism program. All the enterprises capitalize on the village's resources (leftover rice leaves, foraged mushrooms, native knowledge, and people) at the same time as they prioritize hiring and paying people from their village and others nearby communities, keeping money and jobs in the region.

The germ cell of "keeping it in the village" became so important that the village now teaches its children about savings and interest through a savings program in the primary school. All children entering the school get a savings spreadsheet to track how much money they save during primary school with interest calculated monthly. Every week children bring in allowance or earnings from small jobs like traditional dance performances at the village homestay. "It's become a tradition of saving, everyone has to bring their own cash to school, it's like creating a discipline and habit of saving for the kids," (interview, 2020) a teacher explained. Over the course of 7 years (K-6), some children even save enough to pay for secondary school expenses.

Generativity in other domains

Over the past two decades the germ cell, "keeping it in the village," has further developed as villagers implemented concrete intraventions beyond financial initiatives. After six years of work on debt and financial management (with parallel efforts in education and computers), the village sought to study (and then invest in) their *environment* as a source of income:

> After the research of 2544 [2001], we knew that our income mostly came from the forests and mountains. When we knew where the money came from, we became interested in the environment. It started after the research; the research told us to do so. (interview, 2020)

This led to the development of sustainable water and fire management intraventions (see Fields et al., under review) which extended the germ cell to literally keeping water in the village as well as protecting the natural resources the village had. Other intraventions extended the germ cell to keep *health* in the village by banning pesticides and herbicides and promoting organic farming. In more recent years, village leaders have recruited young people (pursuing education and careers in cities around Thailand) to return to the village. Young people have filled positions leading the savings and loans programs, managing the homestay program, teaching in the school, managing dam maintenance, and running fire prevention initiatives. The village is quite literally seeking to keep their *young people* in the village, embodied most fully in a young people's branch of the village council. Though space prevents us from exploring these examples in more depth, the germ cell which the village developed through iterative learning sequences of ascending to concrete change has become extremely generative in the multiple intraventions the village has conducted over more than two decades, beginning in the domain of finances but stretching to the environment, health, and urban/rural migration.

Discussion

In this paper, we documented how the germ cell "keeping it in the village" emerged through Ban Samkha's collective analysis of financial problems. Before their transformative series of intraventions, villagers struggled financially even when provided with outside support such as the early "village fund" program sponsored by the government. They did not understand their financial problems and their causes. Through iterative analysis and collective reflection, villagers developed the germ cell: a concept they could comprehend and apply across different initiatives. Indeed, the germ cell gave them the means to understand the underlying issues of their problems, organize and transform their reality over 24 years, becoming a "model village" in the country (Bruneau, 2009). Our analysis demonstrates that the germ cell played an important role in community-driven learning and formative interventions as members used it to communicate concepts in practice with each other as well as with outsiders, explaining and modeling plausible solutions to problem situations. Like the Brazilian community discussed by Sannino and colleagues (2016), intraventions in Ban Samkha and the development of the germ cell were not researcher-led, but community-driven, with support from outside organizations, resulting in multiple generative, practical, and transformative intraventions by the community for the community. Iteratively modeling the germ cell was key as villagers developed empowering abilities (Freire & Macedo, 1987) to study and understand their problems, think critically, and enact change. The community-driven learning and decades of work of Ban Samkha provides an alternative to the large (and often unsuccessful) efforts of other more top-down development initiatives that do not focus on local understanding and leadership.

While iteratively developing the germ cell "keeping it in the village", the villagers transformed the social and material settings of their community. They applied means of collective analysis and reflection, locally adapting methods (e.g., the philosophy of Thai Constructionism) and tools (e.g., spreadsheets, notational forms of household accounting, models of a community bank) that they learned from other people and organizations. One crucial element was the creation of village-wide policies that mandated that everyone participated in initiatives such as the Household Accounting Program or later banning all herbicides and pesticides from village farms. These tools and policies (mandated or otherwise) bring up the role of infrastructures in the village's work. Engeström and colleagues (2012) recognize the importance of infrastructure in ascending from the abstract to the concrete by calling for "further analysis of the roles and potentials of mediational artifacts in actions and activities" (p. 304). Elsewhere we have begun to explore the series of policies that the village established that supported collective change even if some members were resistant (Fields et al., under review). While it is beyond the scope of this paper to fully account for and explore the role of representational and social infrastructures (Ma & Hall, 2018) that supported the village's generative work, we note this as an area for further research. Studying how germ cells, or conceptual practices, evolve over long periods and how, in the process of ascending from the abstract to the concrete, learners transform representational and social infrastructures that can support the generativity of germ cells themselves, is important for better understanding and supporting community-led transformative change.

Our analysis complements studies that focus in more detail on the first years of germ cell development, providing insights into how a community can evolve, adapt, and iteratively apply a germ cell over time and in practice. The "it" of "keeping *it* in the village" came to mean not just leaked out money, but investments, interest, loans, expertise, water, environmental resources, and people. The longitudinal lens of the study (achieved in large part through the detailed record keeping and collective memory of the villagers) provides insights into the generativity of the germ cell and was essential in seeing its continued, iterative development.

Ban Samkha constitutes an existence proof of the power of emancipatory collective action (Gutierrez, & Jurow, 2016; Freire, 1973) in which communities solve complex problems by learning, collaborating, and getting to the bottom of long-established oppression schemes. By reading and writing the world with a new and expanding lens— keeping it in the village—they transformed the village and transformed themselves.

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Conceptualizing Three Approaches for Integrating Criticality in K-12 Computing Education

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Abstract: As several critical issues in computing such as algorithmic bias, discriminatory practices, techno-solutionism have become more visible, numerous approaches are being proposed to integrate criticality in K-12 computing education. Yet, how exactly these approaches address criticality and translate it into classroom practice is not clear. In this conceptual paper, we first historicize how current approaches in critical computing education draw on previous work which has promoted learner empowerment through critical analysis and production. We then identify three emergent framings: (1) inquiry, (2) design and (3) reimagination that build on and expand these critical traditions in todays' K-12 computing education. Finally, we discuss how these framings highlight issues to be addressed and provide directions for further learning sciences research and design.
Keywords: critical computing, computing education, literacies, empowerment, criticality

Introduction

As CS education has gained an unprecedented momentum, becoming part of the K-12 curriculum over the past ten years (Halvorson, 2020), several critical issues in computing as a discipline have become more visible: (1) algorithmic bias is pervasive and reinforcing historical inequities and damaging minoritized communities, (2) discrimination in industry against minoritized peoples in hiring and management practices continues, and (3) computing continues to be taught and learned as a value neutral subject (Gebru, 2020). Today we recognize that code is not neutral, computing technologies reflect the values and biases of their creators and computing alone is not the solution to all problems, it often perpetuates existing concerns, causes new problems or deepens existing ones (Costanza-Chock, 2020). In K-12 classrooms, computing is commonly introduced and experienced as a "value-neutral tool independent from society" (Ko et al., 2020, p.31) without considering its societal and ethical implications (Vakil, 2018). Yet learning computing with disciplinary authenticity requires attending to its critical and political dimensions (Philip & Sengupta, 2020).

More recently, efforts to foreground criticality in K-12 computing have addressed this lack of concern for societal and ethical implications and limitations of the discipline through numerous approaches, among them: justice-centered efforts (Vakil, 2018; Costanza-Chock, 2020; Lin, 2021), critical computational empowerment (Tissenbaum et al., 2017), critical computational literacy (Lee & Soep, 2016), critical computing literacy (Scharber et al., 2021), responsible computing (Mozilla, 2021), computational action (Tissenbaum et al., 2019), critical algorithmic literacy (Dasgupta & Hill, 2021) abolitionist computing (Jones & araujo melo, 2021), computational empowerment (Iversen et al., 2018), and counter-hegemonic computing (Eglash et al., 2021). While this proliferation of proposals highlights the growing importance given to critical issues in computing education, it is unclear what each approach means by criticality in computing, who is participating in these efforts, and how students and teachers are engaged in critical computing activities.

In this conceptual paper, we take a step back from individual approaches by identifying their historical roots in human computer interaction (HCI) and in language arts and literacy (LAL) studies and how these perspectives foreshadowed today's critical computing education (CCE) efforts. We then identify and describe how three emergent framings— (1) inquiry, (2) design, and (3) reimagination— address criticality in K-12 computing education. Finally, we discuss how these framings highlight issues to be addressed and provide directions for future learning sciences research and design.

Historicizing criticality

Recent calls for considering the political dimensions of learning sciences in design and research (see Booker et al., 2020; Philip et al., 2017) have been followed by efforts in critical science literacy (Ryu et al., 2020), critical history and social studies (Jackson, 2020; Hostetler et al., 2018), critical data literacies (Irgens et al., 2020; Stornaiuolo, 2020), and also in computer science education (Ko et al., 2020; Kafai & Proctor, 2021). Yet critical perspectives in computing and how computing is learned and taught have been present from the early days. For instance, Weizenbaum (1976) argued that the technical innovation of computers did not necessarily promote social progress. Most importantly, he distinguished the differences in human and machine decision making, noting that

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computers lacked compassion in their calculations. From the education side, Papert (1987) pointed towards the fallacy of seeing the computer (or software program) as the agent of change in student learning, considering people and culture as the driving forces of learning. Discussions in computing and education about criticality have developed in HCI around the Aarhus conferences community (Bertelsen et al., 2005) and in the new literacies movement around the New London meetings (New London Group, 1996). These two perspectives combined can be helpful to situate current efforts in CCE and better understand the development of different pedagogical approaches.

Many learning science researchers are familiar with work from language arts and literacy (LAL) studies where critical literacies are seen as ways of being and doing through which learners participate in the world. Central here is Freire's work on critical consciousness and literacy. Freire (1970) proposed an emancipatory model of literacy based on a dialectical relationship between the human beings and the world, where literacy is not seen as a collection of skills but rather a precondition for freedom, participation in the world and social empowerment within a wider project of social and political reconstruction. These ideas were further developed in the New London Group meetings where the multimodality of literacies and pedagogy were considered to propose that literacies must have a critical framing for learners to grow in their practice while consciously engaging with historical, social, and political contexts (see Cope & Kalantzis, 2000). Today, critical literacies bring together ideas from marxist, queer, feminist, postcolonial, and critical race theories to inquire on the dymanics of power present in the world and the learning process. In a recent review, Vasquez and colleagues (2019) argue that such a framework does not always involve taking a negative stance, but rather looking at issues from different perspectives, analyzing, suggesting and creating possibilities for change and improvement. The vast literature in critical literacies can be helpful in bringing CCE to K-12 classrooms. In fact, thinking about computing by applying frameworks from literacies is not new. The relationship between reading and writing code as extensions of literacies has been extensively discussed (see DiSessa, 2001; Vee, 2017) by emphasizing how learning computing is necessary to fully participate in the world.

Lesser known is that in HCI the term "critical computing" has a long history that dates to 1975 when the first Aarhus conference convened to discuss the development of computing systems in context. These conversations at Aarhus emerged through dialogues on how computing could support workers with a particular interest in marxist approaches for understanding the design and use of technology in relation to class and power struggles (Nygaard, 1992). Over time, these discussions have evolved, expanding critical computing to "critical action, not only as workplace actionism, but also by integrating a broader scope of critical analysis and critical practice" (p. 3)—grounded in political, economic, and aesthetic theories—in how computing systems are designed and used in the workplace, education, and at home (Bertelsen et al., 2005). The contributions of the Aarhus community and their perspectives on computing challenge many of the everyday practices of computing professionals and the ways we introduce learners to the field. For instance, within the Aarhus community, Burstall (1992) reflected that computing education that prioritizes technical concepts at the expense of critical awareness of other people and the environment loses the ability to accomplish the goals of the field.

Empowerment

Even though these critical perspectives in computing and education are products of different communities, contexts, and conversations, taken together they provide useful underpinnings for CCE. Indeed, the agency of learners, and the analysis as well as production of texts and code have been conceptualized as foundations for critical engagement in both traditions. To begin with, both HCI and LAL emphasize the need for empowerment or agency of learners. For instance, in Freire and Macedo's (1987) emancipatory model of literacy, literacy is a precondition for empowerment and participation in the world. Recently, critical literacies have been framed as a way of being and doing (Pandya & Ávila, 2014), extending literacies beyond an orientation for teaching and learning. This with the goal that learners can analyze and interrogate the micro features of texts and their macro—institutional, political, societal—conditions while focusing on how relations of power work, design and produce texts beyond classroom assignments (Vasquez et. al., 2019). The goal of literacy here is also one of empowerment, for learners to critically engage with the world to design social futures (New London Group, 1996). From the HCI perspective, Aarhus' "critical computing" proposes that computing is a process of reality construction and transformation of the world (Floyd, 1992). This opens possibilities to reframe the development of computing applications from designing for requirements to designing for the opportunities of creating better, more just, and equitable worlds (Floyd, 2002). In this sense, novice learners must be empowered to use their curiosity and creativity to critically interrogate the history, implications and limitations of computing and create for the possibility of more equitable futures. How do these perspectives envision to promote agency or empowerment of learners? Two approaches stand out: one being reading or analysis, the other being writing or production of "texts" or "code".

Analysis

In both LAL and HCI analysis plays an important role in critical empowerment. For instance, in literacies, critical reading engages learners in reading beyond the words of the page. Indeed, for Freire "reading the world precedes reading the word" (Freire & Macedo, 1987) as learners can use critical literacy to make sense of their reality. Critical reading involves deconstructing texts (e.g., media, discourse, technologies) to question how these are constructed (Vasquez et al., 2019). This kind of reading generates opportunities for "unpacking myths and distortions and building new ways of knowing and acting upon the world" (Luke, 2014, p. 22) by consciously investigating relationships of power, ideologies, and values in the process of reading (New London Group, 1996). As learners critique texts, they deconstruct and reconstruct them creating opportunities to disrupt, examine and sometimes dismantle problematic practices as well as to imagine alternatives, hypothesize how to change things and even take action (Vasquez et al., 2019). Similarly, in the Aarhus community technological criticism also plays an important role for understanding the impact of computing and how computers are used. Indeed, here reflection on the unconscious values embedded in computing applications and practices is central as well as investigating the ways in which technologies perpetuate oppression (Sengers et al., 2005).

Production

To promote agency, writing or production are important. The New London Group (1996), in reframing literacy studies, foregrounds the key role of designing new texts and redesigning existing texts for learners to participate in designing the future. This process of production requires that learners understand the positions from which they design so that they too read their own creations critically. This perspective resonates with Freire's (1985) idea that "reading the word is not only preceded by reading the world, but also by a certain form of writing it or rewriting" (p. 18). In this context, critical literacies are not only critical reading but also critical writing where writing means designing and redesigning texts in ways that aspire towards justice and can be socially transformative. Likewise, Christiane Floyd (2005), who played a key role in shaping the critical computing agenda within the Aarhus conferences, argues that in critical computing, understanding the impact of computing and how computers are used is not enough. She claims that critical computing is intertwined with the development of computing applications and the goal that these applications should have a positive impact in society. Furthermore, Floyd argues that there is a difference between being critical in computing and being critical on computing. Being critical in computing is concerned with design and production of critical computing applications. This is distinct from being critical on computing, which centers technological criticism over the design of applications that can address critical issues. Critical computing involves considering that in producing computing applications social and technical factors are intertwined (Andelfinger, 2002). From this perspective the idea of computer programming must be widened to take the social context of software and its development into account (Nygaard 1986). Programming is framed as the means for non-technical ends or goals (Andelfinger, 2002) which require investigating how the decisions taken when coding have social and environmental implications (Nygaard, 1992).

Integrating criticality in K-12 computing education

Reviewing the historical roots of criticality in both computing and education provides a backdrop to examine how current research promotes CCE. From this review of HCI and LAL it emerges that CCE must empower learners to critically analyze computing, examine power and values, and interrogate the implications and limitations of computing applications. Likewise, CCE should include creating computing applications that aspire towards justice and that reflectively consider the limitations and implications of computing for people and the environment. In this section, we propose that out of these two traditions, three different pedagogical operationalizations or framings CCE emerge: (1) critical inquiry, (2) critical design, and (3) critical reimagination. Each of these approaches promotes the empowerment of learners through critique (reading), production (writing), or combinations thereof.

Critical Inquiry

One approach to CCE, which we call "critical inquiry" involves students inquiring on the implications of computing. Here Lin (2021) argues that affordance analysis can be used in computing education to examine how algorithms and abstractions such as data structures have political implications. For instance, the use of binary trees in hiring decisions, autocomplete for search engines, and shortest paths for navigation can have problematic unintended consequences that reproduce systemic injustice. According to Lin, comparative analysis of data structures and algorithms can enable students to critique the dominant approaches that address social good without design justice and problematize power in computing. Having students be critical on computing in the same courses where they are learning technical concepts and skills can situate conversations and applications of technical concepts in their social context. Other initiatives have addressed how in computing inequities are not just

reproduced but amplified in new ways. For instance, in a design experiment conducted by Vakil (Irgens et al., 2020), students examined surveillance technologies in their communities and created infographics to explain the implications of these technologies. Through this experience students explored the ethical tensions of how the surveillance technologies they use in their everyday lives reproduce practices that disproportionately target and impact minoritized communities.

The "critical inquiry" approach centers on critique—that is looking at issues from multiple perspectives, analyzing dynamics of power, and suggesting possibilities for change (Vasquez et al., 2019), drawing on the tradition of LAL. This approach can be productive when integrated across introductory computing curricula in order to have learners consider how the decisions made while programming have social and environmental implications. That way as novices learn technical concepts and programming skills these can be grounded in critical socio-technical conversations on computing (Nygaard, 1992). When engaging in critique, learning activities can connect to the lived experiences of students, like in Vakil's experiment, by having them investigate the implications and limitations of the technologies they use. Critique can be empowering, giving students the rightful presence—that is legitimized membership and participation, where the community works towards justice by making injustice and social change visible (Calabrese Barton & Tan, 2019)—to interrogate systems of oppression and question what computing is and how computing is enacted in the world. At the same time, learners can have agency to decide what issues they want to investigate. Yet CCE has the potential to go beyond inquiry by engaging learners in the production of critical computing applications.

Critical Design

A second approach to CCE, which we call "critical design", centers on designing and redesigning with computing in ways that aspire towards justice and change. In this approach learners critically design applications that address the needs of communities. For instance, Lee and Soep (2016) argue that when young people design applications to address their own community problems, they create opportunities for themselves and their communities, and that "only through production of these digital tools will youth develop the agency required to make the changes they want to see" (p. 481). Through their experiences at Youth Radio, they have documented how youth create mobile and web applications for their communities, including, for example, an app called "Know Your Queer Rights" that provided resources to support LGBTQ+ youth (Soep et al., 2021) or an app to track and raise awareness of gentrification (Lee & Soep, 2016). Other approaches to critical design have students design for communities other than their own. Bar-El and Worsley (2021) discuss a course, centered around accessibility, designed to encourage students to explore computing as a field that promotes democratization by having learners design tools and activities to broaden participation in CS. In this intervention students were embedded in the spaces for which they designed and were in dialogue with community members. They argue that by creating real-life projects for real communities, learners can benefit from interrogating the history and assumptions of computing and its applications (Bar-El & Worsley, 2020). Overall, Tissenbaum and colleagues (2017) propose that empowerment comes from creating interventions in the real and physical world in which learners analyze the problems of their communities and create real solutions. For them, learners must have opportunities to create applications that have an impact on their communities from the moment they begin to learn how to code (Tissenbaum et al., 2019). This contrasts with common approaches to computing education that prioritize learning technical skills first and working on real-world applications later.

While engaging in critical design, learners have the opportunity to participate in critiquing and producing computing applications. Critical design aligns well with the ideas from the Aarhus conferences particularly seeing programming as a social activity where writing code is the means for non-technical ends or goals (Andelfinger, 2002). It also addresses coding, in a similar fashion to how critical literacies theorize writing, as the process in which learners design and redesign in ways that aspire towards justice while reading their own creations critically (Vasquez et al., 2019). Critical design is also an opportunity to design computing applications beyond requirements, thinking about the opportunities (Floyd, 2002) that computing gives creators and users to make more equitable worlds and to inquire into the sociopolitical values and purposes of making with computational technologies (Vossoughi et al., 2016). Furthermore, analyzing problems in their communities and designing computing applications to address these problems can support the development of learners' rightful presence, empowering students to be and do critical computing in authentic and meaningful ways. But empowering students also means giving them the creative power and freedom to pursue their own interests and projects. These design activities can connect to learner lives beyond deficit views of their experiences (Jones & araujo melo, 2021) recognizing how the cultural wealth of their communities can have a positive impact in the learning environment and the computing applications youth create. This requires thinking about cultural context beyond making superficial connections to computing concepts so that learners can participate in their culture while computing,

draw from their own culture and even remake it by investigating authentic problems and concerns they can engage with in their designs (Blikstein, 2008; Hooper, 2008).

Critical Reimagination

A third approach involves "critical reimagination"—rethinking the present and the past to critically reimagine computing and technology and create more equitable and just futures. Holbert and colleagues, for instance, created the 'Remixing Wakanda' project (2020) in which Black female youth used their personal stories to design speculative artifacts that address social and environmental injustice. Bringing together Afrofuturist and constructionist ideas participants imagined and created possible futures where their communities thrived and where technology helped create a more equitable and sustainable world. They reimagined how technology could be used proactively to improve their communities. They created speculative computing projects such as a cloak that expressed information about the health, wellness, mood and identity of its wearer or a trash can that converted waste into energy. Other efforts have focused on having students reimagine computing cultures that are equitable where female, Black and brown youth can fully participate. Efforts employing restorying (Shaw et al., 2021) build on Black feminist perspectives for youth to imagine and build the worlds and computing cultures they want to live and participate in. Shaw and colleagues (2021) describe how youth engaged in interrogating dominant narratives about CS and crafted computational artifacts that reimagined CS, its values, who can participate and how it is done.

Critical reimagination engages learners with the social and political reconstruction discussed by Giroux (1987) that requires critique, production, and empowerment. As bell hooks (1991) argues imagination is emancipatory because thinking of possible futures involves critical thinking, analysis, and reflection of the present as well as a desire to build better worlds. In this approach when learners engage in production, they design beyond requirements for the opportunity of creating better worlds. Learners address critical computing as emancipation (Dearden et al., 2005) and through their speculative computational artifacts transform the world by constructing and proposing new realities (Floyd, 1992). Here learners are empowered to reimagine what can be done with computing and what computing can be, having the rightful presence to question and rethink the discipline. Yet in critical reimagination activities it is important to provide space for student agency so that they develop their own voices while accomplishing their desired computational goals. Reimagination connects the past, present and future, understanding that technology is not created in a void but builds on previous traditions. With critical reimagination the future is not pre-established but rather learners engage in what Freire (1970) calls hopeful "revolutionary futurity," looking at the past to understand themselves and addressing how the present must change in order to imagine and build the future.

From our analysis, we see that some of these current efforts in CCE align with the three proposed framings while others engage with more than one. For instance, justice efforts (Lin, 2021) align with critical inquiry while critical computational empowerment (Tissenbaum et al., 2017), critical computational literacy (Lee & Soep, 2016) and computational action (Tissenbaum et al., 2019) prioritize critical design. Abolitionist computing (Jones & araujo melo, 2021), counter-hegemonic computing (Eglash et al., 2021), and restorying (Shaw et al., 2021) tend to align better with critical reimagination. Other justice-centered efforts (Vakil, 2018), responsible computing (Mozilla, 2021), critical computing literacy (Scharber et al., 2021), and critical algorithmic literacy (Dasgupta & Hill, 2021) engage both critical inquiry and design. Computational empowerment (Iversen et al., 2018) and justice-centered efforts such as Costanza-Chock's (2020) design justice address critical inquiry, action and reimagination.

Considerations for the Learning Sciences Design and Research

As the learning sciences turn their attention to the political and critical dimensions of learning (Philipps et al., 2017) so is K-12 computing education. By historicizing how criticality has been approached in computing and education we situate CCE in both fields. The three approaches we discussed as framings for learning and instruction emerged from our analysis of efforts to design and research criticality in computing.

In identifying the different directions criticality assumes in each of the framings, we also noticed several issues that require special attention in designing and researching learning tools, activities, and environments: (1) who is involved in addressing critical issues in computing, (2) how to avoid the pitfalls of techno-solutionism, (3) how learners engage creatively with criticality, and (4) how do we connect learning disciplinary skills and concepts with criticality. First, criticality in computing should be addressed by all. In reviewing the various efforts in critical inquiry, design and reimagination we noticed that these involved mostly students from racialized and minoritized communities. While this was probably done with the best intentions, to broaden participation, we

should also be aware that such efforts could put a double "burden" on learners of minoritized communities (Jones & araujo melo, 2021), first as those who predominantly experience marginalization and discrimination when using technologies and participating in computing, and then as those tasked to identify challenges, develop new solutions, fix problems, and reimagine alternate futures. This is important work, but it is essential that *all* learners are engaged in CCE.

Second, while having students create computing applications that address real world problems is beneficial, it is equally important to consider what already exists in the communities that learners engage with, encourage them to be critical towards their own work and avoid the pitfalls of techno-chauvinism and techno-solutionism—the beliefs that technology is always the solution (Costanza-Chock, 2020). Indeed, the critical design and reimagination approaches must acknowledge the limitations of computational solutions, questioning the possible implications of using computing to "fix the world."

Furthermore, we must consider how learners engage creatively with criticality. In inquiry, design and reimagination learners can connect to their personal interests and their lived experiences, to think, create and share their ideas with their peers. To do this, learners' agency must be authentic, giving space for students to decide what issues to investigate and what kind of artifacts they want to create. This with the goal that they can engage in what Freire (1970) calls the "creative transformation" of understanding, coding and participating in the world. Ultimately, while we want learners to "have the opportunity to experience the full conceptual and expressive powers of coding" (Resnick & Rusk, 2020, p. 121), we also see a need to connect criticality back to creativity and curiosity.

Finally, we should also consider how we join criticality with efforts for developing technical coding skills rather than seeing them as separate enterprises. We take note that efforts in CCE predominantly take place in out-of-school settings. This is partly because current curricular frameworks and standards are very much focused on teaching and learning of computational skills and concepts, often relegating criticality to the sidelines. Yet alternatives are possible. In Denmark, for instance, the national K-12 computing curriculum framework (Caspersen, 2022) inherited many of the ideas of the Aarhus conferences (Iversen et al., 2018) giving computational empowerment the same importance as computational thinking. Here empowerment is approached as the concern for learners to understand how computing affects their lives and society to creatively and critically participate in the construction of computing applications.

Conclusions

Our goal in this conceptual paper is not pit approaches against one another but to recognize that inquiry, design and reimagination are each valuable ways to create learning activities that can engage with criticality in K-12 computing research. Indeed, as Vakil and Higgs (2019) write, the goal is that learners "can understand, analyze, critique, and reimagine the technologies that shape everyday lives" (p.31). The approaches, in fact, offer partial but complimentary ways for addressing criticality. Inquiry focuses on understanding the underpinning of technologies and power structures. Design promotes understanding criticality while making computing applications, creating a relevant context for learning technical skills and concepts, and reimagination centers on rethinking the present and the past to critically reimagine computing for the future. We hope our proposed framings may serve as tools for learning scientists to further design, investigate, and harness their potential in driving disciplinary critical engagement not only in computing but also in other fields.

In conceptualizing the suggested operationalizations of CCE, we are reminded that being critical involves both understanding the role of computing in society and of society in computing (Kafai & Proctor, 2021). This requires not only discussing critical issues but deeply inquiring, designing, and reimagining how computing can be transformed to be more just and equitable and to positively impact the lives of communities. Ultimately, as we saw in our historization of CCE, the goal is to empower learners to fully participate in computing through critique and production. We hope that our conceptualization of three emerging operationalizations contributes to advance our understanding of criticality in learning sciences.

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Using Synthetic Knowledge and Interaction Analysis to Investigate Learning in a Collaborative Digital Climate Learning Experience

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Abstract: This paper presents a theoretical argument for investigating moment-to-moment learning processes around socio-scientific issues (SSIs), or complex, often ambiguous issues that intertwine science and society. It argues that prior theories of learning are not sufficient to explain learning that takes place through engagement with SSIs because of the characteristically modern nature of such issues. We argue that applying synthetic knowledge and interaction analysis can advance theory in this area. In particular, we pay close attention to the science learning that unfolds around SSIs, and we argue that designing effective science learning experiences around such issues first merits thorough investigation of moment-to-moment learning processes. We present empirical evidence from a study of a museum-based collaborative learning experience via a digital simulation about climate change to show the complexities of learning about SSIs and, in doing so, take initial steps towards advancing learning theory around SSIs.

Introduction

In a time of rapid climatic change, global pandemic, and social unrest catalyzed by these far-reaching socio-scientific issues (SSIs), the need for well-designed learning experiences about such issues is great. Places of science education, in particular, from K-12 classrooms to informal learning centers, are seeking to implement learning experiences about climate change, COVID-19, and other modern SSIs (e.g. Owens et al., 2017). However, while research in science education has examined instructional approaches for SSIs, few have investigated the moment-to-moment learning processes that take place as learners participate in such instructional experiences (Christodoulou et al., 2021). Yet, we argue that attention to these processes is critical when considering the design of new experiences. Furthermore, we argue that given the nature of characteristically modern SSIs like climate change, existing theories of learning fall short in explaining learning around them, particularly when considering *science* learning, because such issues create a novel intersection of science knowledge, identity, values, and risk assessment not previously accounted for with learning theory. Thus, this paper draws together multiple theories to argue for new research in this field. We then take a step towards advancing such theory through an empirical investigation of an experience in an informal science education center in which participants collaboratively engage in a digital climate simulation to learn about climate change.

Background: Learning through socio-scientific issues

Science education scholars have argued for instruction centered on socio-scientific issues (SSIs)—complex and often ambiguous issues that bridge science and society and demand moral consideration in addition to scientific reasoning (e.g. Sadler, 2009; Zeidler et al., 2005)—such as climate change and genetic engineering. Research has shown that SSI instruction can support science knowledge gains (Klosterman & Sadler, 2010), engagement in science practices, such as modeling (Ke et al., 2021), in concert with moral development (Fowler et al., 2009).

From this work have emerged important pedagogical models for SSIs, as well as cogent claims about the need to adapt science instruction to take up SSIs. Yet, missing is empirically grounded theory to explain the learning processes that occur when students engage with SSIs. Studies in the SSI genre tend to measure gains in knowledge and in other indicators of reasoning through pre- and post-instruction assessments (e.g., Romine et al., 2017). While this work has established clear ideas about what *can* change within learners through SSI instruction, there is little understanding of *how* that learning process unfolds (Christodoulou et al., 2021). What knowledge and resources students draw on and how various changes in context might influence learning trajectories remain largely unexamined; theory to explain the learning taking place within SSI-oriented learning experiences remain underdeveloped. This dearth of theory is particularly concerning given the nature of SSIs. They are not traditional science topics, around which an array of explanatory learning theories exists. Rather, SSIs often reflect "unfinished" contemporary science, or science in the making. Such issues are often touchpoints of controversy, eliciting strong emotional responses and triggering aspects of identity (e.g., Druckman & McGrath, 2019). Furthermore, recent worked has hinted at the complexity of SSI learning processes, showing that learning outcomes are influenced by much more than knowledge gains, and that other factors, such as cultural worldview can interact with knowledge gains in surprising ways (Author et al., 2021). Drawing on this idea, we argue that

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existing theory cannot adequately explain the complexity of learning involved when students confront SSIs. Thus, with this study, we offer an investigation into the moment-to-moment processes of learning involved when confronting these issues with the aim of advancing and deepening theory related to learning through SSIs.

However, this is not to say that no work progressing towards learning theory has been done. Walsh and Tsurusaki (2018) drew on sociocultural theories of identity to show how students' negotiation of their dissonant political and classroom identities influenced learning during an instructional unit on climate change over several weeks. Investigating on a much finer timescale, Philip and colleagues (2018) drew on theories of ideology and positioning to document how ideology, as made material through social interactions, influenced learning within one session of a university-level engineering class studying drone warfare. Taken together, these studies suggest that learning about SSIs is highly complex and involves a large number of likely intertwined variables, such as identity and ideology, more than perhaps can be captured through traditional knowledge assessments.

Theoretical Framework

To advance theories of learning around SSIs, we approach this study with a multifaceted theoretical framework. This framework aims to capture nuances of why learning of SSIs is likely inexplicable fully by current theories. Additionally, in illuminating the theoretical underpinnings with which we approach this study, the following framework guides the methodology and analysis presented here.

Modernity & risk

SSIs are complex and often ambiguous, holding different implications for diverse stakeholders (e.g. Sadler, 2009; Zeidler et al., 2019). Our argument adds that such issues are products of late modernity (Giddens, 1991), which is characterized by abstract knowledge systems typically inaccessible to most people. These abstract systems allow for the creation of territories of future possibilities, or in Giddens' words, the "colonization of the future" (p. 111). For example, transforming fossil fuels into the sorts of energy that power our homes, vehicles, and buildings relies on a complex network of abstract knowledge systems, from petroleum geology to electrical engineering. It is this very network of knowledge systems that then mediates our long-term creation of future possibilities. These systems and associated colonization of the future bring both heightened security and risk. Daily lives are relatively safe, compared to history, yet the risks that do exist are high consequence. For example, with reliable energy sources made possible through knowledge systems related to fossil fuels also comes potentially catastrophic shifts in climate. Such high consequence risks, and individuals' navigation of them, is intertwined with identity negotiation in the modern age, Giddens argued.

We argue for the development of new theories of learning around SSIs characteristic of late modernity, such as climate change. Climate change embodies the sort of high consequence risk inherent to colonizing the future, precipitated by decades of fossil fuel combustion in attempts to secure and stabilize daily life. Furthermore, like typical issues of late modernity, in Giddens' view, climate change is characterized by shifting knowledge claims from experts. Expert knowledge about modern issues is tenuous, as the issues themselves are emergent and fluid. Expert claims around such emergent issues and within related knowledge systems are often shifting and unstable. Therefore, connecting non-experts to such fluid and uncertain knowledge is inherently fraught. Recent sociopolitical history of climate change epitomizes this nature of modern knowledge, with persistent conflict around climate change within US news media (e.g. Bolin & Hamilton, 2018). Shifting claims from the scientific community (albeit some deliberately manufactured via funding from the fossil fuel industry, see Oreskes & Conway, 2011) have made public actions controversial and identity provoking.

The fluid nature of expert-produced scientific knowledge around climate change has real implications for the ways in which learners make sense of such an issue. How people draw on scientific knowledge and practices in conjunction with other resources when learning about climate change is likely not able to be captured by current theories of learning. Predictably, prior work on climate change education has shown that an often complex set of factors influence the learning process, including cultural worldview (Author et al., 2021), social norms (Busch et al., 2019), political identity (Walsh & Tsurusaki, 2018), in addition to science knowledge (Stevenson et al., 2014), with research only beginning to parse these influences. Investigating learning around climate change can provide new insight into how learners draw on science within characteristically modern issues.

Synthetic knowledge & interaction analysis

To understand learning, this study uses an approach that integrates theoretical underpinnings of both knowledge analysis (KA) and interaction analysis (IA), as called for by scholars in these previously disparate traditions (Brown et al., 2016). Undergirding KA is the theory of knowledge in pieces (KiP; diSessa, 1993), which suggests that individuals' knowledge systems are composed of various "pieces", also referred to as resources (Hammer, 2000), or knowledge elements that learners used to make sense of various situations and compose larger

knowledge systems. Knowledge pieces are highly dependent on context, activated by some contexts but not by others. The varied and dynamic nature of these elements leads to complex reasoning that can shift quickly moment-to-moment, as learners draw on a multitude of knowledge resources in sensemaking.

In parallel, undergirding IA are theories that emphasize the significance of the social space in the emergence of knowledge (e.g. Hall & Stevens, 2016). Various contexts created through the constantly shifting social space allow for certain ideas or pieces of knowledge to emerge. And, the emergence of various knowledge pieces and consequent responses to them influence the course of social interaction. Taking up ideas of scholars seeking to integrate KA and IA (e.g. Azevedo & Lee, 2016), this study recognizes the importance of an individual's knowledge resources (and, by extension, the influence of context on emergence of different elements) while also recognizing that the bounds of knowledge extend into the social space and the practices encountered socially. An individual is not a solitary being functioning on their own; rather, the contexts and social situations surrounding them influence their cognitive work. So, this study adopts the view that learners draw on knowledge elements in context-dependent ways within a learning experience, yet also that the social situation of that learner deeply influences that process.

Applied here, this theoretical view suggests that learning about characteristically modern SSIs will likely involve knowledge pieces traditionally seen as "scientific" about relevant science concepts (e.g. the greenhouse effect), as well as knowledge pieces about societal aspects of the particular issue. Furthermore, within the context of learning in a social space, various social positionings, practices, and resources will influence what knowledge elements emerge, are treated as valid, and consequently get taken up and use by others in a group.

Ideology

An ideology is a shared system of representation through which humans act, speak, and participate in the social and material world (Althusser, 1971; Hall, 1985). Such a system guides the assumptions that people use to make meaning; the ideology in place influences the meaning made from an experience. Ideology comes to have "material" existence through human action and speech; an ideology exists to the extent that it is inscribed in practices. Recent work in learning sciences has taken up ideology as a theoretical lens, demonstrating that the making material of ideology by students in classroom discourse influences learning that ensues (Philip et al., 2018). To understand ideology, this work has applied a KiP approach (diSessa, 1993), showing that naturalized axioms, or "pieces" of ideology emerge in context-dependent ways to influence learning (Philip, 2011). As with an integrated KA-IA views, context is critical to the emergence of such pieces—certain contexts make salient certain pieces of ideology, or naturalized axioms, while others do not.

Given the focus of this study on modern issues at the interface of science and society, we are particularly interested ideologies about the distribution of goods in society related to our colonization of the future, such as energy resources. We argue that these ideologies likely influence the meaning making that surrounds such goods, and, further, that this influence extends to the scientific meaning making scaffolded by particular learning opportunities around such issues. Prior research supports this argument, showing that the discourse students used for scientific sensemaking in a US science classroom was at the same time ideological and served in reproducing ideologies about the distribution of goods in society (Author, 2021; Author, in review). Thus, to this study, we bring a theoretical lens that integrates a KA-IA approach with notions of ideology to understand learning around characteristic modern, risk-laden issues. We argue that this novel approach can expand theories of learning to offer fuller explanatory accounts of the learning that takes place of characteristically modern SSIs.

Research questions

1. What knowledge, social, and ideological resources do learners draw on while participating in a climate change digital simulation learning experience?
2. What patterns exist among learners' drawing on of these resources?

Methods

Stemming from the theoretical commitments described above, this study employed methods from KA and IA (e.g. diSessa et al., 2016; Hall & Stevens, 2016) to understand moment-to-moment processes within a collaborative digital learning experience about climate change.

Context, participants, & data collection

Data were collected at a science museum affiliated with a large, public university in the US. Data collection occurred within one of the museum's galleries, where a digital climate simulation is installed. Visitors interact with this simulation in a partially closed room, with up to five visitors participating at once. Each player sits at a console with an individual touchscreen. One big screen is projected onto the wall in front of the players. The

projection shows the simulated city and the overall progress of the simulation, including when and where each player chooses to build or demolish something. The simulated city is made to resemble the local landscape of the museum, and its name references the region.

The simulation includes six rounds of 90 seconds each. During each round, each player is given four options for actions and can pick two actions to enact. Specific options are unique to each player and are randomized. Potential options include constructing various energy sources (e.g. coal plant, solar farm), agricultural sources (e.g. alfalfa farm, bison farm), or recreational opportunities (e.g. amusement park). Options could also include demolishing structures or installing geoengineering devices, such as artificial trees. At the end of each round, players are directed to look up at the projection to see how their city has changed. After each player's decisions are pointed out, the projection shows whether the group achieved a set of goals for the round, including goals for: 1) energy production, 2) food production, and 3) recreation opportunities ("fun produced"). Then, it shows how the group's actions affected the climate by using a bar indicator that ranges from 0 to 10, with 10 indicating extreme climate change. At the end of some rounds, depending on the degree to which the climate has changed, there are catastrophic natural disasters, such as drought, wildfire, dust storms, or sudden snowpack melt. As climate change increases, so does the likelihood of a disaster. When a disaster occurs, it destroys some structures built by the group, which then impacts energy and food production. After a group finishes playing, the simulated world does not automatically reset. Rather, the next group "inherits" the developed world, including the state of its climate. However, a group can choose to reset the world entirely at any point.

Data were collected over five days as visitors interacted with the simulation. Data sources include audio recordings and screencasts of each participant's screen, and observational notes made by a researcher in the back of the room. For this study, we narrowed down the data to recordings and screencasts of 6 groups' experiences. These groups were selected because they engaged with the simulation for at least 9 minutes, included at least three participants, talked with each other consistently throughout, and represented a diversity of age distributions. Audio recordings for each group were transcribed in entirety. Screenshots of key moments were included in transcripts.

Data analysis

All transcripts for the selected 6 groups were reviewed and analyzed for knowledge resources, social resources, and ideological resources drawn on by learners at different moments. This process was guided by principles of microgenetic learning analysis (Parnafes & diSessa, 2013), as well as prior work using similar theoretical lenses (e.g. Philip, 2011). Analysis specifically focused on moments of visible decision-making, evidenced through verbalizations about uncertainties of what to do next within the simulation. We chose to focus analysis on such moments, as decisions represented times in which learners were likely to draw on a variety of cognitive, social, and ideological resources (Aikenhead, 1985); analysis of these moments could shape learning theory related to SSIs and decisions around them. Additionally, understanding resources drawn on in decisions could possibly provide insight into socio-scientific decisions with which people are confronted in their lives.

We bounded moments of decisions in transcripts by identifying discourse markers that indicated the initial surfacing of uncertainty or the need to decide a specific action, as well as discourse markers that indicated the decision had been made. If conversation ever returned to that specific decision, for example several minutes later as participants reviewed the actions taken during the round, such conversation was included in analysis. Guided by extant research in KA and IA (e.g. Brown et al., 2016; Hall & Stevens, 2016; Parnafes & diSessa, 2013; Philip, 2011), we analyzed moment-to-moment processes within these instances of decisions, identifying knowledge, social, and ideological resources made salient.

Findings

RQ1: What knowledge, social, and ideological resources do learners draw on?

Across groups, participants drew on a variety of knowledge, social, and ideological resources, and that often these resources were intermixed in moment-to-moment processes. However, each group also tended to exhibit their own patterns and reliance on certain sets of resources. We will now describe key themes that came from analysis, although given the brevity of this proposal, this is not a comprehensive summary.

Knowledge resources related to mechanism relationships among energy, climate, and ecosystems

Participants across all 6 groups drew on resources related to mechanistic knowledge of relations among fossil fuel combustion, climate, the built environment, and local ecosystems. In some groups, these knowledge resources of mechanisms, or cause-and-effect relationships, were drawn on frequently within decision-making. Typically, these knowledge resources emerged in moments of decision about whether to build a particular energy source, such as a coal-fired power plant or solar panels. For example, after one round of a game in which the group did

not meet their energy goals, a participant said "We need more energy and more food." In response, a few turns later, another participant posed the question to the group "Should I do a coal power plant?". In response, group members shouted "No!", with one calling such a move "bad for the climate." Even without a full mechanistic explanation, such moments indicate participants drawing on various pieces of a knowledge system in which coal-fired energy contributes to climate change, likely through exacerbation of the Earth's natural greenhouse effect.

Social positioning resources and moment-to-moment identity work

Social resources emerging through interaction were often drawn on in decision-making. Typically, these resources relied on social positioning among group members with certain identities—identities that were both relevant to the simulation and those that were more global. Often, identities local to the simulation were identities related to leadership. In many groups, particularly in family groups with young siblings, one participant would position themselves as leader, as indicated by discourse in which that person directed others what to do, or attempted to shape the group's direction by using the first-person plural to phrase directives (e.g. "we should…"). Moments in which the group's progress toward energy, food, fun, and climate goals tended to make salient this position.

Another local identity that emerged through interaction in two groups was an identity of subversion. Such positioning often started early in the game, with a participant audibly positioning themselves as counter to the aims of the whole group. Typically, over the course of the game, they would act in accordance with such an identity, often choosing moves that increased climate change or interfered with others' goals. When others noticed this interference, they would typically respond with anger and further social positioning of the subversive actor into such an identity. An example comes with a family group that played for approximately 40 minutes. The family included 5 children and 2 adults, with the adults supporting from behind and occasionally rotating into play. Within the first minute of starting the game, the following scene unfolded (Transcript 1):

Transcript 1

Line	Speaker	Speech
1	Matt	Okay, we're supposed to all work together for good...good climate.
2		No more climate change!
3	Dad	Okay
4	Eli	Rounds left to make your choices now.
5	Matt	I know where the...
6	Anna	I want to make the coal power plant.
7	Matt	No we go to the garbage
8		Am I the only one that is trying to save the environment?!
9	Bryce	No I am
10	Matt	Are you trying to destroy it? Anna's destroying the environment!
11		Wait don't have a coal power plant. Wait smog vacuum.
12		I'm getting a smog vacuum.

Immediately here, Matt, who positioned himself as a leader throughout the game, verbalized the group's aims, with "we're supposed to all work together for good…good climate" (Line 1). While Eli and Dad responded in relatively neutral ways to Matt's orienting of the group towards reducing climate change, Anna declared that she wanted to build a coal plant (Line 6). Throughout the 40-minute dataset, there is much evidence that Anna understood very well the mechanistic relationship between coal combustion and climate change. And here, she seems to be drawing on this knowledge resource to counter Matt's declared aims for the group and, thereby, position herself as subversive. This attempt at subversion is evidenced further throughout the transcript—she cheered at the end of a round when climate change went up, shouting "Yay climate change!". At one point, she stealthily tapped Bryce's screen while he was not looking to choose to build a coal plant on his behalf. Furthermore, the others took up this positioning of Anna and reinforced it through their social positioning of her as subversive. In the first few moments of the game, in response to Anna's move to build a coal plant, Matt said "Am I the only one that is trying to save the environment?!" and two lines later "Anna's destroying the environment!" (Lines 8, 10). This social positioning of Anna parallels her own positioning of herself throughout the game as a counter-operative. For example, when Anna selected a natural gas plant about 20 minutes into the game, Bryce shouted "Anna, no! Don't place a gas power plant!". This was followed by Matt saying "Anna is literally trying to sabotage it", and Bella following up with "Anna is trying to be the bad guy". This identity of Anna as subversive was made salient at decision-making time, particularly when it was known to the group that Anna had the option to select a carbon intensive energy source, such as coal or natural gas.

Ideological resources

All groups showed evidence of use ideological resources to make decisions. For some groups, ideological resources tended to emerge and be drawn on within decision-making more frequently than knowledge resources, while in others they were less common. In some cases, these resources emerged through assumptions about what was "good for the environment" and what was "bad for the environment", thereby framing many decisions as a binary choice, easily made by consulting with the group. In other cases, participants made material ideological resources that bore assumptions about relationships between people and land. For instance, in one group, a participant repeatedly expressed a "need" to build something in an undeveloped piece of land because "there [was] literally nothing there". This comment made material ideology about hierarchies of humans in the natural world, expressing an assumption that the natural world exists to be developed by people. Similar tacit understandings about relationships among humans, landscapes, and animals were expressed by many participants across groups.

RQ2: What patterns exist among resources drawn on?

Often resources were intermixed in moment-to-moment processes of sensemaking. Some patterns of this intermixing were identifiable across all groups, while some were unique to specific groups.

Pattern #1: Social positions intersected with ideological resources

One identified pattern was the intersection of social positions with ideological resources. For example, in Transcript 1, Matt said "Am I the only one that is trying to save the environment?!" In doing this, he positions himself with an identity as defender of the environment while also drawing on ideological resources about the environment—namely, that it both is something distinct from the human world and that it needs and/or merits saving by people (Line 1). Similarly, the social positioning of Anna intersected and overlapped with the emergence of ideological resources. She positioned herself and was positioned as subversive. To do this positioning, she and the others drew on ideological resources about what was "good" and "bad" for the environment, often opting to do whatever was deemed "bad" to further her position as subversive.

Pattern #2: Ideological resources intersected with mechanistic knowledge resources

Another pattern was the intersection of ideological resources with mechanistic knowledge resources. Often, participants made comments that both reflected an implicit understanding of causal relationships, for example between fossil fuel combustion and climate change, and made material various ideological resources. One example comes with the group described above, evidenced in a short exchange (Transcript 2):

Transcript 2

Line	Speaker	Speech
1	Matt	—Oh, I'm going to do a natural gas plant!
2		Is that good?
3	Bella	Uh no. You could tap on the [inaudible].
4		State park.
5		Do state park.
6	Matt	I'm going to put my state park here in the very corner because there's not that many animals.
7	Bella	That. It's—there. Okay, put it down there.
8		Okay, nice.
9	Matt	We are the climate warriors.
10	Anna	I hate climate.

Here, after Matt declared that he was going to build a natural gas plant (Line 1), he conferred with the group about the move, asking "Is that good?" (Line 2). In asking this question, Matt brought tacit assumptions about the meaning of "good" and "bad" to categorize different energy sources, presumably a categorization that relies on carbon impact to the atmosphere of the given energy source—a knowledge resource part of a larger knowledge system about causal relationships related to climate change. Bella then replied with "no," meaning that a natural gas plant is not good and instead suggested building a state park, which, by the group's tacit definition is "good", in that it does not directly contribute to increasing atmospheric CO_2. Yet, in making this comment, Bella also made material ideology about the relationship among people and land, possibly an assumption that land is to be used by people, even via measures traditional viewed as conservation, such as a state park.

Also evident within this interaction are other resources. Matt declared that he would build his state park in an area where "there's not that many animals" (Line 6), evidencing a knowledge resource regarding the

mechanistic relationship between building a feature and the consequent decline of animal species. He then made material ideological resources by saying "We are the climate warriors" (Line 9), surfacing implicit ideological assumptions about the relationship between people and climate change—that is, that climate change is something that needs to be fought or battled—an assumption that positions humans in a combative role but that also elides human responsibility in climate change. And again, positioning herself as the contrarian of the group, Anna said that she "hate[s] climate", likely indicating here that she hates the idea of doing things on behalf of climate change and/or that she wants to pursue *further* climate change in her local identity as destroyer of the environment.

Discussion & conclusion

While previous work has examined learning outcomes of SSI instruction, little has investigated moment-to-moment learning processes around SSIs. This paper advances the field by integrating multiple theoretical approaches to generate initial ideas about the learning processes unfolding around engagement with an SSI in a digital climate simulation in an informal science center.

First, and perhaps obviously, this study shows that knowledge resources were drawn on by learners. Specifically, we point to the many knowledge resources regarding scientific mechanistic knowledge about climate change drawn on by learners over the course of engagement with the scenario. In particular, specific contexts of the simulation appeared to make salient these resources. Often those contexts were moments of decision-making, and often when that decision-making was encountered socially, as a group. Given that prior work has demonstrated the significance of mechanistic knowledge in navigating climate change in scientifically accurate ways (Author et al., 2021; Stevenson et al., 2014), we see this finding as an important one to highlight, as it speaks to the promise of leveraging digital simulations for climate science learning. Yet, at the same time, this study also demonstrates the multitude of ways in which scientific knowledge resources intersected with both social positioning resources and ideological resources to influence the learning process in, at times, surprising ways.

Of the complexity of knowledge and interactional resources involved in SSI learning, we suggest that the intersection of social and ideological resources could be particularly influential, as in this study we observed how moment-to-moment identity work done by participants contributed to the association of various social and ideological resources for particular participants, such as Anna, with her subversive, counter-operative efforts to "destroy the environment". With this finding in mind, we use this study as a call for further research examining moment-to-moment identity processes and integrating multiple theoretical approaches to study the learning process around characteristically modern SSIs.

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International Society of the Learning Sciences

Shifting from "broadening" to "empowering": One community's perspective on changing the learning sciences

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Abstract: The ISLS theme addresses "global perspectives on equity and justice that promote the empowerment of educational innovation for all." We report on a large virtual convening (n=310), where learning scientists, computer scientists, and educators in one country considered how research should change to address equity and justice. We report on the output of working group strategy sessions and a culminating discussion that elicited "bold steps" for change. Our analysis of bold steps submitted by eleven teams led to re-grouping by the actors involved: (1) researchers, (2) partnerships, (3) technology design, and (4) community values should each change. For each group, we report key themes. We note limitations and broader implications (e.g., what a shift to language about "empowering" implies). Conducting similar meetings in other regions and reporting complementary outcomes could be powerful.

Introduction

The 2022 ISLS conference theme focuses on a wave of change in the learning sciences that is bigger than any one research project, theory, design, or finding: our society seeks to spur transformation of our work to value diversity and drive toward equity and justice. What does this transformation entail? In an unsatisfactory view, it could mean highlighting aspects of what we already do that relate to equity and justice, without much change in how learning scientists are prepared, how they form research teams, how their values translate into action, or in their design focus. Or it could mean that every individual researcher and team must figure out what the desired transformation means in their own unique work—with a community or society role only in providing a forum to report insights and findings. We find transformation only as individuals or in isolation to be untenably hard and ultimately insufficient. Our work is situated within larger systems that reinforce specific ways of doing things. For real change to occur, change also must occur at the system level (as well as at more local levels).

Through our role in a research hub that hosts a national convening of researchers who do learning sciences and innovation work, we sought to organize a two-day virtual convening that would elicit a community-wide prioritization of how our work should change. While our convening was necessarily localized to our context, we hope to make two contributions by reporting on its process and outcomes: (1) to share a virtual community-wide process that others could enact in their regional communities and (2) to share tangible recommendations for change that may contribute to discussion about a society-wide course of action.

Background

In the United States, as in many other countries and regions, government funders of learning sciences research make awards that create a portfolio of related projects. Later, they often host convenings across the portfolio of projects to bring together the teams and to cross-fertilize findings. At convenings, teams discuss their work, identify synergies, and discuss next steps. The authors have been leaders in a nonprofit collective that organizes and hosts such convenings on behalf of the government funders; we have run convenings for one particular portfolio of learning sciences research for about a decade. The portfolio focuses on the "future of learning" and requires computer scientists and learning scientists to collaborate in exploratory research. Over the decade, we observed a shift in the focus of the research community that attends these convenings. The focus of conversation shifted from mostly technical discussions of research about future learning environments to a broad interest in equity and then to a sense of a "call to action"—that we should more directly focus research to address equity (Roschelle et al., 2017). In preparing for our 2021 convening, we organized a program committee of stakeholders in our regional research community and asked them what the central theme of the convening should be. They strongly recommended a thematic focus on the *how* and not just the *why* of promoting equity and justice in our research. We developed a program for the convening to emphasize this theme and to produce collective recommendations for *how* we should change. Approximately 350 individuals registered for our convening and 310 attended. The convening was held virtually for eight hours spread across two days. We report further details on how we organized the program and collected outcomes and other data next.

Before continuing, we acknowledge other important forums where similar ideas are being discussed. Our society now has an Equity and Justice Committee, for instance. Our publications include seminal equity-focused papers (e.g., Gutierrez & Jurow, 2016; Jurow & Shea, 2015; Muller, 2004). Other regions of the world have their

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own forums to organize researchers around equity and justice. We are aware that we offer just one perspective, grounded in a particular set of circumstances, and that we report on just one relatively short event. By sharing what we learned, we hope to learn about and combine with complementary and contrasting perspectives from other places.

We also acknowledge upfront that our process did not converge on one outcome, nor did we converge on one definition of equity. We have observed different foci for equity in our research community, including students with disabilities, students in poverty, students in rural areas, and—of great importance in the United States—students who have experienced racism. We believe it takes more than a single virtual convening to get an agreement on a definition of equity among such a large group of projects, each of which tackles different aspects of the challenge. We chose not to try to wordsmith definitions during our convening, but to focus on prioritization of bold steps and other recommendations our program committee believed we could accomplish in the time available. (A further limitation of which we are acutely aware is that there is scholarly precedent for almost every point raised during our convening, but we could not possibly systematically cite all the relevant prior work and stay within the 8-page limit).

Methods

The convening that we describe in this paper had the theme of exploring how a research community can have a broader impact by reassessing fundamental aspects of its work. With an internal hosting team and an external program committee, we designed a program that had a storyline: we would get to know each other as a community (leaders from different projects often do not have strong relationships), work together to educate ourselves about the theme, and then develop prioritized bold steps for how we could change our work. Overall, our community process follows the method of "forming, norming, storming, and performing." (Tuckman, 1965) Due to the nature of the event as serving a national funding agency, we also allocated time for necessary announcements and informational updates about new funding opportunities and for roundtable sessions and poster sessions where participants could give updates on their work. To launch the theme, we invited two keynote speakers who addressed issues of equity and power in computer science, artificial intelligence (AI), and educational technology. Nicki Washington (2020) discussed how the culture of computing often marginalizes Black and Latinx students, and how we need to explicitly help students in computer science programs create a sense of identity and belonging in that community. In Figure 1, we show a graphic illustration that was created "live" as the first keynote speaker spoke. In keynote 2. Craig Watkins (2018, 2019) discussed his work with Black and Latino students and young professions in STEM and technology, and the nature of specific opportunities and supports that enable their growth and success. These keynotes offered sharp contrasts between meaningfully addressing equity and just evoking it at a surface level, giving participants food for thought. We engaged with a graphic illustrator throughout the meeting to capture and share what was being said and to spur further deliberation and reflection.

Figure 1. Graphic illustration of Nicki Washington's keynote address

In other sessions, such as "expertise connection" sessions and talks on specific research projects, we asked presenters to orient their presentations around the idea of rethinking how we include, reach, and support diverse communities in our work. Near the end of the convening, we asked participants to work in small groups to draw on what they learned and heard over the course of the convening to come up with strategies for thinking about new ways for our work to have a broad impact. The small groups focused on different aspects of our community's research and development work. Some examples of groups included:

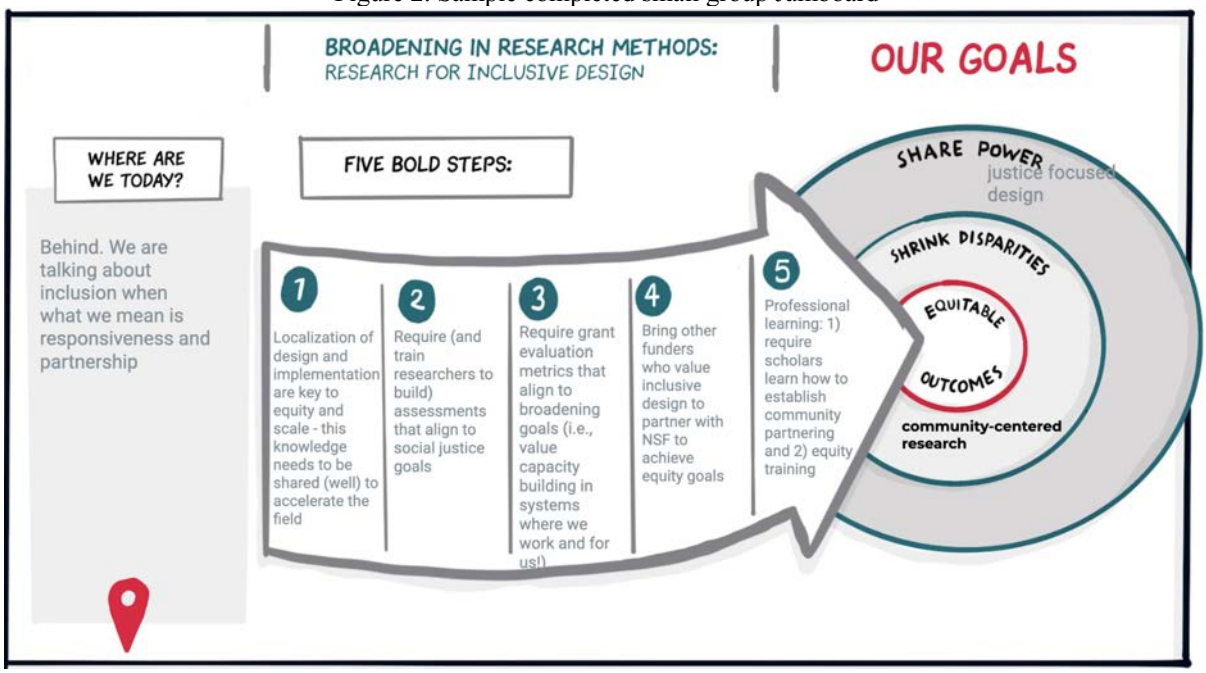
- Research for inclusive design
- New human-technology interactions
- Learning analytics
- AI in education policy
- Communication and dissemination

The groups were asked to discuss where the community is *now* in terms of having a broad impact in relation to their topic and what our *goals* are, and then come up with five *strategies* for getting the community to where we want to be. They made their recommendations on Jamboards. Then we had a "town hall" session to report out with the graphic illustrator. As groups each reported a first idea from their group in a round-robin format, the illustrator captured the emerging recommendations of the collective. A panel commented on these ideas and asked follow-up questions. The effect was of a voice-only panel whose ideas were appearing in an illustration in real time, which was captivating to watch and participate in. Over time, the conversation was opened to everyone present, and they were invited to add ideas via chat.

Data collection

Ideas from the small groups were documented in two ways. Initial brainstorming was recorded on post-it notes on a Jamboard under the headings "Where are we now?" "Bold steps" and "Goals." The groups then had to prioritize and consolidate their ideas so that they could be put into a second Jamboard that had a graphic illustration as its background. (See Figure 2.)

Figure 2. Sample completed small group Jamboard



In addition, we also conducted an evaluation survey that was distributed via email after the convening to get feedback on the event as a whole as well as on the different sessions.

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Data analysis

Members of the convening organization team analyzed the data from both Jamboards from all eleven of the small groups. The analysis used a grounded theory approach (Strauss & Corbin, 1990), in which we read through all of the post-it notes on the brainstorming boards as well as the finalized ideas presented by the groups on the graphic boards and identified key themes that emerged from the data. A draft of these themes was created in which the community's ideas were categorized according to the various ways the work of the community could change for broader and more meaningful impact to be realized. The categories that arose were:

- Changing how researchers are prepared
- Improving community partnerships: valuing assets and knowledge
- Changing our technology design focus
- Rethinking broader impacts across the research community

These categories, along with the supporting descriptive data, were shared with the entire research team, who then reviewed the Jamboards and contributed clarifications and refined the analysis. Evaluation surveys were analyzed using descriptive statistics. There was a response rate of 25% for the survey (79 respondents out of a population of 310).

Findings

The analysis of the evaluation survey showed that 85% of the respondents agreed that they gained a new perspective on how to reassess what we mean by "broadening impact" from the meeting. The analysis of the Jamboard data revealed that our research community had many ideas for strategies to change the way we think about research and development. They recognized that we need to reflect on our practices and norms at multiple levels if we are going to transform how we conceive of broadening impact in our work.

How researchers are prepared

Community members across most of the groups pointed out that we need to examine how we ourselves are prepared to conduct research and how we prepare the next generation of researchers. We are the first agents of change in this larger process of transforming the community's values and practices. Small group participants acknowledged that they were under-prepared for the work that comes into view once we center equity and "remaking broadening." Our analysis identified a set of key ideas about what researchers in this field wanted to change (see Figure 3).

Selecting research opportunities in Pasteur's Quadrant

The community is concerned that researchers may be inclined to select research problems or opportunities that value theoretical or technological novelty over the potential to make a difference in the real world. Consequently, our exploratory research may learn a lot about technologies that have no realistic chance of making large-scale contributions to an equitable society. A revised definition of "innovative" would consider the possibility for highly valuable change in a large community of practice. Likewise, training may overemphasize collecting one's own data over leveraging larger scale data sets that already exist. To define problems for investigation that are "fundamental" in one's discipline yet "powerful" in a community requires researchers to ask what the community's most pressing questions are. This is not currently a typical starting place.

Frameworks for setting goals, assessing learning, evaluating approaches

The community does not want to focus on technology itself nor only on contributions to research journals that follow well-trodden paths. Calls to action use a variety of terms that include justice-centered, human-centered, responsible AI, fairness+accountability+transparency+equity (FATE), inclusive innovation, and value-sensitive design. Researchers need to grow in their ability to understand how to go from the broad call of action to the design of a specific exploratory research project, which includes not only the vision for the project but also how student or teacher learning would be assessed within it, and how the promise of the focal technology design can be evaluated. Although frameworks exist, learning how to engage these frameworks while doing specific research is more aspirational than everyday practice. As one community member wrote, we need to "identify new learner outcomes of interest (which include equity) and instruments that measure these outcomes."

Multidisciplinary refinement of key equity concepts

Participants recognized that within computer science and AI, concepts like bias, fairness, and transparency are still in their early stages. Although the scholarly discourse in education and in learning sciences on these topics may be somewhat longer standing, there is still a lot of room for growth in how learning scientists are trained to work with similar concepts like bias, cultural responsiveness, and including student voice—especially as these concepts are invoked while exploring new designs for learning technologies. A multidisciplinary approach to tackling any of these problems is still very novel and almost everyone in the field must learn to do it well.

Preparing to be a good partner

The community recognizes that partnering with others is challenging and many researchers are under-prepared. This includes the challenge for computer scientists of partnering with learning scientists (and vice versa) as well as challenges of partnering with communities that would use or be affected by new technologies. Foci for learning for researchers before they engage in partnerships could include communication practices, listening practices, understanding and mitigating power differences, and practices that develop empathy and cultural competence. Our community is responsible for developing the next generation of scholars and has the responsibility to make sure that the ethic of inclusion of diverse stakeholders in research and collaboration with peers and practitioners is clearly communicated and expected in dissertation research, valued in job applications, and used in early career evaluations. More discussion on partnerships will come up in the next section.

Figure 3: This illustration (one of several) highlights proposed changes in how researchers are prepared.

Improving community partnerships: Valuing assets and knowledge

In a shift to the social activism model (empowering) from the technology transfer model (broadening), there was a strong call across most strategy sessions about involving communities of teachers and learners early in the research process, listening to them, and yielding more power to their voices while making decisions about what technology designs merit exploratory research and which questions about the novel technologies deserve priority. Researchers' view of who to partner with was very broad—students, teachers, parents, policymakers, school leaders, community center leaders, museum staff, and other stakeholders might all be important partners.

Committing to early, mutual, lasting partnerships

Community members observed that we need to form mutually beneficial, long-term partnerships to ensure our work has a meaningful impact. Getting feedback from teachers on instructional materials or research instruments is not a partnership. That is asking participants to provide a service to the researcher with little to no benefit for the participant. A research partnership requires that the researcher start by learning about and understanding the needs and interests of the partner organization or participants and commit to exploring those together.

Listening to transform

Researchers at the meeting reflected on their own experiences where listening to student voices, working closely with teachers, or connecting with leaders and policymakers completely changed their view of the problem they were trying to solve. They realize they may extrapolate from their own experiences of teaching and learning in ways that do not fit what today's teachers and learners want—and this may block progress towards broad equity goals. Conversely, they reported excitement and challenges resulting from deeply listening to partners for ideas that could transform their intended exploratory research.

Value what communities are already doing

Some of the most important work in building capacity for local communities to achieve self-identified goals is already happening by stakeholders in those communities. The community may have the greatest impact by putting our skills in the service of those stakeholders. Our community can benefit as much from learning about what these communities are doing as we can from disseminating information about our own work.

Valuing capacity building

Researchers in this space recognize that when they work with partners, they have to focus on giving something valuable to the community they work with. Because their exploratory prototypes may not be ready for prime-time even at the end of their project, the work they do to build capacity in communities of practice to solve problems that the community cares about has to count as a valued outcome of doing partnership work. One outcome of valuing capacity building could be the emergence of regional hubs or networks that work over long periods of time with researchers on issues related to emerging technology. Another outcome can be to help partners lead dissemination efforts and outreach to policymakers.

Changing our technology design focus

This research community called for centering the voice of partners in choosing the focus of a research-based technology design project, as discussed above. This is fundamental and is elaborated across points below.

Insisting on accessibility

Accessibility guidelines are well established but too many exploratory research projects do not address them. Accessibility needs to be addressed from a project's conception and viewed as a necessary component rather than an optional "nice-to-have."

Realistic usability and multilevel explorations

Researchers worry that too much of exploratory research is devoted to expensive or "clunky" gear. Obviously, there is a tension here, because technologies that will be commonplace in ten years may be expensive now. The community sees value in a pattern of exploratory research that might look at an overall concept in several different renderings—some which have less fidelity to the vision yet are more usable today and others which have greater fidelity but are more cumbersome or expensive. Although the expensive version may have more fidelity in one way, what we learn about the concept may be broader if stakeholders can use it more easily and often. So, there could be a benefit to exploring the same concept at different "entry points."

Exploring with platforms and infrastructure

There is a limit in how far we can get when each project tries to design its own complete experience. Community members suggested focusing more attention on how innovative explorations could occur within platforms or with infrastructures that are broadly supported in the world.

Rethinking broader impacts at the research community level

The attendees were also cognizant that the research community is structured in fairly set ways, and that they need to consider how community-level roles and processes must be addressed as we "remake broadening." This can include what we value in peer review of proposals, what we consider publishable in journals or presentable at conferences, what we see as the community's outputs or products and how we structure research projects.

From "moonshots" to focused substantial advances in practice

A challenge for researchers in our community is that exploratory research projects often last for only a few years and are funded at relatively low levels, making broad impact difficult. Progress can be made not by sweeping this challenge under the rug but by greater clarity about the kind of impact an exploratory project can have. Taking a

risk to make a substantive or radical change in practice for one school/group/organization rather than reaching a large number of people might be a more appropriate outcome for an exploratory project. Designing processes so that students, teachers, and other stakeholders can contribute to deliberations about the future of learning with technology can count as a meaningful impact. Finding ways to elaborate a concept like "bias" so that computer science, learning sciences, and educator views are all respected can be seen as a broad impact. Creating tools and methods so that partners can look at the transparency of an algorithm could count. Depth of transformation can be changes in the researchers' own practices. Having the community commit to reviewing proposals and their peers' work with this definition of impact in mind would itself lead to transformation in the field.

Values around ethics and risks

Norms and values typically are developed by communities and reside at a community level. Our research community recognizes that "high-risk" research should be valued as we explore technologies that are ten years out, but we also need to be mindful that those who might be harmed must be consulted before we can determine what an appropriate risk is. Similarly, the use of big data or AI in learning technology projects carries risks to privacy, security, and more. When technologies are tested in partnerships that use them with teachers and learners, there are ethical considerations. Our community should insist that, from the onset of a project, researchers must involve local stakeholders in discussions around risks.

Sharing tools and processes for co-design, co-analysis, and partnership

Some members in our community have been engaging in co-design and collaborative analysis of data with local partners for a long time and have learned many lessons about how to do it effectively. The tools and procedures for doing this kind of work should be shared within our community and with our partners so that they can be used more broadly and improved through regular, iterative use. The same emphasis that the research community has given to assessments and data collection instruments should be given to protocols to support effective co-design, co-analysis, and productive partnerships.

Reconceptualizing dissemination

This community repeatedly expressed the need to disseminate research findings to communities of practitioners, local stakeholders, and policymakers rather than the typical academic communities that are primarily valued by funders and tenure review boards. With limited resources in terms of funding and time, expecting researchers to do this kind of outreach in addition to what is already expected is unrealistic. Our community needs to be part of the effort to change incentives around what is shared, how, and where. Members of our community are not only researchers, we are also the people who review proposals and articles, hire new faculty, serve on tenure review boards, and create dissemination plans. It is this community's responsibility to place a higher value on reaching practitioners, local stakeholders, and policymakers than traditional academic audiences. We also need to encourage our partners to engage in dissemination and ensure that the materials that we produce are available to teachers, learners, and communities long after research is completed.

Implications

The analysis of our research community's discussions illuminated the specific directions we want to take. Regardless of whether the small groups were talking about AI, inclusive design, or communication and dissemination, larger themes bubbled up, in part no doubt because of the community's values but also possibly because of the calls to action made during two provocative keynote addresses. A willingness to look at our community critically was a strength of the small group conversations. There was a clear interest in generating practical ideas for moving forward and getting to work. Many of the specific strategies are elaborated above. We intend to plan further activity to move these strategies into action.

From broadening impact to redistributing power

Given that the convening was designed to reassess what we mean by "broad impact," it is perhaps fitting that our final sessions led us to realize that maybe having a broad impact should not be the goal at all, but rather we should be striving to empower others to make their own impact. Time and again community members stated that we need to value capacity building as a key outcome of our research. Even more important, we need to step back and honor the capacity that already exists in the communities we work with and see our role as collaboratively designing the research strategy that will support that community's efforts to achieve the goals they already have. Coming up with an innovative application of emerging technologies to address a problem that we ourselves identify and then sharing that innovation with other academic researchers has up to now been how we conceive our work. The

contributions of our community members indicate that we need to rethink many of these assumptions about who identifies the problem, how we design the innovation, and what kind of sharing is most meaningful and effective.

Aligning exploratory research to the scale and context of disparities

The systemic problems in education and the larger society that the convening keynote speakers and our community member discussions surfaced are not going to be solved by any one research project or even our collective projects. However, the kind of exploratory research that our community engages in has the potential to take bold steps that are necessary to make meaningful changes in the communities where we work. Smaller-scale, high-risk projects can test innovative approaches to integrating technology into learning environments that larger-scale projects might not be able to. We as a community need to realign our expectations of exploratory research so that we can make the most of what it is most suited for.

Strengthening our own accountability to equity and ethics goals

Researchers have a great deal of experience creating data collection instruments to measure how effective our interventions are at achieving certain outcomes such as learning disciplinary knowledge or changing attitudes and interests. We need to use those same skills to ensure that our interventions and our own practices reflect the ethics and values of equity and justice for those involved in our research. We as a community need to support each other in this effort by co-creating and sharing tools to gather this kind of data and preparing both experienced and emerging researchers to do this work and hold each other accountable for living up to these principles. The systemic change that we hope to see requires a mutually supportive and accountable set of expectations for how we do our work.

By sharing our process and findings, we hope to inspire others to orchestrate convenings in their regions to arrive at a community-level agreement on bold steps, and to share their bold steps so that as an international community, we can converge on practices, values and goals that reflect what we hope to achieve.

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Using Problem (Re)framing and Teachers' Pedagogical Responsibility to Facilitate Teacher Learning Opportunities

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Abstract: Although for decades there has been a strong coalition of teachers working for social justice, we still know little about how teachers' learning to do this work can be supported. In this paper, I use interaction analysis to investigate a teachers' learning opportunities, finding that the teacher's learning opportunities were facilitated by coaching strategies including: (1) a co-inquiry approach, (2) deliberate and persistent problem (re)framing, (3) grounding interpretations in student sensemaking, and (4) building on the teacher's pedagogical responsibility. These findings contribute to theory of teachers' learning, suggesting some of the ways in which such learning can be supported in a video-based coaching model.

In mathematics, a movement to teach content in connection with sociopolitical contexts and applications has resonated with many teachers and researchers (Bartell, 2013; Frankenstein, 1983; Gutstein, 2007). However, authentically situating mathematics in real-world, sociopolitical contexts is a complex, demanding endeavor (Leonard et al., 2010) and we know little about how teachers' learning to do this work can be supported. Designing and investigating supports for teachers' learning to do this work is, then, an important research topic for the field (Bartell, 2013).

In this paper, I report an investigation of one teacher's learning to integrate mathematics and social justice, utilizing a video-based coaching model. Through interaction analysis (Jordan & Henderson, 1995) of a *critical case* (Flyvbjerg, 2006) of strategic importance to this challenge, I show how learning opportunities for the teacher arose in coaching conversations. Additionally, I share implications for design of learning environments for teachers, especially as it relates to supporting teachers' learning of justice-oriented pedagogies. Because of growing pressure for teachers to integrate content and social justice topics, a pressing challenge for the field is understanding how to support teachers' learning in this realm. This study begins to illuminate potential mechanisms of teachers' learning through coaching and provides important considerations for future design.

Study context

This study is situated in a four-year research-practice partnership, in which we developed a video-based coaching model. In this research, we partnered with a professional development organization, working with experienced mathematics teachers to support their development of ambitious and equitable pedagogies (Horn & Garner, 2022).

Conceptualizing teachers' learning through video-based coaching

To support teachers' learning in and from practice, we sought a novel form of coaching that would be built around teachers' own personal goals for their learning and that could respond to challenges that arise in teachers' ongoing instruction (Horn, 2020). To this end, we designed our model as "co-inquiry," where teachers and their coaches collaboratively investigate elements of teachers' practice, honoring the teachers' own learning goals and disrupting traditional hierarchies in coaching. In most cases, the focal teacher – whose classroom was filmed – was joined by a colleague (a "partner teacher") for collaborative engagement in the video-based coaching model; this partner teacher worked at the same school and was also part of the professional development organization.

In our model, teachers first identify a question for co-inquiry, then we film in-class instruction to capture phenomena of interest using a two-camera, multi-microphone recording system that captures both the teacher's point of view (Sherin et al., 2008) and a view of the entire classroom with simultaneous tracks of audio from student groups. After filming, members of the research team review the video, selecting clips to share with the teacher based on her inquiry question(s). We then debrief the lesson, using episodes of interest from the classroom video (Horn & Garner, 2022).

Theoretical perspective

To investigate teachers' learning opportunities, I take a situative perspective. This perspective offers useful analytic tools for studying teachers' learning (Greeno, 1998; Peressini et al., 2004), allowing a focus on teachers' contextualized negotiation of meaning (Nolen & Ward, 2008). Situative perspectives focus on "joint interactional accomplishments of individuals in relation to broader communities, processes, and structures" (Hand, 2010), such as how a teacher makes sense of deeply local problems of practice, while keeping broader systems such as the

school and sociopolitical climate that also have a bearing on this meaning-making in sight (Nasir & McKinney de Royston, 2013).

Problem-based learning

Our video-based coaching design was inspired by models of problem-based learning (PBL) for teachers (e.g., Horn, 2013), intentionally building learning experiences around real-life decision making (Horn, 2020). By centering active inquiry around authentic problems, we conjectured that PBL can support teachers' learning in ways that may more easily translate to complex, dynamic classroom life. PBL has most often been studied in K-12 classroom settings (e.g., Malmia et al., 2019), but Horn (2013) argues that teaching consists of copious problem-solving and that many rich learning opportunities occur when teachers engage in problem-solving around their work. Thus, using video, our model capitalizes on naturally-occuring problems in teachers' daily practice, using challenges that are identified by teachers themselves and that occur in their complex classroom ecologies.

Learning opportunities

To understand how teachers' learning can be supported through video-based coaching, I drew on Greeno and Gresalfi's (2008) characterization of learning opportunities as "*affordances* for changing participation and practice" (p. 172). These can include new ways of positioning teachers toward their practice (Horn, 2010); resources available in the activity system that might support different forms of understanding, participation, or practice (Greeno & Gresalfi, 2008; Horn, 2007); or patterns of interaction that afford or constrain different participatory identities (Greeno & Gresalfi, 2008; Holland et al., 1998).

Problem formulation and framing

To understand how learning opportunities arise in problem-based learning, I pay special attention to problem formulation. Problem formulation is a collaborative process that involves teachers' views about their work (Horn, 2013) and can occur through framing (Bannister, 2015; Goffman, 1974). *Framing* refers to the ways that problems, and possible solutions for them, are conceptualized (Horn, 2013). Frames can profoundly shape teachers' learning opportunities; they may orient teachers toward productive solutions or "render a problem insoluble and therefore encourage the abandonment of such a pursuit" (Horn, 2010, p. 230).

Rich representations of practice

Horn (2005, 2010, 2013) found that representations of practice were crucial resources in teachers' collaborative learning (see also Little, 2003). Because problems of practice often occur during the fast-moving work of teaching, "[s]tabilizing these moments to create a common object of inquiry (Bransford et al., 2000) requires means for representing it" (Horn, 2013, p. 134). In this vein, she refers to *rich representations of practice* in the form of video-records of classroom interaction (Horn, 2020) in which we captured the teacher's point of view as well as the whole class and four tracks of student audio. Horn argues that such rich representations of teaching practice can be key sensemaking resources for teachers.

Focal case: Bridgette

In this paper, I focus on one teacher's learning opportunities in one particular debrief from our video-based coaching model. I chose to zero in on this critical case (Flybjerg, 2006) because it highlights important affordances of video-based coaching for supporting teachers' learning, particularly as it relates to justice-oriented pedagogies such as social justice mathematics.

Bridgette and her colleague, Elaine (all names are pseudonyms), were accomplished high school mathematics teachers who had worked together for the majority of their careers. They had a close working relationship and seemed socially open with one another – they often expressed joy and frustration about how both their personal and professional lives were going. Both worked at Katherine Johnson High School, a large community school that hosted three smaller schools on campus. Bridgette and Elaine deliberately chose to work at this school because of deep commitments to supporting students whom the system has given up on and to social justice.

Although Bridgette was passionate about social justice, the lesson debrief analyzed in this paper reflects one of her first attempts to integrate mathematics and social justice in the classroom. On the day our team video-recorded Bridgette's classroom, she taught a lesson about the foundational concept of *functions.* Functions are a concept used to model the world and allow us to make predictions about phenomena. Aiming to show how functions can model sociopolitical realities, Bridgette used the criminal (in)justice system(1) to illustrate the concept. She drew on examples of sentencing for various crimes committed, providing scenarios describing legal infractions and their consequences. Most of the student discourse centered around a situation describing two

different rape charges that resulted in two starkly different sentences. Bridgette asked students to discuss whether the situations described were "predictable" and thus modeling a functional relationship.

Bridgette and Elaine were joined at this debrief by three members of the research team including the author. One member of the research team, Claire, had taken the lead in reviewing Bridgette's video and served as the primary "coach" for this debrief, although the others also occasionally contributed to conversation.

Methods

This analysis was guided by the question, *How can video-based coaching support teachers' learning to integrate mathematics and social justice?* To understand teachers' learning opportunities, our team used ethnographic methods of data collection (Emerson et al., 2011) as participant observers (Spradley, 1980) throughout the 4-year study. This larger ethnographic corpus, including a video-elicited member check interview (Leander, 2004) serves to contextualize and allow triangulation (Denzin, 2009) against the in-depth interaction analysis of one video-recorded debrief.

I use discourse and interaction analysis methods (Gee, 2014; Jordan & Henderson, 1995) to identify interactional, conversational, and design features that afford or constrain Bridgette's learning opportunities. During and after data collection, I wrote reflective and analytic memos about salient moments and emergent questions and hunches that I had (Hatch, 2002). I followed Ochs' (1979) transcription conventions, slightly modified (Table 1).

Table 1

Summary of Transcription Conventions Used in Data Excerpts

Convention	Description
text—	self-interruption
italics	speaker emphasis
(.)	brief pause (less than one second)
:	elongated syllable (each ":" represents one beat)
//text]	overlapping speech
?	rising intonation
…	some of the transcript omitted for brevity
((*text*))	gesture
=	latched speech

Data analysis

To analyze the learning opportunities afforded to Bridgette through video-based coaching, I followed Horn's (2005) method of breaking the debrief transcript into *episodes of pedagogical reasoning* (EPRs). EPRs are "moments in teachers' interaction in which they describe issues or raise questions about teaching practice that are accompanied by some elaboration of reasons, explanations, or justifications" (Horn, 2007, p. 46). EPRs "can be individual, single-turn utterances… or multiparty co-constructions over many turns of talk" (Horn, 2010, p. 237), depending on the boundaries of topical shifts in conversation. Importantly, this unit of analysis allowed me to identify learning opportunities within the interaction contexts in which they arise (Horn & Little, 2010).

After coding for learning opportunities, I looked for sensemaking resources in the coaching interactions that seemed to shape Bridgette's learning opportunities about what it means to integrate mathematics and social justice in her instruction (Horn, 2013). Sensemaking resources that emerged during the coding process included *anecdotes of student thinking* provided by the rich representations of practice as well as ideas related to Bridgette's *pedagogical responsibility* (Horn, 2020) such as *ethical stances, moral precepts,* and *teaching principles*. *Pedagogical responsibility* refers to "whom or what teachers feel beholden to, and often – although not always explicitly – underlies teachers' pedagogical reasoning about their pedagogical actions" (Chen et al., 2020, p. 3). *Ethical stances* refer to teachers' positions about what is right or worthwhile to do (Ricoeur, 1992). These can be outright declarations or implicit in teachers' pedagogical reasoning. I defined *moral precepts* as guiding principles, often taken to be shared general rules about what is good. These were often contained in *teaching principles* – that is, propositions or claims about teaching (Horn, 2013). I then coded for coaching strategies, to understand how the coaches' participation may have supported or constrained Bridgette's learning opportunities.

Findings

Overall, the sensemaking resources that supported Bridgette's learning opportunities included: (1) ethical stances, (2) moral precepts, and (3) anecdotes of student thinking that came from the rich representations of practice. Her

learning opportunities were facilitated by four key coaching strategies: (1) our co-inquiry approach, (2) deliberate and persistent problem (re)framing (Bannister, 2015; Horn, 2010), (3) grounding interpretations in student sensemaking, and (4) building on the teacher's pedagogical responsibility. In the following section, I describe the arc of the debrief by summarizing the seven EPRs analyzed. Next, I present analysis of two focal EPRs that exemplify how learning opportunities arose for Bridgette. Through this analysis, I highlight how Bridgette's learning opportunities were supported through sensemaking resources and the video-based coaching process.

The arc of the debrief

I closely analyzed seven EPRs which contributed substantially to Bridgette's learning opportunities, but for the sake of space, I focus here on three. First, I present in broad strokes a summary of the seven focal EPRs to show the flow of the debrief conversation and to situate the focal EPRs in the larger context. Next, I present a fuller analysis of three focal EPRs.

Because this was Bridgette's first video-based coaching session ever, she was unsure what type of co-inquiry question to pose, so in the first EPR, she and the coaches spent some time discussing what she would like to see and think about. The coaches, Claire and Kyndal, began to formulate a problem by elaborating the complexity of the topic and highlighting different students' interpretations of the term *predictable*. Claire grounded this problem in specific student quotes from the video and began to crystalize the initial problem: that students had varying understandings of the idea of predictability, and this was hampering their ability to draw strong conclusions about the mathematics and the task.

In EPR 2, Bridgette responded to the first clip viewed by sharing more about her sense of pedagogical responsibility, clarifying that part of her purpose in teaching this mathematical topic using the analog of the (in)justice system was that she wanted students "to be very aware of what's happening" and to support them to "*think* more" even when they leave class. In this episode, Elaine asserted the moral precept that "[students] should have their own thoughts about [sociopolitical issues]," and Bridgette responded with an important ethical stance: *I should not foist my own commitments onto students*.

In EPR 3, the coaches responded by building upon the pedagogical responsibility that Bridgette had just expressed, highlighting some specific areas of student discomfort that might need to be addressed. They leveraged Bridgette's expressed pedagogical responsibility to continue reframing the problem, highlighting the teaching principle that *wrapping up such discussions about social issues may be an important piece of this kind of lesson*, especially because students were left with problematic issues having been raised, but with no opportunity for resolution. They acknowledged Bridgette's ethical stances but gently reframed her pedagogical responsibility. Instead of worrying about *telling* "students what to think" (Bridgette's words), Claire asked, "what does it mean to have these types of conversations [in a way] that does feel safe and inclusive for students?" Claire did not dismiss the ethical stance that teachers should not brainwash students, but she layered on a new framing that another important part of teachers' pedagogical responsibility is *fostering a safe and inclusive learning environment*. This reframing was critical; it both affirmed Bridgette's concern about telling students what to think and opened a new way of thinking about her pedagogical responsibilities.

Claire's problem reframing from EPR 3 sparked, in EPR 4, an extended turn by Bridgette in which she named multiple ethical stances and moral precepts that she saw as part of her pedagogical responsibility. First, she took the stance that *simply raising awareness that these issues exist is not enough*. However, in the next breath, she clarified that *raising awareness was important*, a key part of why she taught these topics in a mathematics class ("And like I want them to be aware of them because some of them are like, 'Oh, I didn't know about *any* of that'"; turn 384). She then further elaborated that *raising awareness is insufficient if students are not empowered or motivated to make change* but contrasted this with another ethical stance: *teachers should not foist their own commitments onto students* ("Then, I also don't want to (.) like *brainwash* them [into] what I think"; turn 384). This turn culminated with two more clear ethical stances: *teachers should prepare students to challenge systems of oppression* and *teachers should prepare students to navigate their oppressive world*. As she concluded, Bridgette landed on the pedagogical dilemma of *how to support students to navigate an oppressive world* – a problem framing that arose directly from her expressed pedagogical responsibility.

Focal EPR (5): Coach introduces a new problem frame using rich representation of practice

In EPR 5, Claire again drew on the rich representations of practice – video clips of students' sensemaking – to frame a new dilemma (Table 3).

Table 3
Transcript Excerpt from EPR 5

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Line number	Speaker	Transcript
385	Claire:	I wonder too, you've mentioned using these contexts as a way into the math. Amena said something at the very beginning about the video. Sh— they— When you gave them time to process how they felt about the video, that group mostly talked about, like 'it's really scary,' 'it's really sad,' 'it's really depressing' and Amena said, 'Does this have to do with math?' And the other students were like, 'I don't know, does it?' And she's like, 'Well, if this is math, I don't want to do math because it's scary.'
386	Bridgette:	Mm::::: ((*looks up, smiles tightly, then looks down placing hands on cup*))
387	Kyndal:	Someone here said that too.
388	Claire:	So that makes me wonder a little bit about the connection.
399	Bridgette:	Yeah.
400	Claire:	And like what are— how are students thinking about the relationship between the context that you're using and the math? I don't have more to say than that.
401	Bridgette:	If this is math, this is scary.

In turn 385, Claire built on one of Bridgette's articulated ethical stances, that *social justice topics should bridge students' interests and mathematics*; Claire contrasted this aim with students' reactions as heard in the video clips – they viewed the topic as scary and depressing. Bridgette's response in turn 386 was a drawn out "mm" and was accompanied by a shift in her posture: she looked up sharply, gave a tight smile, then looked down, resting her hands on her coffee cup. Her body language, tone, and utterances suggest that these student perspectives gave her pause. Her repeat of a student's phrase in turn 391, "If this is math, this is scary" also signals that she continued to engage this problem frame and seemed to be bothered by students' emotional response.

Focal EPR (6): Coach builds on teacher's pedagogical responsibility for new problem framing

In EPR 6, Kyndal built on the teacher's pedagogical responsibility and the problem frame offered by Claire in EPR 5 that students may have emotional responses to these topics. She offered an implicit moral precept that *education should not skirt topics simply because they are uncomfortable*, highlighting that as students discussed the case of the two rape convictions, they expressed highly problematic ideas about consent. She then reframed Bridgette's pedagogical responsibility, using language from her own ethical stance (Table 4).

Table 4

Transcript Excerpt from EPR 6

Line number	Speaker	Transcript
394	Kyndal:	I would be okay with brainwashing them about that.
395	Bridgette:	((*laughs loudly*))
396	Kyndal:	//If we're going to brainwash] them about something.
397	Claire:	//there are some things]
398	Bridgette:	Yeah.

Although she used Bridgette's language, Kyndal inverted the pedagogical responsibility as she reframed the problem; Bridgette had earlier expressed reluctance to foist her own commitments onto students, stating that she did *not* want to brainwash them. Kyndal instead asserted a new moral precept that *on some issues, students should be told what to think.* Again using anecdotes of student thinking, Kyndal framed a problem that *students' understanding about social issues was partial and problematic.* Both coaches used quotes they heard from students to vividly illustrate the complexity of the sociopolitical topics, and the partial understandings that students held about them.

Focal EPR (7): Coach builds on teacher's pedagogical responsibility for prognostic framing

In the final EPR analyzed here, the problem framing in EPR 6 was followed by an extended turn by Bridgette in which she reasoned in detail again about her pedagogical responsibility. In Bridgette's opening sentence, she revealed one part of her pedagogical responsibility; she seems to see her work as satisfactory if *conversations about social issues are happening* ("Okay I guess I'm okay then now that those conversations are happening"; turn 403). In her view, if she could support her students to have meaningful discourse about tricky social issues,

this was a step toward empowerment. She concluded "Okay, that's what I want. I want them to be able to speak up and have conversations and be okay with that" (turn 403).

In the next turn, Claire gently extended Bridgette's pedagogical responsibility, as though she was completing Bridgette's sentence. She said:

> I think in a way that also feels good for the people listening. I think this was Mariana, she was doing a lot of hedging when she was making inferences about the Stanford player probably being white and the Vanderbilt player probably— She kept saying, "I'm not racist but, I'm not racist but." I wonder in a situation like that, she's trying to be careful, she's also drawing on patterns and correlations that we know exist in the world. I wonder if a student like her, if she had a little more support around, how to communicate her idea— She clearly has no problem saying what she thinks but if she had a little more support around how to do that, I wonder if she would feel more comfortable and not do as much hedging and not have to worry that she's accidentally offending other people. (turn 404)

In her first utterance, Claire drew on a new moral precept to add to Bridgette's pedagogical responsibility — the idea that *students should not feel too uncomfortable in the classroom*. In the next breath, she illustrated the need for this element of pedagogical responsibility, directly quoting a student to show that more support in having conversations around race and social injustices might be needed. By reframing the problem as one of student discomfort, she set the stage for a new prognostic frame: that *scaffolding students to have conversations about sensitive topics might be an important part of social justice mathematics pedagogy*.

Discussion

The way Bridgette grappled with her pedagogical responsibility in this debrief is not uncommon when teachers begin the work of integrating mathematics and social justice. Bartell (2013) found that teachers centered their goals for social justice mathematics "on student awareness more than on specific understanding of and action toward confronting injustice. In doing so, teachers perhaps avoided grappling with sociopolitical issues in the complex ways that their lesson warranted" (p. 145). In Bridgette's case, video-based coaching provided opportunities for her to confront such avoidance, giving her time and space to process some of what may be beneficial or harmful about this lesson and to workshop ideas for the future.

The sensemaking resources that contributed to learning opportunities for Bridgette included anecdotes of student thinking (provided by the rich representations of practice), as well as ethical stances and moral precepts found in Bridgette's articulated pedagogical responsibility (Horn, 2020). Her learning opportunities were facilitated by coaching strategies including: (1) a co-inquiry approach, (2) deliberate and persistent problem (re)framing, (3) grounding interpretations in student sensemaking, and (4) building on the teacher's pedagogical responsibility. Because teaching mathematics for social justice is such a complex endeavor, the co-inquiry approach was well-suited to supporting learning opportunities, enabling the coaches to capitalize on the challenges Bridgette faced in her specific context and allowing problems of practice relevant to her work to drive discussion. By persistently reframing problems, the coaches repeatedly pressed on Bridgette's sensemaking and surfaced numerous problems of practice within the one-hour debrief, highlighting multiple angles of her pedagogy that may have been invisible without this problem reframing. Finally, by building on the teacher's pedagogical responsibility throughout, the coaches kept problems of practice close to issues of importance to her, and helped highlight areas of potential disconnect between her sense of pedagogical responsibility and her pedagogical actions, supporting robust pedagogical reasoning; these are conditions Horn (2020) describes as ripe for developing pedagogical judgment.

Because of the short duration of this debrief, it is difficult to make claims about Bridgette's learning, thus I focused primarily on the *opportunities* afforded by this video-based coaching model, bolstered by the in-depth grappling with these problems of practice that she and the coaches did during the debrief. In this debrief, analysis showed that Bridgette had learning opportunities about multiple dimensions of her social justice pedagogy, including the complexity and partiality of students' understanding, what it means to support students in conversations that feel safe and inclusive, what the purposes of teaching mathematics and social justice topics should be, how to prepare students for navigating an oppressive world, how to scaffold students to have conversations about sensitive topics, and more. However, I conducted a video-elicited interview with Bridgette two and a half years after this debrief, during which she confirmed several ideas that she has developed as a result of this debrief conversation, including *what it means to support students in conversations that feel safe and inclusive* and *addressing the complexity and partiality of students' understanding*.

Conclusion

Although mathematics teachers hear increasing calls to integrate mathematics and social justice and to learn social justice pedagogies, there remains little support available to them (Bartell, 2013). Those who want to begin such efforts are often on their own to find or develop curricula, and have few mechanisms for feedback or reflection to improve such practice, even though social justice pedagogies are far from straightforward (Kokka, 2017). Because the video-based coaching design relies on teachers' own inquiry questions and rich video-records of classroom interactions for discussion, it positions "participants to think about themselves, their circumstances, and their future actions in ways that are deeply contextualized" (Gutiérrez & Jurow, 2016, p. 4).

This analysis shows some of the ways in which video-based coaching may be a promising tool for supporting teachers' learning to integrate mathematics and social justice—in part by offering teachers a glimpse into students' sensemaking, emotional reactions, and other elements of their experiences of this kind of mathematics. These insights, which were not otherwise available to Bridgette, supported her pedagogical sensemaking about her own students, their experiences in mathematics, and her practice. This model may be fruitful for supporting teachers' learning of other justice-oriented pedagogies. After an extensive database search and literature review (Marshall & Buenrostro, 2021), I concluded that this is the first study to investigate this potential. Self (2016) cautions that "culturally responsive teachers must become vigilant to the possibilities that exist, both positive and negative, for the approach they have chosen" (p. 67). The video-based coaching process afforded opportunities for Bridgette to become vigilant to such possibilities.

Endnotes

(1) The system commonly referred to as the criminal "justice" system is, in fact, wildly unjust. Therefore, I follow Golembeski and Fullilove (2005) in calling it the criminal (in)justice system.

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Lessons from Manoomin: Toward Acknowledging the Sovereignty of Indigenous Making and Sharing

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Abstract: While multiple systematic reviews on constructionist learning activities have been conducted over the past decade, very few acknowledge the unique contributions of Indigenous learners and their communities as part of the maker movement. The purpose of this paper is to provide a review of existing literature on Indigenous approaches to making and sharing with a goal of identifying common technologies utilized when designing learning-by-making experiences for Indigenous youth. We summarize current findings and categorize them in alignment with principles of Indigenous making and sharing practices. These findings promote a comprehensive perspective on ways to enact Indigenous making and sharing approaches while working with Indigenous young learners and their communities. We conclude with recommendations for furthering current understandings of Indigenous making and sharing skills and pedagogical practices as well as weaving in lessons we have learned from manoomin.

Introduction

Throughout wild rice camp, or manoominike, we ate what our ancestors had eaten. We shared stories that our ancestors had passed down. We renewed our relationships just like our ancestors had before us. And we did this all to fulfill our responsibilities to ourselves and our Anishinaabeg community. To this day, this experience remains by far the most enriching and profoundly transformative making activity I have ever experienced during my lifetime. As a result, I wonder how rich learning experiences, like manoominike, are being represented across the current scholarship of making and makerspaces. --Author 1

Wild rice, or *manoomin* (pronounced Ma-nō-min), is hand-harvested each fall by the Anishinaabeg across the Great Lakes region. Manoomin (*Zizania palustris*) is a type of grass that grows on the lakes, and it is one of the only grains native to North America. The Anishinaabe people's companionship with manoomin goes back centuries (e.g., Vennum, 1988). Often referred to as the "seed of life," manoomin is culturally vital and sacred to the Anishinaabeg. The Anishinaabeg believe we owe our lives to manoomin since it provides nourishment throughout each season for human and more-than-human relatives alike, especially when food is not always plentiful. For generations, wild rice camps like these have engaged Indigenous youth, families, and cultural leaders alike in the sharing of traditional teachings and creation stories, demonstrating companionship with wild rice and other more-than-human relatives, and constructing their own rice tools for harvest (e.g., Vennum, 1988).

As a scholar of Anishinaabe (Ojibwe) and European descent, Author 1 was struck by how deeply engaging and transformative her manoominike experience was. Especially in how it embodied the "traditional forms of making as a living legacy of Indigenous scientific and technological activity" (Barajas-López & Bang, 2018, p. 18). Moreover, having participated in the design and research of multiple learning-by-making experiences, the authors were further perplexed as to why Indigenous making and sharing is not more widely represented across the maker movement and maker spaces. The dissonance between such a rich "maker" activity and the limited representation of such knowledge in the maker movement scholarship prompted us to take a deeper look at what we can learn from Indigenous making and sharing. While the scholarship is still largely rooted in western ways of knowing and being, we also encountered rich cultural experiences that enacted principles of Indigenous making and sharing and (re)centered Indigenous ways of knowing and being (Barajas-López & Bang, 2018). In this paper, we look across this work on Indigenous making and sharing with youth to offer expanded understandings through a systematic review woven together with lessons we learned from sacred manoomin.

Overview of Indigenous Making & Sharing Principles

The principles of Indigenous making and sharing have been enacted in Indigenous communities since time immemorial. The Anishinaabeg, for example, have stewarded manoomin ever since it was gifted to them by the Creator (*Gitche Manitou)* for generations prior to settler colonial expansion. While conducting a summer Science, Technology, Engineering, Art, Mathematics (STEAM) camp with Indigenous youth, Barajas-López and Bang (2018, p. 17) observed the principles of Indigenous making and sharing practices to include: (1) Enacts and

communicates stories in a multiplicity of forms in and across temporalities. Knowing, being, and doing are simultaneously unfolding and are essential/defining elements in the practice of material storytelling; (2) Reflects the patterns and processes that cultivate life and draw on deeply interrelated socioecological phenomena requiring interdisciplinary forms of sense-making; (3) Enacts relationships with animate materials that have life courses toward the fulfillment of communal responsibilities; and (4) Enables continual renewal of family and community to assert contemporary presences and living Indigenous nature-culture relations.

Similarly, Author 1 observed Indigenous making and sharing principles during her family's wild rice camp experiences that unfolded near the waters of Little Elbow Lake on Gaa-waabaabiganikaag (White Earth Nation). In our findings, we further discuss Author 1's observations of these principles being enacted at wild rice camp as well as the lessons from manoomin we have learned over the course of this literature review.

Need for Literature Review

Over the past decade, multiple systematic reviews have been conducted on constructionist learning activities (Papavlasopoulou et al., 2017; Timotheou & Ioannou, 2019). While findings from these literature reviews help us further our understanding of making, few acknowledge the unique contributions of Indigenous learners and their communities as part of the maker movement. As a result, they do little to address tensions surrounding equity and pedagogical practices of the broader maker movement (Vossoughi & Bevan, 2014). Therefore, in this paper, we examined studies incorporating Indigenous notions of making and sharing while maintaining and acknowledging Indigenous ways of knowing and being. We focused solely on studies that described any kind of learning-by-making experience with Indigenous youth.

The purpose of this review was to examine the current state of scholarship in the maker movement and how it intersects with Indigenous making and sharing practices. For this systematic review, we examined empirical studies grounded in Indigenous epistemologies that attempt further exploration of the making practices specific to Indigenous communities. Guided by Barajas-López's and Bang's (2018) definition of Indigenous making and sharing, we address the following research question: How does scholarship on Indigenous making and sharing define and enact making and sharing principles?

Procedures & Methodology/Methods Literature Search

We conducted a systematic literature review (Gough et al., 2012) by examining scholarship related to Indigenous making and sharing with youth. We explored article databases in the fields of learning sciences and Indigenous education including Education Source, PsycINFO, and JSTOR as well as journal databases such as Association of Computing Machinery (ACM) and the Journal of American Indian Education (JAIE). Keywords used to search the databases included the following and similar terms: "Indigenous", "making", "youth", "science", and "technology". We found a total of 333 articles.

Inclusions Criteria

We included empirical articles and conference proceedings published in the last twenty years and applied the following criteria:(1) peer reviewed article, (2) full text available, (3) written and/or available in the English language, (4) having Indigenous or Aboriginal young learners in their participant population, and (5) published in an academic journal or conference proceedings. First, we evaluated the titles and abstracts of each article according to the inclusion/exclusion criteria, which resulted in 99 articles. Next, we screened for inclusion/exclusion based upon whether each article was related to learning experiences where Indigenous learners are engaging in learning-by-making as a result. This resulted in 20 articles included in this review.

Classification Criteria

We modified and collapsed principles of Indigenous making and sharing identified by Barajas-López and Bang (2018, p. 17) to classify the articles in our literature search. Specifically, we classified literature based on these four major categories: (1) enacts and communicates storytelling (2) walking and reflections of sense-making and interrelated socioecological phenomena (3) enacts making (including both forms of Indigenous and/or western forms of making) and (4) demonstrates renewal of family and community relations. Category classifications were not mutually exclusive.

First, we identified the types of technologies used to create learning artifacts across each of the 20 studies. We classified the articles into learning experiences that utilized original technologies (e.g., making of moccasins, claywork, building of canoes, etc.) versus digital technologies (e.g., digital storytelling, software, etc.). Similar to Barajas-López and Bang (2018), we refer to Indigenous technologies as "original technologies" in order to reclaim old and new Indigenous making and sharing practices and acknowledge them as more than just "artistic expressions" (pp. 9-10), but rather legitimate productions of the knowledge-making process. Next, we classified

studies based on what categories of Indigenous making and sharing they utilized (Barajas-López & Bang, 2018). To be classified in the "enacts and communicates storytelling" category, youth had to engage in either oral storytelling or digital storytelling practices as a means to "communicate meaning, feelings, and ways of being" (Barajas-López & Bang, 2018, p. 9). For many of the studies, oral narratives were shared through some form of digital media. Therefore, we utilized the following definition of digital storytelling: "Digital storytelling combines the art of telling stories with a mixture of digital media, including text, pictures, recorded audio narration, music and video" (Robin, 2016) to inform our categories. And lastly, we examined studies that specified the renewal of family and community relations. Studies that utilized this principle had to demonstrate some form of collaboration with Indigenous community members in order to be assigned to this category.

Findings

We use principles of Indigenous making and sharing (Barajas-López & Bang, 2018) to frame our findings. We first provide a summary of findings. Then for each principle we provide (1) definitional grounding, (2) discuss related findings from our review, and (3) reflect upon lessons we have learned from manoomin as they relate to each principle.

Summary of Findings

This review focuses on current research in learning-by-making experiences designed for Indigenous youth. Studies noted a range of learning environments that included informal after-school settings, summer camps, in-school spaces, and libraries. Many of the learning-by-making experiences described in sections below utilized Indigenous making and sharing practices. Of the examined studies, we found three studies (Barajas-López & Bang, 2018; Carlson et al., 2011; Searle et al., 2017) that utilized all four Indigenous making and sharing categories in their learning experiences. Also, we found four studies that enacted a single Indigenous making and sharing category in their experiences (e.g., Eglash et al., 2013; Webb et al., 2012). Because these studies demonstrated a single category of "enacted making," it is a matter of debate as to whether Indigenous making and sharing was truly demonstrated across such studies. We highlight these areas throughout the findings as critical needs for further research. Table 1 below provides a summary of setting, assigned category, technology used, and learning artifact(s) created to serve as guide for the remainder of the findings section.

Table 1

Studies using learning-by-making as an educational intervention with Indigenous youth (N = 20)

Study	Setting	Category	Technologies Used	Learning Artifact(s) Created
Bang et al. (2013)	Informal	2, 3, 4	Original	Fire
Barajas-López & Bang (2018b)	Informal	1, 2, 3, 4	Original	Claywork
Beltrán & Begun (2014)	Informal	1, 3, 4	Digital	Stories
Bequette (2007)	Formal K-12	2, 3	Original	Basketry
Carlson et al. (2011)	Informal & formal K-12	1, 2, 3, 4	Original	Moccasins and canoes
Coenraad (2019)	Informal	1, 3, 4	Digital	Stories
Eglash et al. (2013)	Informal	3	Digital	Cartesian coordinate systems
Iseke & Moore (2011)	Informal	1, 3, 4	Digital	Stories
Kafai et al. (2014)	Informal & formal K-12	2, 3, 4	Original and digital	Electronic textiles
Lameman et al. (2010)	Formal K-12	1, 3	Digital	Video games and stories
Mills et al. (2015)	Formal K-12	1, 3, 4	Digital	Stories
Rickard (2005)	Formal K-12	2, 3, 4	Original	Fish racks
Riecken et al. (2006)	Formal K-12	3, 4	Digital	Videos
Searle & Kafai (2015a)	Formal K-12	3	Original and digital	Electronic textiles
Searle & Kafai (2015b)	Formal K-12	3	Original and digital	Electronic textiles
Searle et al. (2017)	Informal	1, 2, 3, 4	Digital	Stories
Tzou et al. (2019)	Informal	1, 3, 4	Digital	Stories
Webb et al. (2012)	Formal K-12	3	Digital	Games and science simulations
Weston & Biin (2015)	Informal & formal K-12	1, 3	Digital	Stories and games
Wexler et al. (2013)	Informal	1, 3, 4	Digital	Stories

Enacts & Communicates Storytelling

Storytelling is a key pedagogical practice and learning tool valued by many Indigenous cultures for centuries (Kawagley, 2006; Marin & Bang, 2015). Central to Indigenous ways of learning and research, the practice of storytelling "sustains communities and validates the experiences and epistemologies of Indigenous peoples" (Iseke, 2013, p. 559). Through storytelling, community members can impart cultural and traditional Indigenous knowledge to young learners (Davis, 2014; Iseke, 2013). Learning scientists are starting to examine storytelling practices in their research with Indigenous learners (e.g., Barajas-López & Bang, 2018; Searle et al., 2017; Tzou et al., 2019). For example, Barajas-López and Bang (2018) youths' participation in storytelling was not only found to allow for Indigenous young people to practice their own forms of storytelling, but it also allowed for them to participate in relationship-building activities with members from their Indigenous communities.

Throughout our review, we found storytelling to take on various digital and original forms. Of the studies we found to utilize storytelling (n = 11), nine studies incorporated digital tools (e.g., film, robotics, video games, digital stories) to assist young learners in their story creation process while two studies used oral technologies (e.g., oral traditions) as part of their learning experience. As an example, Carlson and colleagues (2011) illustrated storytelling practices when they asked Elders to teach part of their science curriculum and share Indigenous perspectives of science with Native students. As part of their study, Elders engaged in ceremonial practices with their students prior to harvesting materials to build heritage crafts (e.g., snowshoes).

The practice of storytelling also emerged as a framework for centering "family-making" practices where family members share stories and memories while creating and learning intergenerationally. As an example, Tzou and colleagues (2019) designed a family-based robotics program, called TechTales, grounded in storytelling that was implemented over the course of multiple weekly workshops. Two Indigenous families used both personal and traditional stories to inform the design of dioramas they co-created using robotics as well as other technologies. Tzou and colleagues (2019) argued that engaging in family-making and storytelling helped the families to deepen their own personal and cultural identities while also participating in acts of "renewal and resurgence" of Indigenous ways of knowing (Tzou et al., p. 324).

Teaching 1 from Manoomin

Prior to the official start of camp, our cultural leader spoke in Anishinaabemowin and offered his blessings for the harvest. He explained how our ancestors were given spiritual instruction to travel to the place where food grows on water and how the thunder beings own manoomin. He also described how manoominike represents a (re)creation of the creation story when the seed falls into the water. --Author 1

In Author 1's narrative, the sharing of creation stories and enactment of ceremonial practices allowed for her to make sense of manoominike through Anishinaabeg ways of knowing. Historically, many Indigenous peoples have demonstrated learning through experiences and the passing down of oral histories from one generation to the next (e.g., Kawagley, 1995). Indigenous oral narratives often include stories of origination, shared life-experiences among community members, and other ancient teachings (e.g., Davis, 2014). Manoomin also reminds us of the significance of storytelling practices as "the accumulation of thousands of years of making that are based on storytelling and apprenticeship relationships" (Barajas-López & Bang, 2018, p. 14).

Walking & Sense-Making with Interrelated Socioecological Phenomena

For many Indigenous peoples, knowledge and culture are heavily influenced by relationships with the land (Brayboy, 2005; Barajas-López & Bang, 2018b). Land-based pedagogies (e.g., Benton, 2017) are commonly used approaches for cultivating environmental awareness among Indigenous learners. Land-based and place-based pedagogies (Feld & Basso, 1996) are similar learning practices due to how deeply situated within the concepts of time and space. Land-based pedagogies also incorporate Indigenous ways of knowing by including Traditional Knowledge perspectives (Tuck et al., 2014). As an example, Barajas-López & Bang (2018) utilized the principle of "walking and sense-making" with youth as they participated an I-STEAM program where learners were encouraged to walk while engaging in storytelling involving their surrounding local ecosystems.

Youth engaging in sense-making with socioecological phenomena occurred in less than half of the studies we examined (n = 6). There were a variety of land-based and space-based pedagogies utilized among the studies examined. For instance, Searle and colleagues (2017) employed space-based pedagogies with Native youth during visits to community sites. The sites youth visited then became incorporated into the designs of their games for future visitors to play. Other land-based pedagogies invited youth to manipulate aspects of their physical world. As an example, Carlson and colleagues (2011) provided Ojibwe students direct interactions with physical space by teaching them to harvest maple syrup. This experience encouraged young learners to engage in their people's ancient traditions while also gaining knowledge in key features of their local food sources. Given the deep connections between many Indigenous peoples and their traditional land and ecologies (e.g., Barnhardt &

Kawagley, 2005), it is concerning that this way of being is not more represented in current work with Indigenous youth around making and sharing.

Teaching 2 from Manoomin

On one side of camp, campers placed moccasins on their feet to jig the rice in a bucket (which allows the rice to loosen its hulls) while the camp cultural leader sang and played a one-sided drum. The camp organizer held a birch bark basket, repeatedly tossing manoomin into the wind and catching it again in the basket. She explained how this process (called "winnowing") causes the hulls to be separated from the rice, leaving only rice kernels behind. Meanwhile, other participants engaged in land-based pedagogies of hunting, fishing, and harvesting only to return in the evenings before dinner preparation. --Author 1

In this narrative, Author 1 witnessed how youth engaged in sense-making with socioecoloogical phenomena, particularly through the jigging and winnowing of manoomin. Similarly, Marin and Bang (2018) investigated land-based pedagogies through their examination of how a Native American family engages in intergenerational conversations and sense-making practices while walking together through nature. Throughout this process, family members participated in the methodologies of "walking, reading, and storying the land" as they engaged in the "coordination of attention and observation between humans and more-than-human others to identify and name living and natural kinds, finding evidence, and generating explanations to create a story about the perceptual field" (p. 90). Their study as well as Author 1's manoominike experience demonstrate the importance of engaging Indigenous learners by connecting learning to their local land-based systems.

Enacts Making

Learning through the process of making has taken place for generations of Indigenous learners. In his study of Yupiaq culture, Kawagley (1995) describes how members of his tribe have long engaged in scientific and technological practices while being guided by the "knowledge of their ancestors" (p. 56). For example, he describes the science and technology incorporated into the design of Yupiaq's local fish camps. Each Yupiaq family owns a fish camp, which serves as a space for living, fish preparation, and storage during the fishing season. While taking a Yupiaq worldview, Kawagley (1995) proposed an educational program to teach Indigenous youth about scientific phenomena including weather patterns and local fauna and flora. The program also teaches how to use solar energy while creating culturally centered products such as a fish rack for their fish camp. His proposed educational program illustrates the making of culturally related artifacts (e.g., fish racks) that could help create authentic learning experiences for students from traditional societies.

All studies we examined (n = 20) enacted making throughout a prescribed learning experience (including forms of both digital and original technologies). We observed original technologies (e.g., making of moccasins, claywork, building of birch bark canoes) to reflect Indigenous forms of making versus digital technologies (e.g., digital storytelling, software, etc.) that reflected more western instantiations of making. We classified only nine studies as including forms of original technologies, while 15 studies utilized contemporary western digital technologies. Three studies utilized both types of technologies and were classified in both categories. For example, Searle and Kafai (2015b) used e-textile construction kits combined with traditional sewing practices for their learning experience with American Indian boys. The medium uniquely pulled in a "strong-community based craft tradition linked to heritage cultural practices and Indigenous Knowledge Systems" (Searle & Kafai, 2015b, p. 31).

The nine studies including original technologies showcased technologies used for developing land restoration practices (e.g., Bang et al., 2013), claymaking (e.g., Barajas-López & Bang, 2018), making moccasins, harvesting maple syrup, building birch bark canoes (e.g., Carlson et al., 2011) and designing fish racks for drying salmon (e.g., Rickard, 2005). Digital technologies, though, were the most common technologies used in current Indigenous making and sharing experiences with Indigenous youth. Of the 20 studies, we classified 15 learning-by-making experiences that utilized some form of digital and/or digital fabrication technologies. This included technologies for digital storytelling (e.g., Beltrán & Begun, 2014; Coenraad, 2019; Iseke & Moore, 2011; Mills et al., 2015; Riecken et al., 2006; Searle et al., 2017; Weston & Biin, 2015; Wexler et al., 2013), game design and development (e.g., Lameman et al., 2010; Webb et al., 2012), and heritage craft design and development (e.g., Eglash et al., 2013; Kafai et al., 2014; Searle & Kafai, 2015a; Searle & Kafai, 2015b). The majority (n = 8) of the learning experiences included digital technologies that specifically supported digital storytelling. The types of digital storytelling media ranged from film or video production to augmented reality and interactive storytelling platforms. In sum, there is currently an overrepresentation of western technologies in the learning-by-making workshops with Indigenous youth.

Teaching 3 from Manoomin

We walked around camp admiring the learning that was going on around us. Children of all ages sat under the canopy of trees, teasing each other, and constructing rick knockers made of cedar and dolls made of corn husks. Occasionally each child made their way over to an Elder and showed off their creations with pride. --Author 1

From this narrative, Author 1 witnessed how youth engage in learning-by-making activities through the constructing of wild rice tools and corn husk dolls. This enabled youth to utilize original technologies of the Anishinaabeg. Many wild rice camp participants engaged in the pedagogies of walking and material storytelling, and constructed rice tools that enabled them to utilize their "own technologies and practices of making" (Barajas-López & Bang, 2018, p. 9). Therefore, manoomin also teaches us the importance of encouraging youth to engage in learning-by-making experiences using original technologies.

Demonstrates Renewal of Family and Community Relations

Including family and community members in the design and implementation of learning experiences is a distinguishing feature of Indigenous knowledge systems (e.g., Barnhardt & Kawagley, 2005) and Indigenous making and sharing practices (Barajas-López & Bang, 2018). Members of Indigenous committees can also serve as cultural practitioners, so-called "cultural gatekeepers," who have critical insights into the cultural practices of Indigenous peoples (Bequette, 2007). Throughout the various forms of these storytelling processes, we reviewed a range from within-family interactions (e.g., Tzou et al., 2019) to larger across community interactions (e.g., Iseke & Moore, 2011). Many of the studies engaged community members as cultural experts. For example, Riecken and colleagues (2006) conducted a participatory research project where Indigenous youth developed their research questions and conducted interviews with members of their family and community to create a video that they would share with their community.

The renewal of family and community relations involves both living and more-than-human relatives (Barajas-López & Bang, 2018). From the perspectives of Barajas-López and Bang (2018), Indigenous making and sharing allow participants to employ their own agency while engaging in the histories and technologies of their ancestors and subsequently maintaining such practices for future generations. One of the participants of their I-STEAM project, Miguel, describes his first-time experience in the use of claywork by stating that he "was able to connect with those that came before me" throughout the experience (Barajas-López & Bang, 2018, p. 7). However, this was the only examined review that demonstrated the renewal of family and community relationships with more-than-human relatives.

To date, many studies that demonstrate aspects of Indigenous making and sharing also involve different forms of community engagement. Of the 20 studies reviewed, 13 studies showed the renewal of family and community relationships in some form during the learning-by-making process. Demonstration of renewal of family and community relationships varied across experiences, but a common thread among the studies was that community members were utilized as cultural experts at some point in time during the making process. Sometimes this took place on a broader scale across communities or in a smaller family setting. Researchers like Tzou and colleagues (2019) conducted their intergenerational, robotics-based storytelling intervention with two Native American families. Other scholars like Wexler and colleagues (2013), who implemented multiple digital storytelling workshops across Alaska, took place across multiple communities. Seven articles did not mention any form of family or community involvement. Further, while the studies we reviewed included aspects of family and community engagement, the extent to which families and communities were engaged throughout the entirety of the learning experience, beyond cultural experts, was limited.

Teaching 4 from Manoomin

The botanist in charge of our plant walk explained that the plants she was showing us had been revealed to her during dream time. She directed us down a gravel road and then down a path sheltered by trees. She showed us the characteristics to look for in wild strawberries, plantain, dandelion greens, and wild ginger. We collected types of each plant, making sure not to take too much and leave some behind for our relatives, especially as the drought had not left many berries. We spent over an hour foraging, cleaning, and preparing food for our communal feast afterward. --Author 1

In this example, Author 1 describes how she engaged in communal responsibilities of foraging and preparing food for other camp participants. Ultimately, many are worried that manoomin and the Anishinaabeg's spiritual connection to the land and each other will disappear as a result of the intensifying climate crisis: "We are defined by manoomin. It is the whole reason we were sent here by Creator...So, when the rice is destroyed, it is modern-day genocide. When the rice is gone, we cease to be who we have been for thousands of years" (Stone, 2021). Consequently, the principles of Indigenous making and sharing enacted by the Anishinaabeg when they

hand-harvest and steward manoomin are also at risk if settler colonial pursuits persist. Therefore, the fourth teaching of manoomin encourages us to engage young learners in maintaining our nature-culture relations.

Discussion, Implications, and Limitations

Our analysis helped us to identify ways Indigenous making and sharing approaches have been enacted while working with Indigenous young learners and their communities. In the following discussion, we discuss the limitations of our review as well as turn to ways in which manoomin has taught us and continues to teach us.

This review seeks to acknowledge the unique contributions of Indigenous peoples to the field of maker education and by further revealing non-normative instantiations of learning-by-making experiences. The major limitation of our review is that our extensive search yielded only 20 articles. While the amount of scholarship on the maker movement is increasing, there remain few projects that further the principles of Indigenous making and sharing. We found limited literature addressing walking & sense-making with interrelated socioecological phenomena (n = 6) as well as literature demonstrating renewal of family and community relations (n = 13). Even more, of the 20 articles included in this review, four studies only include a single category of Indigenous making and sharing principles, specifically "enacting making," in their work with Indigenous youth. Taking this together with the fact that most studies also solely utilized western digital technologies, there is great need for deeper integration of Indigenous and western making and sharing, especially when working with Indigenous youth and their communities. To this knowledge, as we further explore such integrations, scholars like Barajas-López and Bang (2018) warn us to not "fit or impose Indigenous knowledge systems into Western conceptions of knowledge means maintaining asymmetrical power relations and reproducing inequities and dominance" (p. 20). After all, Indigenous knowledge systems and practices are not assets to be appropriated nor exploited but rather embraced.

Throughout our search, we did not identify any guidelines for conducting Indigenous making and sharing principles with Indigenous families and communities. As such, as we continue such scholarship, we must begin to acknowledge our responsibilities toward protecting Indigenous making and sharing from appropriation and exploitation. Sovereignty and stewardship of these practices require the highest levels of protection as we work to provide and sustain reciprocal relations (e.g., Kimmerer, 2015). Like manoomin, wild rice camp and other forms of Indigenous making and sharing are spiritual entities with their own agencies that require reciprocal relations. Therefore, as we reflect upon the lessons that manoomin provides us, we also question how and to what extent we as scholars should move to protect the sovereignty of Indigenous making and sharing as its own entity.

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Examining the instructional norms that support student participation and engagement in whole class science discussions

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Abstract: The latest reform efforts in science education emphasize the centrality of productive classroom discourse to learning science with an emphasis on students' learning to explain and argue. These instructional demands require that teachers master instructional norms and routines that support these discursive practices. Novice teachers have difficulty learning to notice and respond to student thinking, a crucial element to promoting productive classroom talk. This paper examines a whole class discussion in one novice science teacher's classroom to document the teacher moves that promote and manage productive discourse and the instructional norms that support them. Structuring learning experiences around these instructional routines and norms in university teacher education programs can help teachers learn to facilitate these types of productive whole class discussions.

Introduction

Science instruction that meets the demands of the Next Generation Science Standards (NGSS Lead States, 2013) emphasizes the idea that students must learn to explain and argue around everyday science phenomena. Designing this type of instruction asks teachers to create opportunities for students to interact regularly with each other's ideas and explanations (Windschitl et al., 2012). For these student-to-student interactions to be meaningful, students need to be positioned as constructors and critiques of scientific claims (Ford, 2008) taking ownership and responsibility for the aims, processes, and standards of scientific knowledge production (Elgin, 2013). Positioning students in this way empowers them as epistemic agents (Stroupe, 2014) where students are participants in the knowledge production process. This epistemic agency is fundamentally dialogic and demands that teachers re-orient their teaching around promoting and managing whole class discussions among students (Kelly, 2014; Mercer, 2009).

Promoting and managing productive classroom discourse require teachers learn to notice, elicit, and respond to student thinking (Barnhart & van Es, 2015). Noticing and responding to student thinking is a complex task that requires that teachers having a clear sense of specific responses and ideas they are looking for in the context of a particular science lesson or idea that is being discussed and the practices that will make students' ideas visible (Luna, 2018). Given this complexity, teachers need to implement instructional norms and routines that support these discursive interactions. Exemplary teachers establish discursive norms using effective questioning techniques (McNeil & Knight, 2013), talk moves (see Michaels & O'Conner, 2012), appropriate responses to student questions and ideas to promote elaboration and student to student discourse (Colley & Windschitl, 2016; Kazemi & Cunard, 2016), and noticing moments of interaction that can be leveraged for student learning (van Es, 2011). Yet, novice teachers have difficulty effectively using these practices and establishing consistent norms for student-to-student talk (Kang & Anderson, 2015; van Es & Sherin, 2008). In this study, I examine a whole class discussion facilitated by a novice teacher where students were productively engaged in science discourse with both the teacher and each other. In this whole class discussion, I identify the instructional norms that are evidenced by student responses to teacher questions and probes.

I draw upon the work of Michaels, O'Conner, and Resnick (2008) who describe a set of practices and norms for academically productive talk in the classroom (i.e., Accountable Talk). Accountable Talk was conceived to promote equitable student participation in rigorous academic settings and encompasses three dimensions of practice for promoting productive student talk (i.e., accountability to the community, acceptable standards for reason, and knowledge). I used the Accountable Talk framework to document the ways that students responded to one another and the teacher during whole class science discussions. I used these interactions as evidence for the instructional norms in place. Although there are many participation structures where students interact with each other, I have chosen to focus on whole class discussions because the facilitation role that the teacher plays, provides insight into the ways that the teacher notices and responds to student thinking during the interaction and it reveals the extent to which instructional norms are adopted by students during their interactions with the teacher and each other.

Methods and study context

This study asks, how do pre-service teachers enact instructional norms intended to promote productive student discourse? In answering this question, I aimed to document the instructional norms that created a learning

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environment conducive to whole class discussions. Documenting these instructional norms can provide teacher educators and pre-service teachers concrete examples to support teacher learning around the practices that encourage productive student participation and engagement in whole class discussions.

This study takes place in a teacher preparation program in a large university in metropolitan southwest United States. The program has an explicit focus on preparing social justice educators to work in schools serving working class communities of color. The program's conception of social justice and equity centers on the idea that students' histories, experiences, knowledge, and dispositions are assets that support them to engage and learn in the classroom (i.e., humanizing pedagogy). To define asset-based teaching, Yosso (2005) uses Critical Race Theory to conceptualize cultural wealth of marginalized groups that may go unnoticed by teachers. It is vital for social justice teachers to use the knowledge of students, families, and their communities to inform their classroom teaching (Yosso, 2005). Humanizing pedagogy calls teachers to debunk notions of deficit thinking around the academic achievement of students who have been historically marginalized (Bartolome, 1994). In the program, teachers are prepared to design science units and lessons using a humanizing approach. Teachers are also asked to dive deeply into what it means to be a social justice educator by reflecting on their multiple identities in relation to privilege and power. By understanding their positionality, teachers form a deeper understanding around why practices that value student voice are necessary for enacting humanizing pedagogy (Takacs, 2003). Teachers come to realize that to meet the needs of their students, critical theories and pedagogies must shape the way they approach science teaching.

The faculty in the program have developed and piloted a classroom observation framework that operationalizes science teaching from a justice and equity perspective (Nava et al., 2019). The second dimension in this framework focuses on promoting content discourse in the science classroom. The framework guides all the courses that teachers take in the program, and thus promoting content discourse was a major emphasis throughout pre-service teachers' preparation program. The cohort understudy included 24 secondary pre-service science teachers participating in a yearlong science methods course. In the methods course, teachers have multiple opportunities to video record their teaching during their clinical experiences as part of a series of feedback and reflection cycles to prepare them for their performance task at the end of the program (i.e., EdTPA).

In total, I collected 31 video recorded lessons (~10 min each) for a little over 5 hours of video. I used interaction analysis (Jordan & Henderson, 1995) to examine the opportunities teachers provided for students to interact with each other. Interaction analysis involves identifying episodes of analytic interest and the iterative viewing and analysis of such episodes to identify patterns in interaction. When useful, particular events or sequences of events within episodes were transcribed to explore in fine-grained detail how talk is organized in the moment. My analysis involved viewing episodes of interest, generating potential descriptions and explanations of events, and testing those against the rest of the corpus, through progressive and recursive analytic induction (Erickson, 1998). During my analysis, I focused on student responses in relation to teacher talk as well as any student-to-student discourse. For this paper, I focused on videos that contained whole class discussions because I was interested in how instructional norms were evidenced in this setting. Of the 31 video recordings, 16 included a whole class discussion. Of those 16, most of the whole class discussions resembled elicitation discussions (Michaels & O'Conner, 2012) where the teacher's questions to students intended to draw out the "correct" answer, with little attention to student thinking and rare effort to juxtapose students' ideas. Elicitation discussions are important for making student thinking visible but are not the types of discussions that foster productive science learning. One video was an exception. The whole class discussion in Margret's (a pseudonym) class stood out because of several moves she made that fostered the types of students' sensemaking that take place during productive discussions in science classrooms (e.g., juxtaposing students' ideas, promoting student to student discourse). Given this one video, I sought out to determine the conditions that allowed for this whole class discussion to take place. I used interaction analysis to create a detailed account of teacher and student moves during the whole class discussion and used this account to identify the instructional norms that were present during Margaret's whole class discussion.

Findings

To illustrate my findings, I describe Margaret's 10-minute whole class discussion that followed a week-long experiment. In the experiment, students identified two locations within their school to collect and document insect biodiversity. Each group of students selected two locations for their data collection, a large space covered with dirt, and another covered by grass, flowers, and other shrubs. The goal of the lab was to document the number of different insect species that collected in a sticky cup with a sugar solution throughout the week. The disciplinary core idea understudy is *Interdependent Relationships in Ecosystems (LS2:A)*. I share excerpts from a transcript of the discussion to depict how Margaret promoted and managed the conversation as it unfolded over the 10 minutes and call attention to the different instructional norms present in the discussion.

Provide reasoning that connects the evidence to a claim

The first example of an instructional norm that Margaret installed into her class was the expectation that students needed to provide some reasoning that connected their claim and evidence. In this example, students shared the areas that they found the most biodiversity.

Turn	Speaker	Utterance
1	T:	Why was that location more biodiverse though?
2	S1(B):	It had more species.
3	T:	Ok, it had more species, but why did it have more species, what was in that environment.
4	S (many):	It had more dirt
5	T:	It had more dirt, so why is dirt important?
6		So, it can hide
7	T:	So, the insects can hide, ok, excellent work, S2(G), you had a question or
8	S2(G):	I wanted to help her.
9	T:	Ok, did you want to agree or disagree? She said that location 1 had more biodiversity.
10	S2(G):	I disagree with S1(B) because I found more biodiverse in location 2, I think it happened because it had grass and water and they are there at the same time, not just dirt.
11	T:	Ok that is an excellent reason. Why are those important again?
12	S2(G):	That is what insects live off of, grass.

In line 5, Margaret asked students to tell her why dirt was important for the insects. This move acted as an ask for students to make a connecting statement between their claim and evidence. In the excerpt above, S1 claims that location one was more biodiverse because it had dirt. Dirt was important because it allowed insects to hide from, presumably, predators. Margaret repeated this ask for justification in line 11, where a student disputed the claim that the dirt area had the most biodiversity and instead claimed that she found that the grass had more biodiversity. Margaret asked the student to explain why grass was important and the student responded with a justifying statement, "that the insects live off (i.e., sustain themselves) of the grass". Later in the transcript (see line 25 in the next excerpt below) Margaret once again asked a student to offer a reason that connected their claim and evidence, and the student responded with appropriate reasoning that connected their claim and evidence. It seemed that students were accustomed to responding to this type of request from Margaret. On all three occasions, multiple students responded to her question of why something was important. I can infer, then, that using reasoning to connect claims and evidence was a norm that Margaret consistently reinforced during these types of discussions. This instructional norm aligns with the *accountable to the standards of reason* dimension in the Accountable Talk framework. Using evidence and reasoning to support a claim is a foundational epistemic practice of the scientific community and, here, Margaret holds her students accountable to this standard.

Students are competent contributors to class discussions

Another instructional norm that Margaret instituted within her classroom was around positioning students as competent contributors to constructing and critiquing science claims (Ford, 2008). This excerpt is a continuation of the conversation above.

Turn	Speaker	Utterance
13	T:	Ok, great, excellent, who agrees or disagrees with S2(G)? S3(B), say I agree because…
14	S3(B):	I agree because we found four species in location 2, it's more, more culturally diverse.
15	T:	Culturally diverse? *(students laugh),* we don't know the insect life, we can't say if insects have culture, but what kind of diversity?
16	S3(B):	uh
17	T:	Do you need help?
18	S3(B):	It's like genes or genetic.
19	T:	Not genetic
20	S4(G)	Can I help?
21	T:	Yes

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22	S4(G):	Species biodiverse
23	T:	Yes, S3(B) helped that species have biodiversity, S4(G) helped us out to show that we have more species biodiversity, it helps all species help survive in these locations and so we have a few people who have agreed on location 2 being more biodiverse and only 1 that agrees that location 1 is more biodiverse. Anyone else want to agree or disagree or add on, I haven't heard from team 2, team 1 or 4. Do you want to agree or disagree. Accept or reject? Yes, no? S5(B)?
24	S5(B):	I agree with S2(G), section 2 was more biodiverse. Instead of more plants there was more water and dirt in location 1.
25	T:	That is important because…
26	S5(B)	Well, the plants were taller so they could blend in from the public
27	T:	So, they could remain hidden, so that is like S1(B) reasons for the dirt, so that is an interesting idea. I love it! Ok, so it is interesting that we have some agree and some disagree with where we found more biodiversity, yes no?

In this excerpt, students discussed their experimental data, trying to determine which specific location in their experiment was most biodiverse. In the first turn, Margaret followed up a student claim with a talk move asking other students whether they agreed or disagreed with their classmate. In the same turn, she used a sentence starter to help S2 respond to S1 (i.e., 'Say I agree…'). Margaret's moves were an attempt to get students to respond to each other's ideas, a move that she scaffolded with the sentence starter. In the next three turns, Margaret sought clarification from S2 on a response he gave. When S2, struggle, S3 offered him help. In this case, building on one another's answers included helping fellow students. After S3's assistance, Margaret revoiced all of the responses and explicitly juxtaposed students' responses with one another. This move to juxtapose students' ideas makes the disagreement explicit for students that may not have noticed the disparate ideas. Then finally, she asked the tables that had not responded whether they wanted to agree or disagree or add on to the existing responses. Having students respond to the ideas of others and juxtaposing conflicting accounts during this whole class discussion acted as an effort to support consensus building within the classroom community, an important feature of scientific discourse. This discourse extends beyond eliciting students' ideas and positions ideas in relationship to one another to figure out the most suitable explanation. The instructional norm that students are competent contributors aligns with the *accountable to knowledge* dimension in the Accountable Talk framework. Students shared their ideas and knowledge and that knowledge had to hold up against the critique and expertise of the other students in the classroom.

Maintain a safe and positive science learning environment

Participating in a whole class discussion can make students vulnerable to ridicule from their peers, evaluation from the teacher, and self-doubt about their linguistic and content knowledge, especially in schools that serve working class communities of color. Yet, classroom discourse is a key aspect of learning and engaging in science. Thus, teachers that use whole class discussions need to have norms and routines in place that create a safe and positive learning environment so that students are willing to participate without fear of these vulnerabilities. In this excerpt, we see how Margaret maintained a safe and positive learning environment when two students had a negative interaction after one of the students volunteered that he had tried this experiment at home and wanted to share his findings with the class.

Turn	Speaker	Utterance
28	T:	So, none of you are wrong. We can't know for sure which is more biodiverse from this experiment. This is what real scientists do and when they come to conclusions that are conflicting and they have to figure out how to make them better. So, what could we have done to make our experiment better or would we keep it the same? We could have changed our materials, added more juice to the cups, or was it good. We waited a week to collect, we put it in the Wednesday before or maybe our data table was bad, and we wanted to look at more factors.
29	S (many):	More time, more time
30	T:	So, if you have ideas, just volunteer, S6.
31	S6(B)	Materials, I did something creative, I put honey and lettuce into the cup and let it sit out for the week.
32	S7(B):	If the bugs hit the honey, they are going to stick

33	S6(B):	That is the whole purpose to count the bugs, dummy
34	T:	Hey, hey, positivity! Do not talk to another classmate like that S6.
35	S6(B):	That is the whole purpose is to count the bugs. Mr. S7?
36	T:	We did count them on a sticky pad. So, he is right. We did want to catch them, maybe our materials didn't collect enough insects because we didn't have enough to attract them to the location. So, we didn't get an accurate measure. So, what are you thinking S8(G)?
37	S8(G)	um I think, I agree with Shaun, but I think you guys should have had sticky cups and honey to attract them
38	T:	So, S8(B) is saying that we needed honey to attract. S8(G) is saying that we needed both to get an accurate measure. What are you thinking back there? Is that a hand raise?

This is tricky situation for teachers to navigate. In that moment, Margaret must either stop the entire conversation to address the name calling, why it is inappropriate to say that a person with a wrong or incorrect answer is a "dummy", or take quick and affirming, yet holding students accountable type action, and keep the conversation moving. In this instance, she quickly intervened, and the student restated his claim using the appropriate address to the student who was contesting his idea, "that is the whole purpose is to count the bugs, Mr. S7". In the video, the tone from S6 was somewhat sarcastic, but nonetheless, S6 responded appropriately to Margaret's ask for positivity simply continuing with his argument for why he did his own experiment, even addressing S7 in a collegial way. It is plausibly more common in moments such as these that the science discourse ceases altogether, and the conversation moves to intervening around the insult. In this case, Margaret's intervention and the student's subsequent response indicated that there were instructional norms in place around maintaining a safe and positive learning environment. Instructional norms around maintaining a safe and positive learning environment align with the *accountable to the learning community* dimension in the Accountable Talk framework. The learning environment must be conducive to student participation where students intently listen to their peers' ideas and ask clarifying questions on areas that are unclear. This is the initial stage to building consensus within the classroom community.

It is also noteworthy that Margaret started this conversation saying that none of the students were wrong and that competing findings often occur in science. Furthermore, she stated that competing claims and evidence were a necessary step in coming up with the most accurate findings for an experiment. Margaret's move helped students understand the nature of science as tentative and uncertain, affirming that students' inaccuracies and mistakes were necessary steps in their scientific investigation.

Position science in the context of local and community issues

There is one final excerpt that does not align with the Accountable Talk framework, but also revealed an instructional norm within Margaret's classroom. The instructional norm was that students should think about the connection of science to their everyday lives. This excerpt takes place at the end of the 10-minute discussion and Margaret attempted to connect the experiment to a broader issue that was facing the community, the building of a new football stadium.

Turn	Speaker	Utterance
39	T:	I am going to mention this quickly, the new NFL stadium is being built about six miles from here, it is being built over the park and race track. So, how many species and individual bugs did we see in this little location? I just want you to think about how this relates to biodiversity here. What happens if the NFL stadium is built over the park?
40	S9 (B):	They are gone, the bugs are gone.
41	S10 (B):	They will build houses.
42	S11(G):	Rent will go up.
43	T:	So, you are thinking more human implications. Rent will go up, maybe a little bit more tourism. But what about the environment? If we don't have this place for the insects to come and live and built over it…
44	S12(G):	They are going to die.
45	S13(B):	They are going to lose their homes
46	T:	They are going to lose their homes, so knowing what we know about how important insects are to life, like bees that we will lose 1/3 of our food if we lose bees, so just think

	about the implications of this stadium for biodiversity in our city and what can happen to it.

Students' responses to this community issue were rather typical and mundane, possibly because Margaret asked known answer questions rather than open questions that with multiple answers. Yet, responses from S10 and S11 indicated that these two students were thinking about some causal effects for themselves or people they know that live close by the stadium (i.e., human implications). Responses from S12 and S13 indicated that these two students were considering the consequences of the new stadium and how it might displace wildlife that were native to that area.

Discussion and implications

This study sought to understand the instructional norms that supported student participation and engagement in whole class discussions. To do this, I analyzed the interactions between a teacher and her students during a whole class discussion around a student-centered science experiment where they investigated insect biodiversity at their school site. My analysis revealed that students responded to the teacher and each other in ways that demonstrated that there were specific instructional norms in place that allowed for meaningful and productive participation in the whole class discussion. For example, Margaret asked students on three separate occasions the question, and why is that important? Each time, students responded with some reasoning that connected the evidence that they were presenting to the claim they were making. Margaret's move of asking for reasoning in a way that made sense to students (i.e., why is that important?) supported student participation and engaged them in the scientific discursive practice of using reasoning to connect a claim to its supporting evidence (c.f. McNeil & Krajcik, 2011). Anecdotally, it seems that practitioners use of the claim-evidence-reasoning framework often strays far away from the discursive practice from which it originated and is largely used as a summative assessment that students submit at the end of a science unit. Using the idea of providing reasoning to connect evidence to a claim as a discursive norm engages students in a knowledge building practice of the scientific community (Manz, 2015).

While the instructional norm of using reasoning to connect evidence to a claim is specific to the discipline of science, the other instructional norms evidenced in Margaret's class were more generally aimed at building a classroom learning environment conducive to classroom discourse. The teacher education program that prepared Margaret uses a science teaching and learning framework that includes dimensions that are science specific and those that are more general (e.g., classroom ecology/learning environment dimension) (Nava et al., 2019). As mentioned previously, this framework also has a dimension around promoting content discourse. Margaret's effort to engage her students in rigorous science tasks (i.e., designing and conducting their own experiment on biodiversity), lead students through whole class discussions, and build a positive classroom ecology and learning environment are all evidence of her adoption of these practices from her teacher preparation program. Yet, my review of the video recorded lessons from her cohort revealed that this type of learning was more of an anomaly rather than the norm suggesting that these instructional norms are difficult for novice teachers to adopt and incorporate into their classrooms. Documenting the instructional norms present in Margaret's class highlights the ways that the Accountable Talk framework manifests itself in the classroom, yet additional work is needed in teacher preparation to ensure that more teachers can incorporate these practices and norms into their science classrooms, so that students have opportunities to engage in productive conversations around science ideas.

I draw two conclusions from these findings with implications for teacher educators and teacher preparation programs. First, is that teacher preparation programs need to find ways to support teacher development around teaching practices that helps them to incorporate instructional norms for managing and promoting student discourse into their classrooms. Encouraging productive classroom discourse is a pedagogical indicator of classrooms that promote greater equity and access to sciences instruction (Lee, Miller, & Januszyk, 2014). Yet, productively promoting and managing student discourse, especially whole class discussions, is difficult for novice teachers. Research suggests that specific practices in teacher preparation can support teachers' learning of productive instructional norms and routines, including rehearsals and field-based methods courses (Kazemi & Waege, 2015; Lampert et al., 2013). In addition, having pre-service teachers analyze and reflect on video recorded teaching episodes, both exemplars and recordings of their own teaching, can support teachers to recognize areas for improvement around making student thinking visible and promoting student talk (van Es et al., 2017). Giving pre-service teachers multiple opportunities in their teacher preparation program to observe these instructional norms in classroom teaching as well as opportunities for them to incorporate these into their student teaching placements is needed so that they can include classroom discourse and whole class discussions into their unit and lesson plans. Documenting the instructional norms in Margaret's class during this whole class discussion provides some concrete examples of what these norms look like in practice and evidence for their productiveness in supporting student participation and engagement in classroom discourse.

Second, I recognize that Margaret's discursive segment followed traditional notions of scientific discourse and epistemology. Margaret was prepared in a justice and equity focused teacher preparation program, yet I did not necessarily see her engage with her students with issues around power and race that were emphasized in the program. Nor do I see students' histories and identities affirmed within this discussion. It is not to say that Margaret or any of the other science teachers in her cohort do not take up these types of issues, just that they were not evidenced in the video recorded lessons that were analyzed for this paper. Agarwal and Sengupta-Irving (2019) take up this issue to broaden how and in what ways minoritized students of color meaningfully participate in classroom discussions drawing on their identities and histories as students of color and providing epistemic diversity in the perspectives that are valued and shared about whose and what knowledge counts in a science classroom. Supporting teachers to develop the instructional norms and practices that support student participation and engagement in whole class discussions can both support students to learn science and provide opportunities for students to share and affirm their ideas, histories, knowledge, and identities in ways that contribute to learning within the classroom community.

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Applying Sequence Mining to Explore Students' Problem-solving Practices Using an Interactive Simulation-based Task

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Abstract: Extensive research has been done to capture and understand human problem solving across different research methods and traditions. This study examines how interaction data generated in an open-ended, interactive task could be used to identify patterns of effective and ineffective practices for solving problems in science and engineering domains. We collected data from 80 undergraduate students on their solutions and problem-solving processes as interaction data logged in the task environment. The log data was parsed to reveal the sequence of test trials conducted by individual participants when solving the problem as well as the pauses in-between test trials. Results of the clustering analysis showed that distinct trial sequence patterns were associated with different levels of performance and provided evidence for specific problem-solving practices. These results have implications for how to assess a complex construct like problem solving and how real-time feedback could be provided to improve students' problem-solving practices.

Introduction

Problem-solving situations arise as scientists investigate and build models and theories about the phenomena in the natural world and engineers design and build systems (NGSS, 2013). Authentic problems like these need to be incorporated into science and engineering classrooms to help students develop expertise in systematic practices of scientific inquiry and problem solving (Krajcik, 2015). One efficient and cost-effective way of engaging students in authentic problem solving is through technology-based, open-ended learning environments, such as interactive simulations. In this paper, we employ an interactive task embedded in a physics simulation to elicit undergraduate students' problem-solving performance. Furthermore, we explore how different patterns of students' interactions in the task environment as recorded by the log data are associated with effective and ineffective problem-solving practices.

Background

Student-centered, open-ended learning environments (OELEs) provide opportunities for students to engage in authentic scientific inquiry and problem solving (Hannafin et al., 1994; Land & Jonassen, 2012). In contrast to traditional end-of-chapter exercises in science textbooks, interactive tasks embedded in OELEs can be designed to better mimic authentic problems by situating the task in an engaging, real-world context and providing minimal data upfront. One example of OELEs is educational simulation, where students explore scientific phenomena and solve problems in an authentic, safe, and cost-effective manner (Wieman, Adams, & Perkins, 2008). The interactive task environments uniquely allow students to decide what information they need to solve the problem, how to collect that information, and what conclusions they can draw from it. These decisions are integral parts of the practices adopted by scientists and engineers to solve problems encountered in their work (Price et al., 2021).

In the process of students working on the problem embedded in OELEs, large volumes of log data are generated in the backend of the task environments. How to analyze the log data and extract insights about students' cognitive and metacognitive processes is an evolving area of inquiry, especially in the fields of learning analytics and educational data mining (Fischer et al., 2020). Approaches and techniques adopted to process and model log data in previous research include directly hand coding log data to create a training set for classifying students' inquiry skills (Gobert et al., 2013), engineering features based on raw data and using them to identify patterns of productive actions in a circuit simulation (Fratamico et al., 2017), and conducting sequential pattern mining analysis to group students based on their behavior sequences (Eichmann et al., 2020). One promising approach for feature extraction is to incorporate human knowledge gained through domain expertise or direct observation of students solving the task into log data processing, creating a set of semantically meaningful features. These features can then be used as inputs to either supervised machine learning algorithms to predict performance, or to unsupervised algorithms to identify differentiating patterns among students. In this paper, we applied such approach to analyze the log data generated in an interactive problem-solving task in a physics simulation. Our goal is to identify patterns of students' actions that reflect specific problem-solving practices and understand how these patterns are associated with different levels of problem-solving performance.

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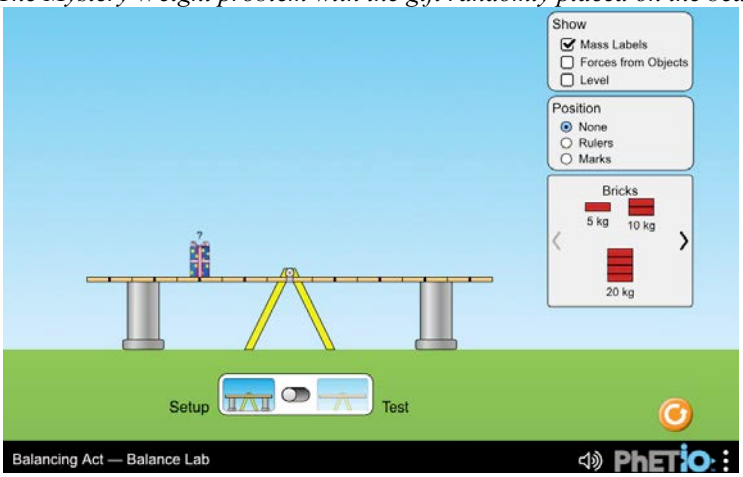
Methods

The Mystery Weight problem embedded in the PhET Balancing Act simulation was used in this study (phet.colorado.edu/en/simulations/balancing-act). Students were first introduced to a scenario of needing to measure the weight of a gift to be mailed without access to a weighing scale. They were then presented with the task of figuring out the weight of the gift using a seesaw and a few bricks of known weights in the Balancing Act simulation. Figure 1 presents the user interface of the task. Students can place bricks and the gift at various marked locations on the beam in the "Setup" mode and observe the outcome of the trial (i.e., how the beam would rotate or stay balanced) in the "Test" mode. The simulation does not allow bricks to be stacked on top of each other, which makes the problem less intuitive and more difficult. Furthermore, the weight of the gift was deliberately chosen to be unsolvable using a single brick. Balancing the beam thus requires a combination of different weights placed at different locations.

Figure 1

The Mystery Weight problem with the gift randomly placed on the beam



80 undergraduate students in STEM majors across the US (47.5% female) were recruited via an online research crowdsourcing platform, Prolific (www.prolific.co). Students received $4 for participating in the 30-min online study and up to $4 additional bonus for correctly solving the problems. During the study, participants first worked on a Mystery Weight problem and were then randomly selected to view one of the two versions of worked examples demonstrating how to solve the problem. Participants worked on a second Mystery Weight problem afterwards. In this paper, we focus our analysis on participants' performance in the first problem prior to any interventions.

Data collected to capture participants' problem-solving performance include 1) their solutions for the mystery weight (the gift's weight in kg); 2) their responses to a post-task question probing whether the torque formula was used when solving the problem; 3) log data recording participants' actions within the task environment in JavaScript Object Notation (JSON) files as they worked on the problem. The log data was parsed using a Python script to reveal a sequence of test trials conducted by individual participants and the pause time after each test trial. The TraMineR R package (Gabadinho et al., 2011) was used to visualize and analyze the sequential data. In the following section, we first discuss participants' overall problem-solving outcomes as measured by their solutions to the problem. We then present the features extracted from the log data and results of a cluster analysis on the sequential features.

Results

Problem-solving outcome

Participants' problem-solving outcomes were determined by their solutions for the weight of the gift. We coded the correct solution and near-correct solutions (17-19kg) both as "correct" and solutions outside the range (< 17kg or > 19kg) as "incorrect." Four participants were excluded from data analysis due to extremely low time-on-task (< 1 min). Among the remaining 76 participants, 45% reached a correct or near-correct solution while 55% did not.

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Number of test trials conducted

In the mystery weight simulation, users can place objects on and remove them from the beam in the "Setup" mode. Once they set up a trial, they can toggle to "Test" mode to observe how the beam might tilt based on the weights and positions of the objects. A test trial is thus characterized by the number and type of objects used (both the gift with unknown weight and bricks with known weights) as well as their positions on the beam. Guided by qualitative observation of students solving the problem in a pilot study, we focused on the test trials instead of discrete actions and abstracted sequences of low-level actions into test trials conducted by individual participants, along with timestamps recording when the trials took place during their problem-solving processes.

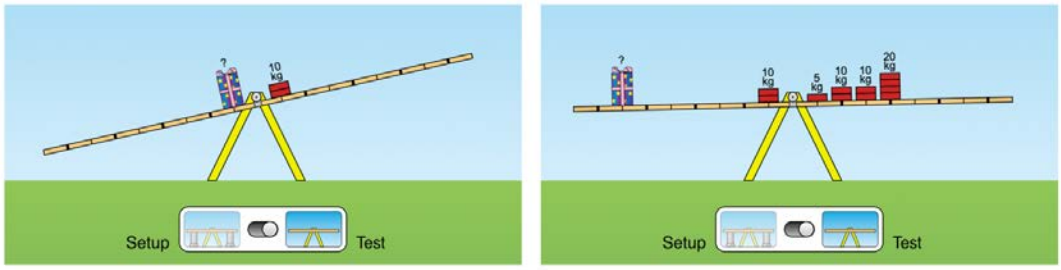
Participants were instructed to solve the mystery weight in 15 test trials or less and stop working after reaching 15 trials. However, the log data revealed that 41% of the participants (n = 31) continued working on the problem after Trial 15, indicating deep engagement with the task. One exceptional participant conducted 106 test trials in 26 minutes. The mean number of trials conducted excluding this participant was 17, with a minimum of 4 trials and a maximum of 46 trials.

Number of weights used in a test trial

The test trials conducted represent participants' efforts to collect the data needed to solve the weight of the mystery gift. Figure 2 shows two sample test trials: the left one features a simple set-up using two weights (the gift and one brick) while the right one features an overly complex set-up using six weights (the gift and five bricks) at different locations on the beam. The optimal number of weights required to solve the problem is three (one gift and two bricks). Across all trials conducted by all participants, the mean number of weights used in a test trial was 3.4 (sd = 1.3), with a minimum of 1 and a maximum of 13 weights used.

Figure 2

Two sample test trials conducted when solving the mystery weight problem; the left trial used two weights and the right trial used six weights



Pause after a test trial

While the number and nature of test trials conducted represent how participants actively went about solving the problem, the pause times, or periods of inactivity in the simulation after each test trial, potentially constitute an important signal on how participants managed their problem-solving processes. Based on our previous research (Wang et al., 2021), we define a meaningful pause as one where the time between the action of toggling to "Test" and the next action recorded in the simulation being longer than 10 seconds. This definition allows us to differentiate between longer, meaningful pauses indicative of underlying cognitive processes and shorter, mechanical pauses that are approximately the time required to view the outcome (i.e., how the beam will tilt) of the test trial. A few extremely long pauses (> 2 mins) were excluded from the analysis as they were likely incurred due to off-task behaviors. Among all participants, six did not have any meaningful pauses throughout the problem-solving process. The number of meaningful pauses range from one to eleven for the remaining 70 participants.

Qualitative interviews of students' working through the mystery weight problem in our previous research revealed that the underlying cognitive processes during a meaningful pause may include 1) pause to understand the nature of the problem and devise a solution plan; 2) pause to record and interpret the data observed from the trial using relevant physics knowledge; and 3) pause to evaluate and revise their strategies after unsuccessful attempts to solve the problem.

The sequences of test trials conducted by individual participants

We plotted the sequence of test trials conducted and whether each trial was followed by a meaningful pause for individual participants. Figure 3 illustrates the test trial sequence of a participant who did not solve the problem (top) and one who reached the correct solution (bottom). A qualitative examination suggests that there were differences between the two sequences, notably around the frequency of meaningful pauses. We applied cluster

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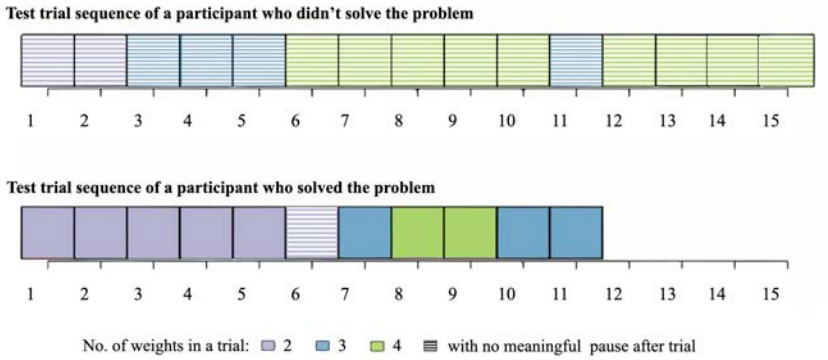
analysis to further investigate whether there exist differentiating interaction patterns among participants and how these patterns are connected to problem-solving performance.

Figure 3

Test trial sequences of individual participants. The length of the sequence reflects the no. of test trials conducted. The colors reflect the no. of weights used in each test trial. Solid colors indicate that the trial was followed by a meaningful pause.



Clusters of participants' test trial sequences

As shown in Figure 3, a test trial sequence is characterized by its length (no. of trials conducted), simplicity (no. of weights used in each trial), and pace (whether the trial was followed by a meaningful pause). Given the large variance in the number of trials conducted by individual participants, we truncated the sequences of all participants to the first 15 test trials to be used as inputs to cluster analysis. This decision ensures that the sequence length will not be the dominant factor for clustering and allows us to explore how we might be able to efficiently identify different problem-solving profiles with only a portion of students' interaction data.

A matrix of pairwise distance between individual participants' test trial sequences was computed using an Optimal Matching algorithm. The Ward hierarchical clustering method was then applied to cluster the sequences into distinct groups based on the distance matrix (Murtagh & Legendre, 2014). The average silhouette width was used to select the appropriate number of clusters (Rousseeuw, 1987). Figure 4 shows the resulting three cluster groups: the horizontal bar plots on the left show the distribution of different trial set-ups (i.e., no. of weights used at each trial); the line plots on the right show the number of participants remaining at the *n*th trial ($1 \leq n \leq 15$). For example, in Cluster 2, around 60% of the first trial conducted by participants used two weights on the beam with no pause afterwards and there were 18 participants remaining at Trial 15. In contrast, in Cluster 3, around 80% of the first trial conducted by participants used two weights and included a meaningful pause afterwards. There were only three participants remaining in Cluster 3 at Trial 15, as most solved the problem within 15 trials. In the following, we will describe the three clusters in detail and discuss how different problem-solving practices were reflected in these clusters.

Figure 4

Distribution of different types of trial set-ups (left) and no. of participants remaining at each trial (right) in the three clusters. The x-axis denotes the no. of trials conducted by participants. The left y-axis denotes the frequency of different trial set-ups, and the right y-axis denotes the no. of participants remaining at specific trials through the problem-solving trajectory.

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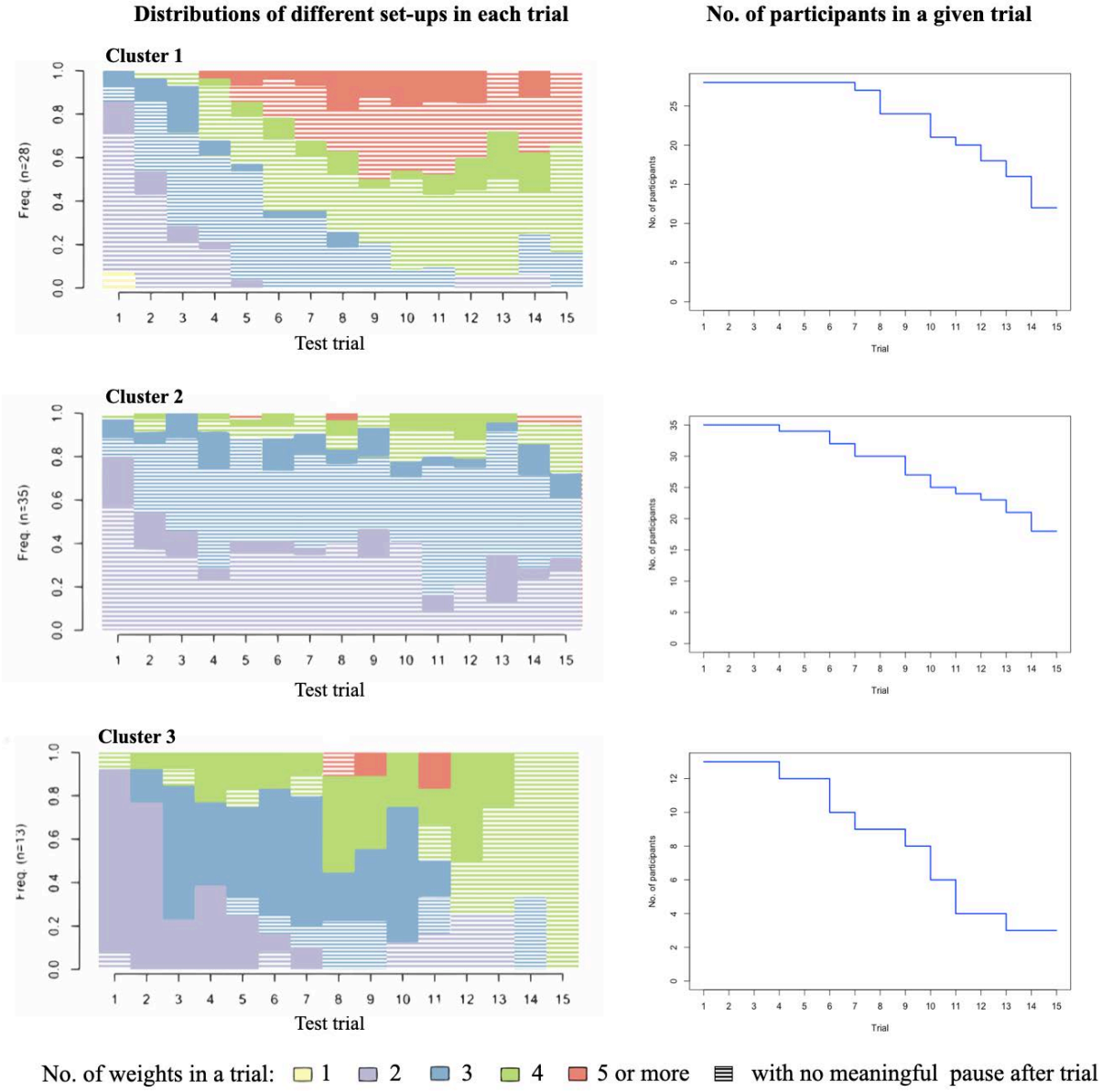

Cluster 1. Participants in this cluster (n = 28) quickly increased the number of weights used in subsequent test trials from two to five or more and rarely paused after conducting a trial. These sequences of test trials represent participants' attempts to counter the direction of the tilting and get the beam balanced by adding more weights to different positions on the beam. The lack of meaningful pauses indicates that there were minimal efforts to make sense of a test trial and use it to estimate the weight of the gift, or to evaluate whether their strategy was an effective one. 39% of the participants in this cluster self-reported using torque when solving the problem and 32% recorded some form of notes using a table provided in the task environment. In the end, 36% of the participants in this cluster reached a correct or near-correct solution. We label the problem-solving practices observed in this cluster as *ineffective data collection using overly complex set-ups and non-reflective*.

Cluster 2. Participants in this cluster (n = 35) generally kept the set-up of test trials simple with two or three weights on the beam yet paused minimally after test trials. Like participants in Cluster 1, they made minimal efforts to pause and interpret a test trial. Only 23% of the participants self-reported applying the torque formula when solving the problem. Their actions of moving the weights around different positions on the beam were largely driven simply by the reaction to counter the tilting of the beam. 23% of the participants in this cluster took notes and 37% reached a correct or near-correct solution. We label the problem-solving practices observed in this cluster as *collecting data using simple set-ups yet non-reflective*.

Cluster 3. Participants in this cluster (n = 13) kept their trial set-ups simple in the first ten trials and mostly paused after conducting a trial. As shown by the last plot on the right, the majority of the participants in this cluster solved the problem by Trial 11, and so the last four trials, with few participants remaining, were not representative of the general pattern of the cluster. Cluster 3 participants were systematic and deliberate in their problem-solving approaches: first putting the gift on one side of the beam and a brick on the other side to narrow down the range of the gift's weight, followed by adding a second brick to balance the beam after they discovered that the weight of the gift could not be solved by a single brick. Participants also paused after test trials to interpret and record the data collected in the trials and plan for the next ones. 85% of participants in this cluster reported applying the torque formula when solving the problem and 92% took notes using the table provided in the task environment. In the end, 85% of the cluster reached a correct or near-correct solution. We label the problem-solving practices found in this cluster as *effective data collection using simple set-ups and reflective.*

In summary, the cluster analysis of test trial sequences revealed that we could derive semantically interpretable clusters of participants who adopted similar problem-solving practices. For example, one cluster primarily consisted of effective problem solvers who set up easy-to-interpret trials and frequently paused to record and make sense of the data collected in each trial. Another cluster contained problem solvers who set up increasingly complex trials by piling on many objects on the beam and did not pause meaningfully throughout the problem-solving process. We checked the external validity of the clusters with participants' solution correctness and found a significant relationship between cluster membership and obtaining the correct solution, $X^2(2, N = 76) = 10.10$, $p < 0.01$. Furthermore, we found significant relationships between cluster membership and applying torque to solve the problem, X^2 $(2, N = 76) = 15.13$, $p < 0.001$, and between cluster membership and taking notes during the problem-solving process, X^2 $(2, N = 76) = 20.01$, $p < 0.001$.

Discussion & Conclusion

Despite the recognition that students need to learn science and engineering practices useful for solving authentic problems, valid and efficient assessments of these practices remain scarce (Quellmalz et al., 2013). Researchers in the learning analytics and educational data mining communities have explored how to model student abilities and knowledge states using large volumes of interaction data generated in open-ended learning environments. In this study, we extend the research efforts and seek to understand how the log data of students solving a problem in a physics simulation could be used to capture and evaluate specific problem-solving practices of college students in science and engineering domains.

The results indicate that there exist distinct patterns of test trials conducted by effective and ineffective problem solvers. Effective problem solvers set up simple trials and paused frequently after conducting a trial, while ineffective problem solvers either switched to increasingly complex trials by using more and more weights or kept the trial set-up simple yet quickly moved the weights around many different positions. There were minimal pauses in-between test trials among both clusters of ineffective problem solvers. These differentiated interaction patterns were closely related to how well participants adopted specific problem-solving practices, including collecting data, recording data, interpreting data using domain knowledge, and reflecting on their progress towards a solution. Specifically, the difference in pause patterns provided microscopic behavioral evidence for how effective and ineffective problem solvers differed in their monitoring and management of problem-solving processes as noted in Schoenfeld (1981). While effective problem solvers were deliberate in considering and accommodating new information gained from each test trial, ineffective problem solvers largely resorted to unstructured exploration.

The finding that the absence of meaningful pauses during problem solving is associated with poor performance is consistent with previous research that used OELE-based tasks to study students' higher order thinking skills. For example, Amerish and Conati (2009) found that low-performing students paused significantly shorter on average than high-performing students when interacting with an OELE presenting artificial intelligence algorithms. Perez et al. (2017) reported that a strategic use of pauses during an inquiry activity in a circuit simulation is associated with productive learning outcomes. Wang et al. (2021) found that the occurrence of meaningful pauses can predict problem-solving performance above and beyond students' domain knowledge. Instances of pause during students' work process may foreground key cognitive and metacognitive processes involved in problem solving and inquiry and should be explored more fully in future research.

This study has important implications for how we assess students' proficiency in science and engineering practices, as well as for how to provide real-time feedback to help students improve their problem-solving practices in simulation-based tasks. As shown by the results of the cluster analysis, differentiating patterns already emerged in the first few minutes of students working on the task. Understanding which pattern a student's sequence of operation falls into would allow us to support and guide them with targeted feedback, potentially in real-time in the task environment. This would afford students the opportunity to iteratively adjust their problem-

solving approaches and acquire expert-like thinking and practices. In future studies, we will also explore whether students' problem-solving practices as captured by the brief simulation-based task are connected to their broader academic performance.

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Summary Writing Support by Structural Organization with Kit-build Concept Map for EFL Readers

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Abstract: The activities learners do in making summaries facilitate them to think more carefully than only reading. Although summary writing can be helpful both for fostering and assessing performance in reading, it remains a challenge for most learners, especially in languages learners are not familiar with. Moreover, summary writing can be a problem for students to master because some learners have difficulties identifying the main ideas from detailed information in the text. This study focuses on the issue of improving the performance of English as a foreign language (EFL) learners' summary writing skills by utilizing the kit-build concept map tool and text structure strategy. A web-based system has been developed, and an online cross-experiment has been conducted, with 75 Indonesian students at the intermediate level of language proficiency involved. Students' written summaries were collected and evaluated based on two indicators. The result indicates the effect of system use on improving the quality of summary is positive. It supports learners by helping them clarify important ideas and write summaries with organized information.

1 Introduction

Summary writing is a bridge that connects writing and reading. The writing of a summary plays a dual role in reading comprehension. It can both boost and measure reading comprehension: when learners are involved in writing a summary of a reading text, they need to attend more closely to what they are reading to communicate the text in their own words; on the other hand, they are supposed to demonstrate how they comprehend the given source text through writing (Mokeddem & Houcine, 2016). Ferris and Hedgcock claimed that learners summarizing what they are reading get involved in the process of reproduction which includes: (a) thorough comprehension of the source; (b) selection of the text's most salient information; (c) deletion of less-than-essential information; (d) comprehension and integration of the selected information; and (e) arrangement of selected material in a way that reflects the rhetorical structure of the original. When they start to write a summary, there are two main tasks. One is to sift through material, extracting the main ideas. The other is to integrate those important ideas or information, weaving them into a consistent expression of words. They are supposed to review the source text during this process, weighing each piece of information presented. Such activities mean that making summaries while reading will think more carefully than only reading. Therefore, summary writing is a conducive way to better performance in reading. By doing this, readers are required to concentrate on the overall comprehension of the source text compared to those who just focus on following the idea at the word or sentence level.

2 Problem and research goal

Although summary writing can be useful for fostering and assessing performance in reading, it remains a challenge for most learners. The situation could be even worse when it comes to a language that they are not quite familiar with, such as English as a foreign language (EFL) learner. Previous studies shed light on this issue. Researchers claimed that summary writing appears to be the most difficult to master (Lin & Maarof, 2013). It is "a highly complex, recursive reading-writing activity involving constraints that can impose an overwhelming cognitive load on students. (Kirkland & Saunders, 1991)" Othman (2009) stated that the result of her study based on the reports of 60 secondary school teachers revealed that learners have difficulties in differentiating between main ideas and supporting details from source texts. As mentioned before, the process of summarization can be mainly divided into two parts. Whether learners can properly pick the main ideas should be given great weight, and these choices significantly affect their summarization performances. Learners can never make a good summary if they cannot decide what kind of ideas should be given more weight. However, problems are far more than this. In light of other studies, students generally follow a strategy of copying sentences from the source text; have difficulty writing summaries with their own words (Kirkland & Saunders, 1991)(Othman, 2009).

Hutchins (1987) has claimed that summarization involves the understanding of texts. Kintsch and Van Dijk (1978)(1983) that discourse comprehension necessarily involves recognizing text structures and the ability to summarize. When it comes to the structure of a text, two notions should be made clear: the microstructure and

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the macro-structure. There is a basic distinction between these two terms. The micro-structure represents the relation between the sequence of sentences in the actual text. The macro-structure represents relations between blocks of sentences and the global organization of texts. These relations, at both levels, may be thematic and semantic. Thematic relations include anaphora, backward and forward reference, and topicalization. Semantic relations include cause-effect, time, and logical relations (Hutchins, 1987). Hutchins (1987) also stated that there is no unique summary for a text because summaries are expressions of the macro-structure of the source as interpreted by an individual in the light of background knowledge.

This study aims to try to tackle one or some of the problems discussed above to help EFL learners reach better performance in summary writing. The criteria applied to evaluate a summary focus on two perspectives. In terms of the content, whether learners' summaries contain main ideas (important information) from the original text as many as possible and to what extent the redundancy is. On the other hand, from the perspective of the organization of information, whether they can arrange their ideas in an organized way or whether their ideas are logically connected/integrated to follow the macro-structure of the source.

3 Method

The structure strategy teaches readers to identify the overall top-level structure of the expository text and to use that structure to organize their reading comprehension. Comprehension is defined as the synthesis of new ideas with existing memory structures using the framework of the structure strategy (Meyer & Wijekumar, 2007). Generally speaking, the top-level structure has five patterns: cause and effect, problem and solution, sequence, description, and comparison. The power of teaching students the structure strategy includes helping them follow the logical structure of text to understand how an author organized and emphasized ideas" and "help learners organize their writing such as written summaries" (Meyer & Ray, 2011). The structure strategy's main idea patterns give them even more help in identifying and strategically using the organization of the text." (Wijekumar et al., 2012) A concept map or conceptual diagram is a diagram that depicts suggested relationships between concepts (Hager & Corbin, 1997). Tajeddin and Tabatabaei (2016) also have stated the advantages of using concept mapping include: "allowing students to think deeply about concepts and to store information more effectively in their memory" and "helping students organize different concepts and visualize the relationships between the main concepts in a meaningful way." Chin et al. (2010) state the effectiveness of interactive feedback and automated assessment of concept maps. Kit-build concept map (Hirashima et al., 2015) is a digital tool derived from the common concept map and supports a concept map strategy (Pailai et al., 2017). The ability of Kit-build concept map includes a construction tool where users can construct concept maps and an automatic concept map assessment where the system can report diagnosis reports.

4. Function design

Dealing with summary writing as a whole would be a challenge for learners. Summary writing requires learners to have the ability to understand what is important and how the important ideas should be logically organized or related. To address this issue, an alternate is to decompose the task into certain sub-tasks. Based on this, learning activities carried by the system can be defined as follows:

1) **Kit-building on paragraph level**: In this step, learners can construct concept maps from given kits for each paragraph and get diagnosis feedback.
2) **Clarification of important information:** following the instruction of structure strategy. In this step, learners can pick up propositions, choose a structure for the proposition and clarify the roles of concepts. Feedback is also available.
3) **Integration of information:** identifying as a structure. In this step, learners can merge/integrate concepts. They can also split merged nodes in case of mistaken operation.

4.1 Kit-building on the paragraph level

To reach a summary with good quality, one premise is that learners need to understand each paragraph of the original text. By utilizing the kit-build concept map, learners can check the reflection of their understandings and see the difference between their comprehension and the instructor's comprehension. They can choose to modify their maps according to the feedback they get. Figure 1 shows an example of a kit decomposed from a concept map made by a teacher. In Kit-building, learners make propositions with the provided nodes and links for making a concept map of the reading text. This phase aims to make the same concept map as the teacher to understand what is written in the text correctly. The system provides feedback to learners on the difference between the learner's and the teacher's concept map, as shown in Fig.2. The solid arrows represent that the learner's link is

the same as the teacher's one, and the dotted arrows represent that the learner's one is not the same as the teacher's one.

Figure 1
An example of a kit for kit-building of a concept map.

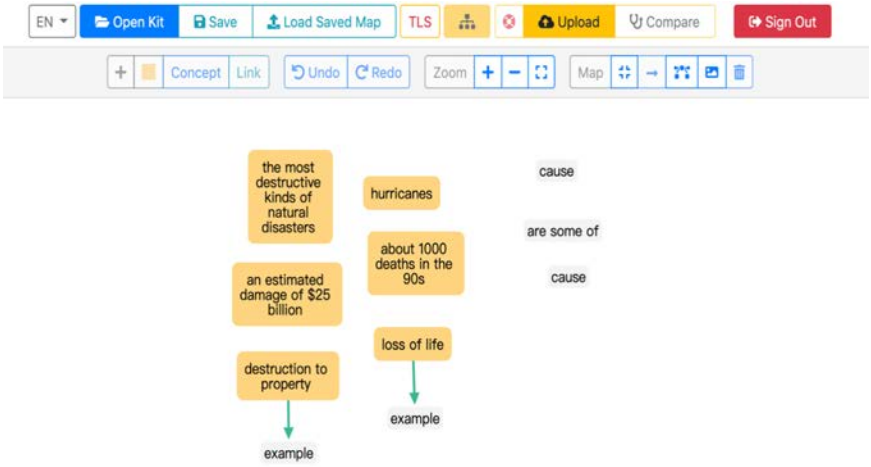
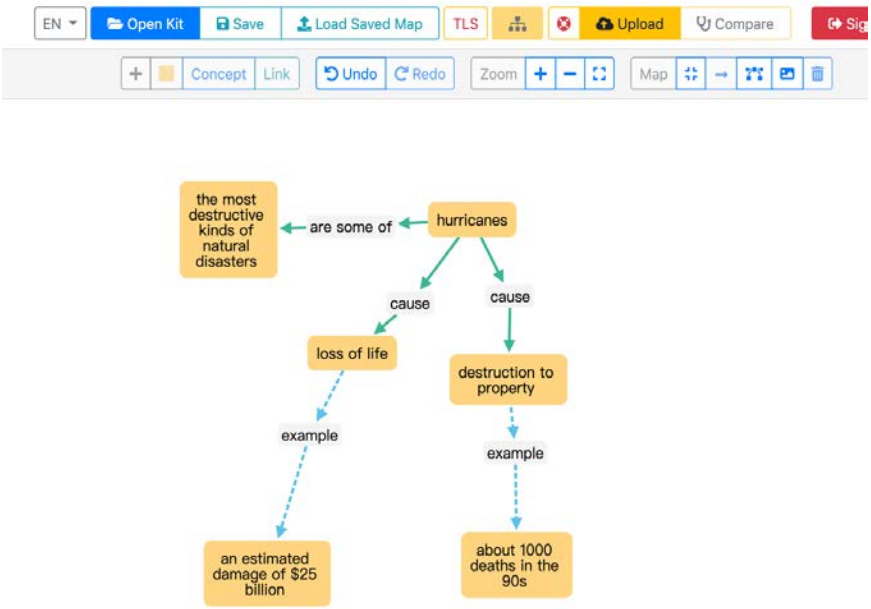


Figure 2
Feedback from the system.



4.2 Clarification of important information

Structure strategy focus on information that describes the relationship generalized into five patterns (or structures): problem/solution, cause/effect, sequence/time order, description, and contrast. That is, information that describes one of the five relationships mentioned above should be viewed as important information (This study only focuses on two structures which are problem/solution and cause/effect). In this phase, learners should identify whether the idea presented fits one certain structure. In the system, learners pick up important information by choosing important propositions from the concept maps they have made for each paragraph in the previous phase. Figure 3 shows the scene in which the system provides the list of propositions made in the concept map made in the previous phase. With this interface, learners put structure patterns on important propositions. For example, in Fig. 3, the learner identifies the second proposition from the top as an important proposition and puts a cause/effect structure on it. This means that "hurricanes" cause the *effect* of "distraction to property."

4.3 Integration of information

In the last step, learners comprise the text's main ideas by connecting important propositions picked up from each paragraph in the previous phase. To achieve a coherent summary, it is necessary to integrate the ideas. The structure strategy's main idea patterns can help them identify and strategically use the text's organization. In this phase, the propositions picked up by learners in the previous step are shown with the structural roles in Fig. 4. The task in this phase is that learners unify nodes and make a structure in which all the picked-up propositions are connected. Figure 5 is an example of a structured summary. The learner unified "hurricanes" linked with "distraction to property" and "loss of life." He also unified "loss of life" and "lives being lost" even though the labels differed. Like this, learners can unify nodes with different labels on their decision.

Figure 3

List of propositions and pattern assignment.

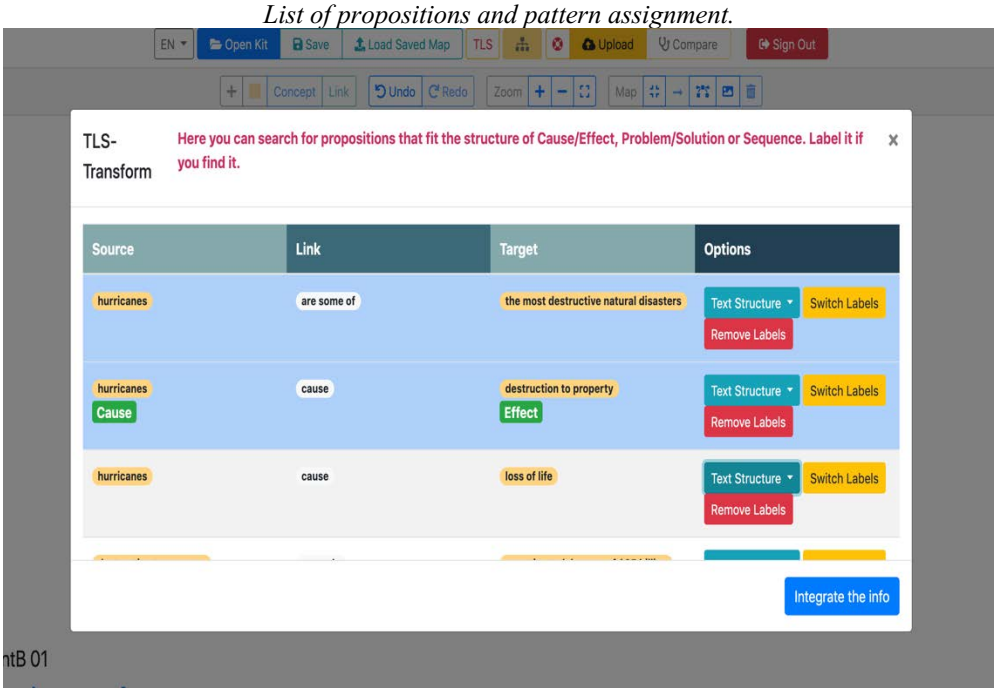


Figure 4

Important propositions picked up from paragraphs.

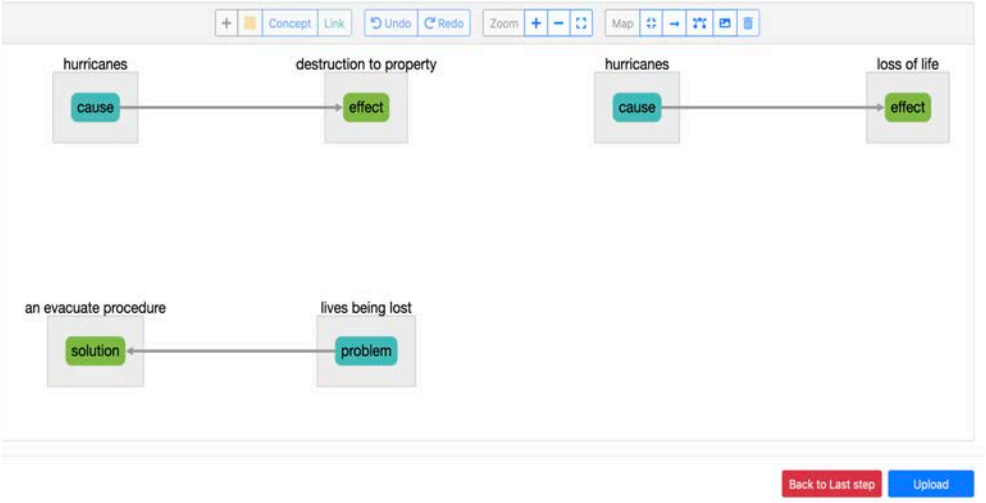
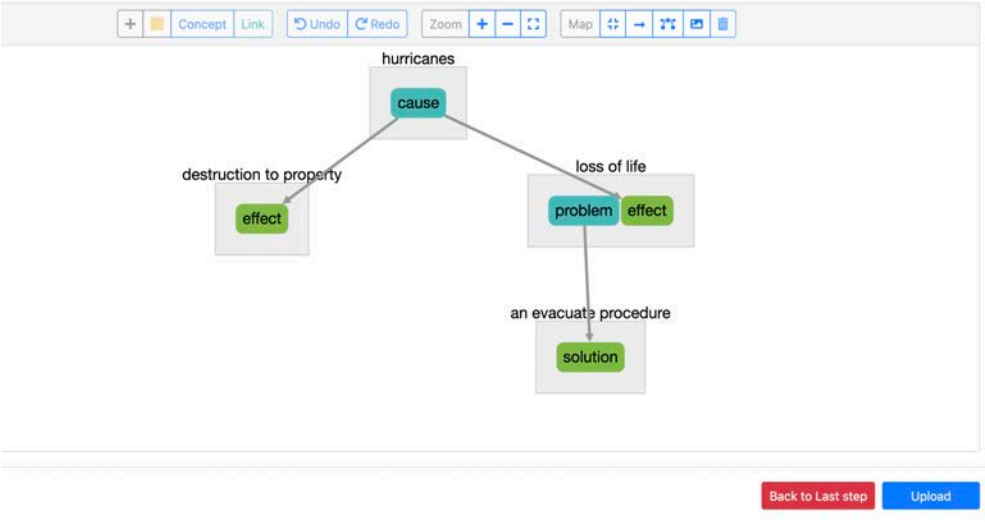


Figure 5
The structured summary (Top-level structure).

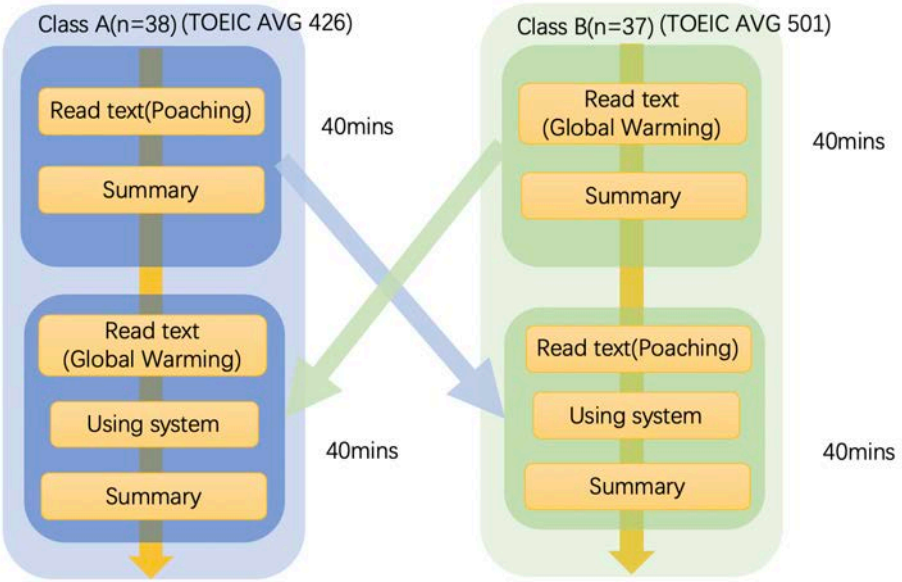


5 Experimental results

5.1 Experiment

An experiment was implemented involving 75 Indonesian college students (2 classes, class A: n = 38, class B: n = 37). Before the experiment, they all practiced with the system for 1 hour. The flow of the experiment is shown in Fig. 6. This experiment is designed and implemented to answer the following research questions:
1) Does the use of the system positively affect the quality of learners' summaries?
2) What aspect of quality of summary writing can be improved by the system?

Figure 6
The flow of the experiment.



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5.2 Results

As shown in table 1 and table 2, there is a significant difference between results without and using the system. Parameter Main Points denotes the number of main ideas a learner mentioned in his/her summary. It evaluates their ability to clarify important ideas from the source. Redundancy refers to the number of information that is less essential. Integrated ideas show the number of pairs of ideas from different positions or paragraphs a leaner integrated into his/her summary. These tables show that their scores of main points and integrated ideas increased while their redundancy decreased with the use of the system. An increase in scores of main points means that students' summaries focus more on the important information. A decreasing redundancy indicates the conciseness of their summaries has been improved. With the use of the system, learners' ability to identify what kind of information is salient and the ability to get rid of less-useful information has been improved. An increase in integrated ideas implies that learners can better see global connections among ideas by using the system. Global connections point to the global organization of the text. It is a sign of a better arrangement of information.

Then we checked the average map scores and top-level structure (TLS) map scores and the qualities of their summaries between the classes. We can tell from Tables 3 and 5 that there are significant correlations between the TLS map score and the number of pairs of information integrated. For Global Warming, only a marginally significant difference between the TLS map score and the number of main ideas. At the same time, there is a significant correlation between them in Poaching. However, there seems to be no strong correlation between the KB map score and other parameters used to evaluate the summary's quality. Based on this result, table 4 and table 6 imply a significant positive linear relationship between TLS map scores and the number of integrated information. Therefore, they will have a good performance in the combination of ideas. Good use of a TLS map can help them see the connection between ideas and thus lead to a good arrangement or organization of these ideas. As for the relationship between the TLS map score and main ideas, table 6 shows no significant relationship between these two.

Table 1
Result of nonparametric test on summary writing performance (Global Warming)

	Median		p value
	Without system use	With system use	
Main points	3.000	4.000	0.007**
Redundancy	3.000	0.500	<0.001**
Integrated ideas	0.000	1.000	0.001**

Table 2
Result of nonparametric test on summary writing performance (Poaching)

	Median		p value
	Without system use	With system use	
Main points	3.000	5.000	<0.001**
Redundancy	4.000	2.000	0.001**
Integrated ideas	0.000	2.000	<0.001**

Table 3
Result of correlation test between map scores and other parameters (Global Warming)

		Main points	Redundancy	Integrated ideas
TLS map score	coefficient	0.136	-0.167	0.481
	p value	0.064	0.197	<0.001**
AVG KB map score	coefficient	-0.161	0.212	-0.136
	p value	0.411	0.968	0.815

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Table 4
Parameter estimates (Linear regression) for Global Warming

Parameters		R^2	p value
Independent variable	Dependent variable		
TLS map score	Integrated ideas	0.234	0.002**

Table 5
Result of correlation test between map scores and other parameters (Poaching)

		Main points	Redundancy	Integrated ideas
TLS map score	coefficient	0.351	-0.183	0.438
	p value	0.033*	0.278	0.007**
AVG KB map score	coefficient	-0.043	0.027	-0.082
	p value	0.799	0.873	0.631

Table 6
Parameter estimates (Linear regression) for Poaching

Parameters		R^2	p value
Independent variable	Dependent variable		
TLS map score	Main points	0.059	0.147
TLS map score	Integrated ideas	0.201	0.005**

Table 7 and Table 8 show another parameter: structural organization. This parameter denotes whether information within a summary follows a structural organization. Following a structural organization means information in such summaries is well-arranged and is logically connected. By contrast, not following a structural organization means information in summaries is simply listed, and the logical relationship between information has been omitted. The result of binary logistic regression shows a positive relationship between the TLS map score and the possibility of following a structural organization. This result means the better the TLS map a learner makes, the higher possibility his/her summary could have followed a good structure.

Table 7
Parameter estimates (binary logistic regression) for Global Warming

Parameters		Coeff	Std. Err	p value	OR
Independent variable	Dependent variable				
TLS map score	Structural organization	0.030	0.012	0.013	1.030

Table 8
Parameter estimates (binary logistic regression) for Poaching

Parameters		Coeff	Std. Err	p value	OR
Independent variable	Dependent variable				
TLS map score	Structural organization	0.034	0.015	0.029	1.034

There is a gap between the two classes' AVG TOEIC scores (426 versus 501). Table 9 and Table 10 show that the correlation between TOEIC scores and learners' performance in summary writing is weak.

Table 9
Result of correlation test between-group AVG TOEIC score and other parameters (class A)

		Main points(GW)	Redundancy(GW)	Main points(P)	Redundancy(P)
group AVG TOEIC score	coefficient	0.161	-0.188	-0.013	-0.132
	p value	0.404	0.328	0.949	0.495

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Table 10
Result of correlation test between-group AVG TOEIC score and other parameters (class B)

		Main points(GW)	Redundancy(GW)	Main points(P)	Redundancy(P)
group AVG TOEIC score	coefficient	0.068	-0.028	0.162	-0.283
	p value	0.671	0.858	0.304	0.070

6 Concluding Remarks

According to the results, we can now answer two research questions remained. First, the use of the system has a significant positive effect on the quality of learners' summaries. With the support of the system, the content of learners' summaries contains more important ideas and is more concise than those without using the system. On the other hand, students tend to easily see connections between ideas. The way they arrange information within their summaries has also been improved with the support of the system. The three learning activities integrated into the system each contribute to each step of summary writing. The use of kit-build concept mapping and its instant feedback positively affects learners' summary writing. The application of structure strategy helps learners clarify essential information; TLS mapping is conducive to seeing the connections between ideas and organizing ideas.

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International Society of the Learning Sciences

The learning must go on: Experience of keeping participants engaged in online robotics competition during COVID-19 lockdown

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Abstract: Participant retention in online learning has often been discussed as a challenge in educational research. During 2020-2021, the existing challenges were burdened by the COVID-19 pandemic. This study explores certain engagement techniques with participants through an online project-based learning mode provided as a part of a nationwide robotics competition during the pandemic. 54 teams (176 participants) from 42 institutions participated in the competition to build a sophisticated Field Programmable Gate Array (FPGA) architecture. The study aims to understand participant engagement, the effect due to COVID-19 pandemic and lockdown, personal development due to competition, and the effect of scaffoldings and guided efforts. Despite the challenges due to the pandemic, additional scaffolding and guided efforts lead to approximately 24% of teams successfully building the architecture. This is similar to an average of 26% in pre-pandemic editions of the competition without these additional scaffolds. These efforts and mode of learning are thus found to successfully engage participants during pandemic.

Introduction

With technological advancements, online learning gained popularity (Hung & Chou, 2015; Peltier et al., 2007) and provided opportunities to learn from renowned faculty and universities in a distance mode (Phatak, 2015). However, participation, satisfaction, and retention in online learning has been a challenge that is continuously researched by the educational community (Alqurashi, 2018; Panigrahi et al., 2018). COVID-19 followed by lockdown forced educational institutions across the globe to adapt to online learning in 2020 (Patricia Aguilera-Hermida, 2020). The pandemic and lockdown led to several new challenges for online learning. It tested the readiness of teachers to adapt to online learning (Scherer et al., 2021), student's preparedness for the same (Alshurafat et al., 2021), and innovativeness in the educational systems (Pokhrel & Chhetri, 2021) to face the new challenges in changing times. The closure of universities for the physical presence of students and teachers forced researchers to explore new ways of engagement, especially for implementing pedagogies such as project-based learning in an online mode (Charania et al., 2021). Thus, participant retention and providing an apt learning experience became even more challenging. Adequately planned and designed instructions are needed for online education in such crises to achieve learning goals (Adedoyin & Soykan, 2020).

Due to pandemic situations, learning has also been affected due to lifestyle changes (Lee et al., 2021), fear in the community due to pandemic (Hall et al., 2008) causing increased stress and anxiety (Hasan & Bao, 2020; Rehman et al., 2021), etc. Attempts are being made continuously to provide as much engaging learning experience as possible in the online mode. These attempts are not only to make the learning experience similar to the in-person mode of learning but also to support and motivate students through conversations and collaborations (Yates et al., 2020). These conversations are found to foster knowledge construction among participants, especially through discussion forums leading to collaborative learning (Sun et al., 2018). This collaboration among peers and with instructors is also found to influence learner retention by keeping participants engaged (Hone & el Said, 2016; Peltier et al., 2007). To further keep participants engaged, a well-orchestrated learner-centric course that understands and addresses learner needs and enables them to learn by doing also results in better engagement (Murthy et al., 2018). Apart from engagement, the learning experience design also plays a crucial role in learner retention. Studies have found course design as an important factor in guiding learner retention as well as in achieving learning goals (de Freitas et al., 2015; Lai & Bower, 2020; Rayyan et al., 2016).

Thus, various factors affect learner engagement in online learning. However, the existing literature does not discuss the effect of these factors in pandemic situations in massive project-based learning conducted in an online mode. This paper explores the effect of various scaffolding and guided efforts on participant's experience in such a learning experience. We study the experience of participants in the e-Yantra Robotics Competition (eYRC). eYRC is a massive online robotics competition with typically 10000+ participant conducted in a distance mode. This competition is conducted annually during September to March by e-Yantra (a project funded by the Ministry of Education, Govt. of India) at the Indian Institute of Technology Bombay since 2012. In eYRC,

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students from undergraduate engineering, polytechnic, and science colleges participate as a team of four. These teams are allotted a problem statement called a "theme" which is an abstraction of a real-world problem. Each theme requires teams to learn and implement complex robotics and embedded systems tasks to win the competition. Participants learn these skills at a distance in a project-based learning mode (Krithivasan et al., 2015). The competition is conducted in two stages wherein the first stage provides all the participants with the basic knowledge and trains them in the skills required for solving the theme. Typically, 25% of the top-performing teams in the first stage are qualified for the second stage of the competition. In the second stage, teams are given all the necessary hardware to implement the learnings to solve the theme problem. They are provided with more resources, tips, guidance, and doubt clearing through discussion forums and online sessions to build a robot for solving the theme problem statement. They are provided with a document called "Rulebook" that describes this problem statement and the evaluation criteria in detail. The overall problem is divided into three sub-problems. These sub-problems are given as tasks.

In this study, we attempt to answer the following research questions pertaining to the second stage of a theme called "SankatMochan Bot" in the competition conducted during COVID-19 lockdown (December 2020 to March 2021):

(RQ 1): What was the level of engagement of participants as they complete the competition?
(RQ 2): What are the self-rated effects of COVID-19 and lockdown on the performance of participants?
(RQ 3): How do participants report the impact of competition on personal development?
(RQ 4): How do participants perceive scaffolding and guided efforts?

SankatMochan Bot

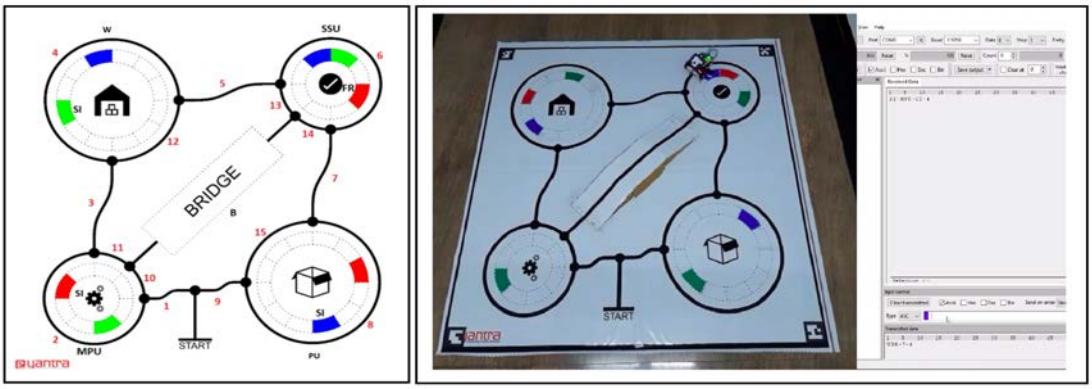
Theme Play: Problem

"SankatMochan" is an Indian word in Hindi language that can be split into *sankat (danger)* and *mochan (saviour)* to resemble someone who saves a person in danger. "SankatMochan Bot" is an abstraction of an Industry 4.0 problem where teams build a robot to identify potential dangers/threats and act before any crisis. Figure 1 (a). shows a 6ft x 6ft arena that represents the various units of an industrial plant. These units are called Warehouse (W), Main Processing Unit (MPU), Packaging Unit (PU), Safety Services Unit (SSU). On the arena, the units are represented as circles, and are connected by a black-lined path for the robot to navigate. The path is divided into sections identified by numbers as shown in the figure. There is an elevated path called "BRIDGE" that connects MPU and SSU directly. Colored patches are placed in W, MPU, and PU on the arena to indicate industrial faults. For example, fire, chemical spill, and circuit trip are indicated by red, blue, and green color patches. Their remedies are the same color patches present in the SSU. The teams had to build an autonomous robot that begins at the "START" and navigates through PU, MPU, and W checking the safety status at each unit using a color sensor. As soon as the robot identifies a fault, it indicates the same by glowing a corresponding color on the Red-Green-Blue (RGB) LED and communicating to a computer system through wireless communication. It then reports to SSU, identifies remedies for the faults found, and turns OFF the corresponding LED. Finally, it wirelessly communicates the fault resolution to the computer system.

Theme Play: Tasks

Participating teams were guided through three tasks to solve the theme problem statement in the final task. The first task had two parts which were printing the arena on the flex sheet and testing the hardware. The teams received all the major hardware along with their datasheets and manuals to build the robot. Some of the major components included a Field Programmable Gate Array (FPGA) board, color sensor, line following sensor, ZigBee module, motors, motor drivers, wheels, battery, etc. All these components were tested by the participants as per the instructions provided in the first task. In the second task, participants had to build a robot using the provided components to autonomously follow the line and encircle one of the units on the arena. The robot also had to identify a color patch and establish wireless communication with the computer system. In the third task, participants had to make the robot traverse autonomously through two units. The robot was required to use the bridge and identify the faults as it encountered them and communicate wirelessly to the computer system. In this task, teams integrated all the modules which they had developed in previous tasks. This task was a mini version of the final problem statement and aimed to prepare participants for the final task. In the final task, participants were given a configuration (placement of color patches, a combination of unavailable paths, etc.) of the problem statement to be solved. Figure 1 (b). provides a snapshot of the theme run of one of the teams showing the robot traversing the arena and the messages displayed on the computer system.

Figure 1
Arena and theme run on arena



(a) (b)

Scaffolding and guided efforts

We aimed to keep the participants engaged in the competition and to ensure that maximum teams complete and submit the final task. For this, teams were provided with various scaffolds and were guided through various activities during the tasks. One of the scaffolds was the structuring and problematization of the final problem. In the literature, these are found to be effective scaffolds to change the task so that it helps learners accomplish it, which otherwise would be out of the learner's reach (Reiser, 2004). The competition was structured and the entire implementation for the final problem statement was broken into different tasks. Some major technical challenges were to design a robot with FPGA (acting as a brain), wireless communication, sensor interfacing, path planning, bridge traversal & algorithm design using concurrent programming. These challenges were divided into different tasks as described earlier.

A thorough understanding of the problem statement in the first place is necessary to solve the problem. This problem statement with rules and scoring formula was described in the rulebook provided to the teams. A quiz was provided to the participants that gave them an opportunity to test their understanding of rules through taking this quiz enabling them to learn by doing (Murthy et al., 2018). In this quiz, they were provided necessary hints and were directed to relevant sections of the rulebook for incorrect answers. They could attempt the quiz multiple times until they have thoroughly understood the problem statement and rules.

Apart from scaffolding, instructor-student engagement plays a significant role in ensuring continuous participation and apt learning experience in online learning mode (Hone & el Said, 2016; Peltier et al., 2007; Petronzi et al., 2016). We used Piazza (https://piazza.com/) to facilitate interaction among students and instructors. This platform was available for students to clear their doubts 24x7. Piazza also provided an opportunity for peer-to-peer interaction where other participants can help to clear the query. Being a competition, they were instructed to help each other but not to publish or share the solution. Apart from query resolution, each week on Monday and Thursday, instructors posted hints and tips called Monday Mantras and Thursday Tips. These posts aimed to help participants get different perspectives on the problem and develop various approaches to test and debug solutions and guide them to be informed designers (Crismond & Adams, 2012). To further assist teams, instructors conducted three online doubt clearing sessions through video conferencing during the competition. These sessions were intended to resolve doubts and queries that were difficult to be addressed on the discussion forum. Furthermore, one-to-one interaction was also conducted where instructors guided teams on their approach to solving the problem, clarified their doubts, and motivated them to complete the competition.

Method

Participant Details

In the second stage of the competition, 54 teams (176 students) had participated. These participants were undergraduate engineering students from 42 institutions and various engineering streams. This included 146 participants from Electrical, Electronics or Electronics & Communication Engineering, 15 participants from Computer Science and Information Technology and 15 participants from other streams such as Mechanical (8), Mechatronics (4), and Robotics and Automation (3). Among the 176 participants, 56 were in the final year of their engineering, 95 in the third year, and 25 participants in the second year of engineering. There were 120 male participants and 56 female participants.

Data Collection

Online feedback was taken after submission of the final task to understand the experience of participants through a questionnaire. These questions were based on various aspects of online learning and pandemic situations found in literature, as discussed earlier. Participants were asked to rate theme design, competition structure, doubt clearing through the discussion forum, live interaction, rulebook quiz, weekly tips, hints, etc., and the perceived impact of lockdown. They were also asked if they had COVID-19 cases at their home which affected their participation. Informed consent was taken from participants to use their feedback and demographic details for research purposes. Total 143 participants filled the feedback which is considered in this study.

Results

Participant engagement as competition continues (RQ 1)

To understand participant engagement, we first consider the trends of submission and completion of tasks. Table 1 provides participant engagement statistics regarding submission and completion trends and discussion forum activity. A score of 40% or more in a task is treated as task completion. We see an average 37.56% drop in submission at each task. A drop of 59.13% was observed till task 3 in the number of teams completing the tasks. We also observe that all the teams that submitted the final task also completed it. Four teams that could not complete task 3 were also found to complete the final task.

In terms of activity on the discussion forum, although the number of posts increased, the number of active participants significantly dropped in task 2. The participants were again active in task 3.

Table 1
Participant engagement in competition

	Count of	Task 1	Task 2	Task 3	Final Task
Submission and completion statistics	Submitting teams	54	30	19	13
	Completing teams	54	21	9	13
Discussion forum activity	Posts	277	339	265	230
	Active participants	60	26	44	31

Instructors also conducted 90-120 minutes of online doubt clearing sessions during task 2 and task 3 and a one-to-one session with teams during the final task. Total 36, 31, and 24 teams attended the doubt clearing session for task 2, task 3, and one-to-one session respectively.

Impact of COVID-19 and lockdown (RQ 2)

To understand the effect of pandemic and lockdown, questions pertaining to COVID-19 situations were asked in the feedback. In the feedback received from 143 participants, 86 mentioned no COVID-19 cases at their home, 21 mentioned having COVID-19 cases at home but it did not affect their participation, while 36 mentioned having COVID-19 cases at home which affected the participation. Due to lockdown, team members were not necessarily in the same locality and the required hardware was sent only to one member of the team. Feedback was collected from the participants to understand the impact of the availability of hardware. 43 participants reported not having access to hardware, 33 reported that they were able to visit their college and work in a group, 47 participants reported working together on hardware at other team members place and 20 participants reported having access to hardware at their own home. Table 2 provides the final task completion-wise statistics of COVID-19 impact and hardware access.

Table 2
Impact of COVID-19 and hardware access on completion of final task

	Impact	Final task complete	Final task not complete
COVID-19	No case – not affected	20	66
	COVID-19 case – not affected	4	17
	COVID-19 case - affected	4	32
Access to hardware	Yes	47	53
	No	3	40

Participants were also asked to provide their perceived experience if the competition had been in non-COVID-19 situations. The participant response collected on a 5-point Likert scale (5-Strongly Agree, 1-Strongly Disagree) is presented in Table 3. We see the participation of the teams is affected by COVID-19 situations and access to hardware due to lockdown. Also, the teams perceived better performance, learning, increased focus, less stress, and better time and work management in non-COVID-19 situations.

Table 3
Perceived experience in non-COVID-19 situations

Question	Subquestion	Rating	
		Mean	SD
If the same competition were conducted during a non-COVID-19 situation, you would have had	Better performance	3.94	1.13
	Better learning	3.78	1.25
	Increased focus	3.82	1.22
	Less stressed	3.64	1.35
	Better Time and Work Management	3.72	1.36

Impact on personal development (RQ 3)

To understand the impact of competition on personal development, feedback was collected through a rating on a 5-point Likert scale (5-Strongly Agree, 1-Strongly Disagree). Table 4 provides the participant response. We find despite the impact due to COVID-19 and lockdown, participants have reported the competition to have helped in personal development.

Table 4
Personal development due to competition

Question	Rating	
	Mean	SD
I would prefer an individual format rather than team	2.72	1.47
My hands-on learning skills have improved	4.62	0.49
I have become a better Team Player after competition	4.52	0.5
I have become more confident in taking up challenges	4.54	0.5
My "peer-learning abilities" (ability to understand concepts, information, etc. from teammates and peers) have improved	4.54	0.5

Effect of scaffolding and guided efforts (RQ 4)

Table 5 provides the response of participants pertaining to various scaffolding and guided efforts on a 5-point Likert scale (5-Strongly Agree, 1-Strongly Disagree). We observe that participants appreciated the scaffolding and guided efforts to have helped them keep engaged in the competition.

Table 5
Feedback on scaffolding and guided efforts

Question	Subquestion	Rating	
		Mean	SD
There was a gradual increment in task difficulty		4.08	0.97
Discussion forum was effective in doubt-clearing		4.24	0.66
Following was helpful and encouraging to continue participation	Doubt Clearing Session	4.34	0.77
	Motivation by mentor on Piazza	4.26	0.75
	One-to-one interaction	4.44	0.61
	Thursday Tips and Monday Mantras	4.02	0.8
	Rulebook Quiz	4.18	0.63

To further understand the impact of these scaffolds, we consider the completion rate of past year's competition. Table 6 provides the percentage of teams completing Stage 2 in the previous four years (pre-pandemic) (e-Yantra, 2021). In these years, participants worked on similar problems with similar technologies having the same level of difficulty and complexity. The competition format (participation as a team, breaking problems into tasks, use of discussion forum, providing hardware, etc.) was also similar. However, the scaffolding and guided efforts such as more engagement through weekly posts, online doubt clearing sessions, one-to-one

interactions, and rulebook quiz were introduced in this edition to keep participants engaged. As we see, the average completion rate is 24.07% for the current year compared to 26.15% for the previous four years. Although the completion rate has not improved, but it is similar to that in pre-pandemic years. Thus, the effect of these efforts is evident in keeping participants engaged.

Table 6
Comparing the completion rate with pre-pandemic editions

Year	% teams completing the competition in Stage 2
2020-21	24.07
2019-20	34.44
2018-19	26.67
2017-18	19.47
2016-17	24.03

Discussion

The competition discussed in this paper is conducted annually since 2013 and has received an immense response from students (Sabanwar & Arya, 2019). However, during 2020-2021, in a pandemic situation, many factors were different. The team members were not necessarily at the same place. This hindered the participants from effective meetings and discussions necessary for collaborative learning (Kolodner et al., 2009). This effect could be implied from the gradual decrease in the submission rate in the tasks. As the tasks become difficult, more collaboration and brainstorming among participants becomes necessary. Although participants had various online modes of collaboration such as video conferencing, hardware availability became another obstruction in participant retention. The hardware kit to solve the theme problem was available to only one team member. As a result, only the team member having access to hardware could undertake robot building, testing, and all other tasks which also leads to increased load, resulting in dropout (Bawa, 2016). Thus, among the participants completing the final task, we see the majority of the team members had access to hardware (47 of 50).

Studies have found the pandemic situation impacting learner engagement due to changes in lifestyle, increased stress, and anxiety (Hasan & Bao, 2020; Lee et al., 2021). This paper also shows a similar impact. Almost 50% of the participants that did not complete the final task reported their participation was affected due to COVID-19 cases in their home during competition. Participants also reported COVID-19 situations to influence their experience. Their feedback on perceived experience in non-COVID-19 situations highlights the aspects of non-course or learning-related factors influencing learner retention (Henderikx et al., 2018).

Understanding the challenges due to COVID-19 situations, various efforts were taken for participant retention. These efforts are found to help participants in continued participation. These findings are in line with previous studies to engage learners in online mode (de Freitas et al., 2015; Hone & el Said, 2016; Peltier et al., 2007). Studies have reported the pandemic situation to negatively affect learner engagement, satisfaction, and retention (Wang et al., 2021; Wester et al., 2021). However, the extra efforts to scaffold the learning and motivate participants in this edition of the competition resulted in continuous participation and similar retention rates as during pre-pandemic editions of the competition.

Participants reported a positive impact of competition on their personal skills. Although all members did not get the opportunity of working on hardware, the collaborative activity helped them contribute at their own level leading to learning (Alibali & Nathan, 2018; Lave & Wenger, 1991). Despite the issues in collaboration due to online mode, participants preferred to work in teams rather than individually. Thus, even in these challenges, the competition achieved various project-based learning goals (Krajcik & Blumenfeld, 2005).

Conclusion

This study discussed various efforts for participant retention in a massive online robotics competition conducted during COVID-19 lockdown. Our study shows that the pandemic situation has impacted the participants performance. Apart from the impact on performance, pandemic also impacted their learning and focus leading to increased stress. Scaffolds such as a gradual increase in task difficulty, doubt clearing, and continuous engagement through the discussion forum and online interactions through video conferencing helped in keeping participants engaged in the competition. As a result of these efforts, despite the pandemic, the completion rate was 24% which is similar to that in the pre-pandemic situation. The study is based on participant feedback through an online self-reported survey. This limits the generalization of findings in this scope. Further studies with more ways of data

collection and application of the scaffolding efforts in other domains (other than engineering education) can confirm the findings discussed to be generally applicable.

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"It's good because he said so" — The Effects of Pre-Service Teachers' Passive vs. Constructive Engagement on Technology Acceptance

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Abstract: Pre-service teachers' rather suboptimal use of technology in teaching may be explained by low levels of technology acceptance. We assumed that encouraging pre-service teachers to constructively engage with information about technology rather than passively reading information about tools should increase their perceived usefulness (PU), perceived ease of use (PEU) and intention to use (ITU). *N*=53 pre-service teachers were either asked to read a blog post about the potential of a mind mapping tool (passive condition) or to work on small tasks that covered the same informational aspects as the blog post (constructive condition). Contrary to our assumptions, reading a blog post significantly contributed to pre-service teachers' PEU and PU (in tendency) compared to working constructively on open-ended tasks. The results also suggest that it may be necessary to differentiate between the learning activity that is prompted and the activity that is performed. Possible explanations for these effects will be discussed.

Introduction

Digital technology is attributed great potential to facilitate student learning in the classroom. For example, quiz apps can help to incorporate activities that are associated with higher levels of engagement and knowledge change processes of the learners (Sung et al., 2016). However, teachers only partially make use of technology affordances to engage students in high-level learning activities (Sailer et al., 2021).

In the past two decades, a number of researchers have sought to determine what may prevent teachers from an effective use of digital technology in the classroom (e.g., Eickelmann & Vennemann, 2017; Ertmer & Ottenbreit-Leftwich, 2010). For example, low technological pedagogical content knowledge can lead to teachers not using digital technology in a way that is beneficial for learning (Pamuk, 2012; Joo et al., 2018). Also, a possible lack of technology acceptance might be a potential factor of maladaptive use of digital technology, and prior research seems to support this concern (Backfisch et al., 2021). In addition, German teachers in particular show less positive attitudes than teachers from other countries regarding the results of learning with digital technology (Fraillon et al., 2019).

Therefore, since intervention studies that target pre-service teachers' technology acceptance are rare (Kale, 2018), the objective of this study is to determine how pre-service teachers' technology acceptance may be promoted when engaging with information about a particular digital tool. More precisely, the aim is to investigate whether having pre-service teachers engage in different kinds of learning activities (passive vs. constructive; see Chi & Wylie, 2014) while interacting with information on a particular digital tool has differential effects on their technology acceptance.

The technology acceptance model (TAM)

The design of appropriate learning opportunities may be informed by the Technology Acceptance Model, originally developed by Davis (1986). It points to users' perceived usefulness (PU) and perceived ease of use (PEU) of a technology as relevant factors that influence both the intention to use a certain digital technology and its actual use, with the perceived ease of use having a direct influence on perceived usefulness (see Fig. 1).

Davis defined perceived usefulness (PU) as the degree to which a person believes that using a particular technology would enhance her/his job performance. In the case of teachers, Scherer et al. (2015) showed that teachers found those tools useful that promoted learners' interest and learning outcomes. In contrast, perceived ease of use is defined as the degree to which the person believes that using the particular technology would be free of effort (Davis, 1986), for example, whether a teacher finds the user interface of a tool easy to understand. Both beliefs were hypothesized to be directly influenced by external variables (Venkatesh & Davis, 2000), such as system features or user training (Chuttur, 2009; Venkatesh & Davis, 1996).

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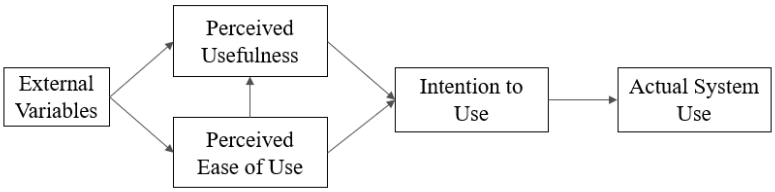
Figure 1
Technology Acceptance Model (Venkatesh & Davis, 1996)



Existing research indicates that pre-service teachers' perception of the usefulness and ease of use of particular tools predicts their intention to incorporate them in their future teaching (e.g., Joo et al., 2018; Scherer & Teo, 2019). An extended form of the TAM with PU, PEU and subjective norm (i.e., perceived social pressure to perform certain behavior; Teo, 2010) explained about 43% of the variance for intention to use among Swedish pre-service teachers (Ma et al., 2005). Similarly, in a study by Teo (2009) in Singapore and Malaysia, TAM (PU, PEU and attitude towards computers) was able to explain 27% of the variance in pre-service teachers' ITU (Teo, 2009). Scherer et al. (2019) also found in a meta-analysis that TAM is applicable to both pre- and in-service teachers. For example, Sadaf et al. (2016) investigated predictors of student teachers' intention and actual use of Web 2.0 applications in a two-phase, sequential explanatory design with surveys (N = 189) and interviews (N = 12). They found that PU was one of the strongest predictors of intention to use and actual use of Web 2.0 applications. In addition, there was a significant positive relationship between intention and subsequent behavior of pre-service teachers (Sadaf et al., 2016). In a study by Yuen and Ma (2008), however, PEU was the only determinant to predict ITU.

Taken together, these results point to the importance of technology acceptance of digital tools for their actual use in the classroom. So far, however, research on how to positively influence the perceived usefulness and perceived ease of use of the technology, especially among pre-service teachers, is scarce (Kale, 2018).

Fostering pre-service teachers' technology acceptance with constructive learning activities

When teachers encounter digital tools that might support their teaching, they often do so on the Internet. For instance, there are websites and blogs that contain texts or videos that provide arguments for the effectiveness and usability of a given digital tool to be used in the classroom, such as "www.edutopia.org". In terms of TAM, such websites typically are designed in a way that is intended to facilitate the perceived ease of use and the perceived usefulness of the tool under scrutiny, for example by sharing the experiences of other teachers that report on their positive experiences with the tool.

From an instructional perspective, it however is questionable whether reading about the alleged advantages of a certain tool will be enough to positively influence the perceived usefulness and perceived ease of use on the side of a potential user of that tool. For example, based on the ICAP framework by Chi and Wylie (2014), it might be expected that having learners passively receive information about digital tools would probably be less effective than engaging them to productively interact with that information, for example by having them sort and weigh information about the tool in terms of its usefulness and ease of use.

More specifically, the ICAP framework defines cognitive engagement activities based on students' overt behaviors. It proposes that engagement behaviors can be categorized and differentiated into one of four modes: passive, active, constructive, and interactive (Chi & Wylie, 2014). The so-called ICAP hypothesis states that as students become more engaged with the learning materials, i.e., the more they move from an engagement in passive towards an engagement in interactive activities, the more their learning will increase, because each mode corresponds to a different set of underlying knowledge-change processes and a deeper understanding of the learning material. Thus, reading a website or a blog post would correspond to a *passive* learning activity. In this case, learners simply read a text or watch a video about a digital tool without doing anything else. This way, the received information is stored in an isolated fashion and not well integrated with existing prior knowledge (Chi & Wylie, 2014). In an *active* mode of engagement, learners manipulate the material, for example, by marking passages in the text. In this manner, prior knowledge is activated, and existing schemata may be completed. The new knowledge can then be applied in similar contexts, and there is a superficial understanding (Chi & Wylie, 2014). When learners engage in *constructive* learning activities, they create content that goes beyond the existing materials. This applies, for example, when learners draw concept-maps, take notes in their own words, or explain concepts. As a result, constructive activities are assumed to induce inference processes, whereby new information is integrated with prior knowledge. This way, a deeper understanding and transfer of the learning material can

take place (Chi & Wylie, 2014). Finally, being *interactive* requires that learners refer to other learners' ideas, for example by arguing in dyads or small groups about a digital tool. This enables learners to generate new knowledge together through interaction and the opportunities for sharing feedback or ideas that come with it. According to the model, this activity has the potential for an in-depth understanding of the learning material and the greatest possibilities for developing new ideas together.

A study by Menekse et al. (2013) confirmed the ICAP hypothesis in a study with engineering students. They investigated the effects of all four modes of engagement on learning outcomes in a learning unit on atomic bonds and crystal structures. With respect to the comparison we intend to investigate in our study, the results showed that students' knowledge significantly increased in the constructive condition in which students were instructed to interpret a diagram that contained information from a text compared to the passive condition (in which students only read the text) from pre- to posttest. However, a few studies also suggest that under some circumstances, passive learning may be more beneficial for learning success. For example, MacDonald and Frank (2016) showed that learners perform better in sequences in which they first passively and then actively engage with the learning material than vice versa. For this reason, it is questionable whether higher-order learning activities as defined by the ICAP model are generally associated with higher learning success than passive learning activities. Even though the ICAP model does not focus on the effects of student engagement in these different kinds of activities on attitude change, but rather on knowledge acquisition, it is conceivable that a more comprehensive knowledge about the tool, such as its potential or application scenarios, might be positively related to technology acceptance. Therefore, student engagement in constructive activities should be beneficial for reaching higher levels of PU, PEU, and ITU. However, this has not yet been investigated in previous research. Thus, the aim of this study is to compare the effects of passive and constructive learning activities on the technology acceptance of pre-service teachers.

Research questions and hypotheses

In this quasi-experimental study, we provided pre-service teachers with information about a specific digital tool that might be used in the classroom to support student learning. We then created two experimental conditions: In one condition, students just read a blog post about the tool (passive condition), while in the other, students were instructed to perform six constructive tasks covering the same aspects as the blog post.

Consequently, our research question was: To which degree does an engagement in constructive learning activities while learning about the potentials of a certain digital tool (compared to an engagement in passive activities) have a positive effect on pre-service teachers' (1) PU and (2) PEU and (3) ITU of technology?

Based on ICAP, we assumed that because an engagement in constructive activities should result in deeper processing of information about the tool than an engagement in passive activities, student engagement in constructive compared to passive learning activities should contribute to higher perceived usefulness (H1), higher perceived ease of use (H2), and an increased intention to use the tool (H3).

Method

Participants and design

A total of 53 pre-service teachers participated, who were on average 22 years old (MAge = 21.42, SDAge = 4.18). The majority of our participants were in their second semester (MSem = 1.94, SD = .99) and mostly female (approximately 69.8%). They took part in an online experiment that was embedded in a psychology lecture, which was compulsory for all students. They received course credit for participation. Establishing a 1x2 between-subjects design, students were randomly assigned to a passive or a constructive condition (Npassive = 25, Nconstructive = 28). According to their allocation, participants in each condition had to carry out one passive or several constructive tasks related to a specific digital classroom tool (see below).

Procedure

After completing a survey that asked for demographic data, participants received basic information about an online collaborative mind mapping tool, called Coggle (https://coggle.it/). The user interface of the tool and an example for a mind map were shown. As a short description of its features, it was stated that Coggle can be used to generate collaborative mind maps in real time. This way, participants should get a rough idea of the tool, even if they were not familiar with it yet. After that, they were asked to rate its PU, PEU and ITU.

In a next step, all participants read a one-page text about the ICAP framework to help them understand the subsequently presented learning-related potentials of the tool. Then, participants in the *passive* condition were asked to read a blog entry of a fictitious teacher who described his personal experiences handling the tool and who addressed its usefulness by referencing the ICAP framework. In the *constructive* condition, participants

worked on six, mostly open-ended exercises covering the same informational aspects as the blog entry. For example, in the first task of the constructive group as well as in the blog post, there was a labelled illustration of the user interface of the tool. Participants in the constructive condition were instructed to inspect the illustration and to describe the illustrated functions of the tool in a text field in their own words. In the blog post of the passive group, the functions are described in sentences by the teacher. Furthermore, in a second task, a diagram from an article by Menekse et al. (2013) about learning success in a knowledge test after performing different learning activities was presented. The constructive group was instructed to interpret the graph in their own words in the light of the ICAP model. The same graph was also included in the blog post. There, the teacher talked about the results of the study and described the graph. In addition, for example, participants in the constructive condition were instructed in another task to develop usage scenarios of the tool based on the ICAP model, whereas participants in the passive condition could read about the usage scenarios of the fictitious teacher in the blog post. In the posttest, participants rated their PU, PEU and ITU again.

Variables

The scales used to measure PU, PEU and ITU were adapted from Hu et al. (2003), Teo (2011) and Venkatesh et al. (2003) and were reformulated to fit the tool "Coggle". Before and after the intervention, participants were asked to rate its PU (5 items, e.g., „Using Coggle would enhance my job performance", Cronbach's α=.90) and PEU (5 items, e.g., „I find it easy to get Coggle to do what I want it to do", Cronbach's α=.75) and ITU (4 items, e.g., „I intend to use Coggle in my lessons in the future", Cronbach's α=.84) on a Likert scale from (1) do not agree to (4) totally agree.

Statistical analyses

To examine our research question, we performed three separate mixed ANOVAs. The condition represented the between-subjects factor (passive vs. constructive), whereas the within-subjects factor was time (pre- vs. posttest). The alpha level of all analyses was set to 5%.

Results

Effects of engagement in passive vs. constructive activities on PU, PEU, and ITU

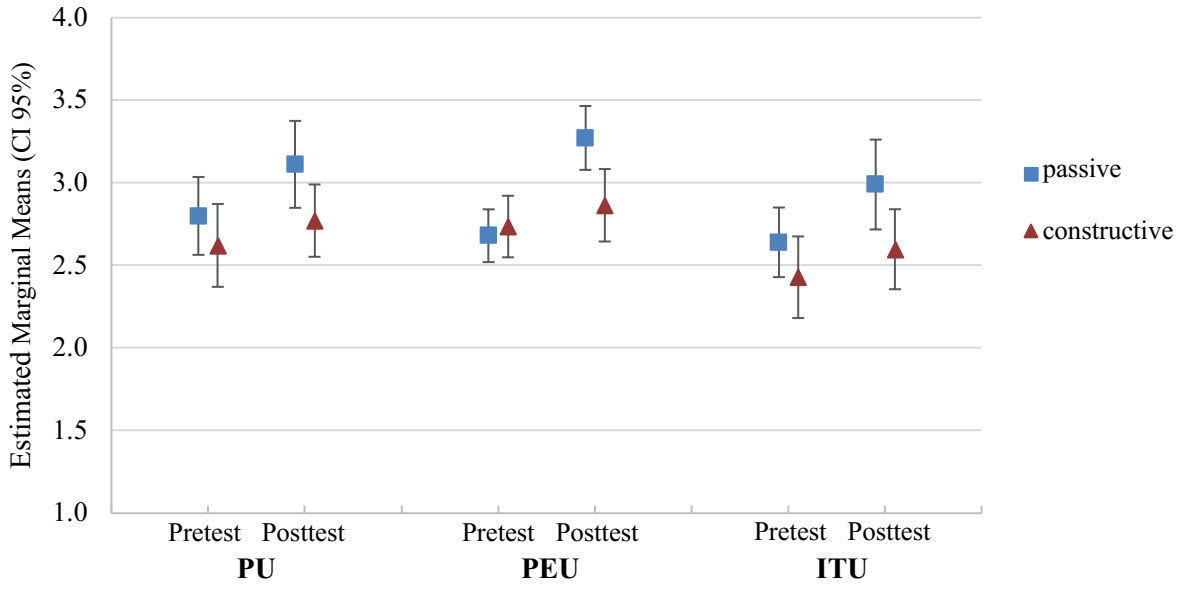
Concerning H1, figure 2 illustrates the descriptive statistics for PU for both groups. Descriptively, the means of both groups were higher in the posttest than in the pretest, and learners from the passive condition generally (i.e., both in pre- and posttest) displayed higher values of PU than learners from the constructive condition.

A mixed ANOVA with condition (passive vs. constructive) as between- and time as within-subject factor did not result in a significant interaction for PU, $F(1,51) = 1.15$, $p = .29$, partial $\eta^2 = .02$. A main effect of group was only significant by tendency in favor of participants in the passive condition, $F(1, 51) = 3.04$, $p = .087$, partial $\eta^2 = .06$. However, the increase of PU over time for both conditions was significant, $F(1, 51) = 9.38$, $p = .004$, partial $\eta^2 = .16$.

Regarding H2, figure 2 illustrates that PEU increased over time for both conditions, with a more pronounced increase from pre- to posttest in the passive condition. Subsequently, a mixed ANOVA with condition as between-subjects factor and time as within-subjects factor and PEU as dependent variable showed a significant interaction effect, $F(1,51) = 8.88$, $p = .004$, partial $\eta^2 = .15$, albeit in an unexpected direction. The simple main effect of condition was significant in the posttest, partial $\eta^2 = .14$ $p = .006$. The simple main effect of time was significant in the passive condition, $F(1, 24) = 44.95$, $p < .001$, partial $\eta^2 = .65$, but not in the constructive condition, $F(1, 27) = 1.08$, partial $\eta^2 = .04$, $p = .31$.

With respect to H3, figure 2 shows that ITU increased over time in both conditions. For ITU, an analogous mixed ANOVA with condition as between-subjects factor and time as within-subjects factor and ITU as dependent variable did not result in a significant interaction ($F(1, 51) = 1.15$, $p = .25$, partial $\eta^2 = .03$). However, the main effect of condition was significant, $F(1, 51) = 4.05$, $p = .05$, partial $\eta^2 = .07$, with students in the passive condition displaying a higher level of ITU than students in the constructive condition. There was a significant increase of ITU over time for both conditions ($F(1, 51) = 11.45$, $p = .001$, partial $\eta^2 = .18$).

Figure 2
Means and 95%-confidence intervals of PU, PEU and ITU by mode of engagement



Further analyses

Based on the hypotheses, these results were rather unexpected. Therefore, we wondered to what extent participants in the constructive condition actually engaged in constructive activities (N = 28). For this reason, we looked at how extensively the tasks in the constructive condition were actually carried out. As a first indicator, we found that the number of words in the first task significantly and positively predicted the change in PEU between pretest and posttest, $F(1, 26) = 5.98$, $\beta = .48$, $p = .02$, indicating that the more constructive students were, the more positive they rated the PEU of the tool. However, the prediction of the change in PU was not significant, $F(1, 26) = .94$, $\beta = -.39$, $p = .34$.

Discussion

The present study was designed to determine the effects of prompting pre-service teachers to engage in passive and constructive learning activities on their acceptance of a particular kind of technology. The literature on technology acceptance provides very little information on the question of how technology acceptance can be influenced (Kale, 2018). Based on the ICAP framework by Chi and Wylie (2014), we assumed that a constructive engagement with learning material about the digital tool would result in a higher technology acceptance than an engagement in passive activities when being confronted with the tool. Yet, at least at first sight, our results do not provide much evidence for this assumption.

Regarding hypothesis 1, no significant interaction between time and group on PU was found. Nevertheless, the significant effect of time on PU suggests that participants' PU improved significantly regardless of condition. Thus, on the basis of this result, an engagement in constructive activities does not seem to have larger effects on PU than an engagement in passive activities. Obviously, reading about a fictitious teacher's positive experiences regarding the usefulness of digital tools may already suffice to boost PU in the intended direction.

Concerning hypothesis 2, we found a significant interaction effect for PEU. Contrary to our expectations, however, reading a blog entry passively seemed to have a stronger positive effect on PEU compared to working constructively on open-ended exercises. Moreover, this effect can be considered large (Cohen, 1988). Interestingly, the examination of the simple main effect of time also shows that only passively reading the blog post resulted in a significant improvement in PEU, but not performing the constructive tasks.

Finally, with respect to hypothesis 3 for ITU, the results show no interaction effect. Yet, a significant effect of time and group could be observed. The effect of time again suggests that participants' ITU improved regardless of their condition. In other words, both passive and constructive learning activities thus might be related to an improvement in ITU. Moreover, this effect can again be regarded as large (Cohen, 1988). Presumably, this

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can be interpreted as a result of the fact that PU and PEU were supposed to predict ITU and that similar effects were observed in the previous analyses (e.g. Joo et al., 2018; Ma et al., 2005; Teo, 2009).

Consequently, contrary to expectations, for none of the factors PU, PEU or ITU did the constructive tasks have a larger effect than reading the blog post. The only interaction effect indicates that reading a blog entry passively seemed to have (at least partially) contributed to pre-service teachers' more positive technology acceptance as compared to working constructively on open-ended exercises, having a significant effect on a more positive PEU. Also, the effect of reading the blog post on PU tended to be almost significant.

However, these initially surprising results could be explained in several ways related to the assumptions of the ICAP model: First, there may be differences between (a) the activities that learners are instructed to perform and (b) the activities that they actually carry out (Vogel et al., 2017). For example, learners may have been instructed to constructively summarise the functions of the tool, but then might simply have copied the information. This in turn would mean that they did not work constructively, but rather actively. This might also be concluded on the basis of the preliminary analysis on word count. The opposite scenario is also conceivable: Even if the learners were instructed to merely read the text information, it is possible that they thought more deeply about the content, such as explaining it to themselves. This in turn would mean that they elaborated on the content more than the ICAP model would assume (Chi & Wylie, 2014). For this reason, it is possible that the participants in the constructive condition showed a lower level of engagement or in the passive group a higher level of engagement than actually assumed. Ultimately, the ICAP model only ever refers to a probability that certain visible activities are related to the corresponding (possibly more profound) learning processes. Chi and Wylie (2014) recommend that the outputs generated by the learners should be analysed in order to arrive at an indication of which activity was actually carried out. It is possible that further analysis of learner responses could be helpful in uncovering such discrepancies. Beyond that, it is likewise conceivable that in this case a certain sequence of learning activities, beginning with passive learning activities, are better suited to promoting technology acceptance, similarly as in terms of learning success (MacDonald & Frank, 2016).

Yet, there are further possible explanations for our findings: For example, it might be that the constructive condition imposed high cognitive load on students, with the effect that they might not have had sufficient opportunity to invest effort in elaborating the information about the tool, as following the task instructions might have been too strenuous to follow. Indeed, research shows that working on complex tasks without further instructional guidance is particularly ineffective when learners have little prior knowledge (Kalyuga et al., 2001; van Gog, et al., 2008), which might have been the case for our sample of (beginning) pre-service teachers. In this sense, the tasks of the constructive condition might be seen as complex tasks in which the learners have not received any additional support. In contrast, the elaborated blog post of a teacher about the potentials and the use of the tool might be considered as a worked example to the constructive tasks, in which participants in the constructive condition had to generate the corresponding knowledge themselves. In view of the present sample of students in the second semester with a supposedly low level of prior knowledge, a so-called worked example effect might have occurred in the passive condition (Renkl, 2014).

The low level of prior knowledge is accompanied by another challenge: students with little prior domain-specific knowledge tend to overestimate their competences (Dunning et al., 2003). If students only superficially engage in a topic, they may mistakenly think that they have already grasped the learning content, although this is not always the case (Renkl, 2014). It is possible that reading the blog post and the teacher's explanations gave the students the impression that they had already comprehended the affordances of the tool. For this reason, the passive learners might underestimate the challenges occurring when using the tool and overestimate the PU or PEU of the tool accordingly. Consequently, future studies should control for learners' prior knowledge and assess their cognitive load. In light of this reasoning, it would then also be thinkable that the actual use in the classroom differs in a similar way and is, for example, associated with greater difficulties.

Limitations and conclusions

Of course, this study is not without limitations. Besides our rather small sample size, it is important to note that we exclusively used subjective data. Thus, we do not know whether students who indicated a high ITU would actually use the tool in their classrooms more often than students with lower levels of ITU. Second, applying ICAP (which actually focuses on learning processes and outcomes) on the build-up and change of attitudes might be an inappropriate theoretical stretch. Perhaps, taking more specific theories into account that may explain attitude change (such as Elaboration-Likelihood-Model, Petty & Cacioppo, 1986) might be more fruitful for the design of effective interventions.

Furthermore, it must be taken into account that we did not include a control condition without treatment. Also, follow-up studies are needed to test the sustainability of the effects. In addition, it must be examined whether the higher intention to use actually results in more frequent use in the classroom in the long term. Moreover, the

small sample size increases the likelihood of a type II error. Future studies should therefore be conducted with larger samples and a subsequent investigation should assess actual use of the tool.

Despite these limitations, our study suggests that technology acceptance can be promoted by engaging with information about a digital tool. If an experienced teacher's accounts, as in the form of the blog post, are particularly conducive to technology acceptance, a possible approach would be for in-service teachers to share their personal experiences of digital tools and their use in the classroom. In this way, pre-service teachers' technology acceptance might potentially be promoted in a very economical way. Thus, the present study provides important insights on how the technology acceptance of pre-service teachers could be further investigated and promoted.

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International Society of the Learning Sciences

"I'm still learning": Experienced Mathematics Teachers' Development of Adaptive Expertise Amidst the COVID-19 Pandemic

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Abstract: In 2020, the global COVID-19 pandemic disrupted education across the country, requiring a re-organization of instruction on a large scale. This study examines the experiences of highly-committed secondary mathematics teachers in a large urban U.S. public school district as they shifted their instruction online for an entire year. Using the framework of *adaptive expertise* – processes and dispositions that can enable teachers to extend their knowledge to novel situations – this paper contrasts the cases of three teachers' development of adaptive practices over time. Drawing on data gathered from semi-structured interviews, participant observation, and content analysis, we discuss how teachers' engagement in the processes of *identification* and *negotiation* contributed to their adaptive orientations. By documenting how highly-reflective educators adjusted their instruction to respond to unprecedented teaching demands, this study contributes to the field's understanding of adaptive expertise in mathematics teaching.

In March 2020, school districts across the country spontaneously moved all instruction online as the COVID-19 pandemic spiked. Teachers who had spent years honing their craft in the classroom were forced to learn a different job. As a field, we know little about the processes through which experienced teachers continue to learn to adapt their existing knowledge to new and novel situations. This study explores the ways that secondary mathematics teachers developed adaptive expertise to meet the demands of their various novel teaching contexts. To do so, this paper builds on an existing four-year partnership with a highly-selective professional development organization for mathematics teachers, most of whom teach in a large urban school district in the Western United States. These teachers demonstrate strong commitments to their own and their students' learning and occupy resource-rich professional networks. By working closely with mathematics teachers and documenting their responses to teaching in the midst of the pandemic, this study contributes to educational practice and research. Practically, this study offers examples of the different ways teachers developed adaptive expertise in their unique learning environments. Theoretically, this is a case study of adaptive expertise as a process of mathematics teacher learning, contributing to the field's understanding of how teacher learning environments can be designed to support the development of experienced teachers' adaptive expertise in post-pandemic learning contexts. Specifically, this study examines the question: How are well-resourced, experienced secondary mathematics teachers in a large urban school district transforming their teaching during the COVID-19 pandemic?

Theoretical Framework and Prior Work

Adaptive expertise

We take a situative view of teacher learning, a subset of sociocultural theories rooted in Vygotsky's (1978) early work (Lave & Wenger, 1991). Because of its attention to learners-in-context, it is possible to leverage this perspective to investigate teachers' transformations and adaptations, in the context of the COVID-19 pandemic. Teachers were thrust into mandated online teaching, bringing about entirely new demands that required them to move beyond the application of existing knowledge. Faced with a novel situation, teachers had to make a situational adjustment (Becker, 1964) – rather than completely reinventing their practice, teachers made adjustments, changes, and choices between situationally feasible alternatives, choosing actions that best meet their professional demands and expectations as well as align with their professional, ethical, and personal commitments. This kind of problem solving supports the construction of knowledge, making this context a compelling place to study teacher learning.

The unique context of pandemic teaching lends itself to specifically examining teachers' development of adaptive expertise. Drawing on ideas about adaptive expertise in teaching (Crawford et al., 2005), adaptive expertise can be described as flexible and innovative and marked by the ability to extend current understandings to meet the demands of novel problems or atypical contexts. This stands in contrast to what has been described as routine expertise (Hatano & Inagaki, 1984), marked by speed, efficiency, and automaticity but does not necessitate flexibility or adaptability to new situations. Adaptive expertise is a *stance* on knowledge and practice: adaptive

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experts approach new situations flexibly and learn throughout their lifetimes (Bransford et al., 2000). Furthermore, adaptive expertise is not only a way to describe how teachers have changed their practice, but it also motivates their own learning, as they recognize when rules and principles do not apply to situations, seeking instead to develop new practices (Gott et al., 1992).

Crawford et al. (2005) describe several necessary dispositions and skills that teachers must possess in order to develop adaptive expertise, adaptive practices – an instructional practice that is evolving in order to meet the demands of a novel situation – and to be considered adaptive experts. Particularly relevant to this study is an inclination to acknowledge and even push the limits of one's ability while also assessing the adequacy of current knowledge or practices for meeting the needs of particular problems. Cognitively, adaptive experts look for evidence to inform their plans, seek causality as well as feedback, monitor the results of their decisions and their own learning, and assess their own and the field's knowledge for addressing the situations at hand. These dispositional and cognitive tendencies support a balance between efficiency and innovation in teaching. On the one hand, by having and relying on developed routines, adaptive experts can move through predictable aspects of their work smoothly. On the other hand, by sensitizing themselves to the feedback that things are not going as expected, they can seek new forms of practice rooted in well-understood principles. This conception of teacher learning implies that knowledge is flexible and contextual and that teachers' ongoing learning is responsive to a changing context and dynamic community instead of being a set of skills or static knowledge.

Adaptive expertise in teaching and learning has been studied in a multitude of contexts: exploring different conceptions of mathematics student understanding (Hatano & Inagaki, 1984); characterizing reasoning and problem solving processes that enable adaptive experts to continue to learn in adult professional settings (Bransford et al., 2000; Feltovich et al., 1997; Gott et al., 1992); and describing the epistemic/dispositional aspects of adaptiveness and the habits of mind involved in science teacher professional development (Crawford et al., 2005). This body of work has evolved over time to recognize that the content or characteristics of learners in any context are not static over the course of teachers' careers. However, this research fails to discuss how adaptive expertise is developed.

Identification and Negotiation

In keeping with the goal of understanding teachers' developing adaptive expertise from a situative perspective, we draw on Horn et al.'s (2008) conceptions of identification and negotiation in their discussion of preservice teacher learning. Specifically, this paper is in alignment with their view of identity:

> Identity, as an analytic construct, provided access to both individuals' dispositions and the environments they encountered. Because accounts of identity necessarily provide for the description of individuals, it helps us see the people we are trying to understand. At the same time, identities are constructed through culturally available descriptors, narratives, and archetypes, embedding and linking the individuals in the contexts around them. (p. 62)

Viewing identity as both individual and contextual provides insight into the ways teachers' pre-pandemic, in-person teaching identities evolved during mandated online teaching as they adapted their existing knowledge through processes of identification and negotiation. *Identification* is the process through which teachers integrate new understandings into their existing identities while *negotiation* is when teachers modify their existing identities based on new understandings. Together with adaptive expertise, the processes of identification and negotiation serve as a rich theoretical basis through which to investigate experienced teachers' transformation during the COVID-19 pandemic.

The ideas of identification and negotiation are similar to the cognitive, adaptive processes of assimilation and accommodation (Piaget, 1970). In their discussion of identification and negotiation, Horn and colleagues (2008) extend Piaget's ideas in their work with pre-service teachers. Liking identity to Piaget's concept of cognitive structures, they consider the ways preservice teachers maintain or transform their identities in the face of external elements. This work has since been taken up by many scholars – primarily the idea that teacher identity formation involves the interweaving of the individual and the social (eg. Beltman et al., 2015; Stenberg et al., 2014). Together with adaptive expertise, the processes of identification and negotiation serve as a rich theoretical basis through which to investigate experienced teachers' transformation during the COVID-19 pandemic; this analysis seeks to connect teacher identity – namely identification and negotiation – with the ideas on adaptive expertise to gain understanding on how adaptive expertise can be developed.

Methods

This study extended a four-year ethnographic study of secondary mathematics teachers in urban public schools, conducted in partnership with a professional development organization (PDO). Teachers were recruited from the PDO, resulting in a convenience sample of 8 teachers (Gerson & Damaske, 2020).

Research Context

In mid-march 2020, the first documented COVID-19 cases appeared in the United States, including the city in which the PDO teachers work. Several days later, district leaders emailed teachers that schools would close for two weeks, initially with no mandated online learning. In the midst of this initial closure, teachers in this study were notified that the closure was extended through the end of the 2019-2020 school year and that continued online learning was mandated. In July 2020, all teachers in the district were notified that the 2020-2021 academic year would remain virtual indefinitely. The effects of COVID-19 on schools have had a global reach – internationally, teachers found themselves in similar positions as teachers in the US and in our study. Unique to this study, some of the burden regarding safety as well as untenable working conditions in the shift to online teaching was eased by the strong local teachers union as well as effective district leadership. One teacher, Amber (1), who was the union representative at her school described the extensive time the union spent negotiating over the summer for continued online instruction in the 2020-2021 school year with school administrators and district leadership: "I think we didn't get everything that we asked for, but we never will. I think we ended in a place that was doable for what we were about to start" (Interview 2, August 2020) – indicating the strength, influence, and support of the union. Furthermore, district leadership prioritized teacher and student safety throughout the pandemic. The teachers in this study did not experience some of the same uncertainties that others across the country have, such as having access to vaccines to go back to school in person or not having access to adequate professional development to learn new technologies (Cornish, 2021). The specific sources of uncertainty that remained – like how to be a good online math teacher – presented opportunities to study the development of adaptive expertise. For example, one of the focal teachers, Linda, explained "the fact that [reopening during the 2020-2021 school year] hasn't been a part of the narrative- it hasn't been a huge piece of the conversation has made everybody else feel better and feel like they could focus more" (Interview 4, March 2021). This supportive local context freed up emotional stress and physical time for teachers in this study to focus on transforming their teaching, making it an ideal location for the study of adaptive expertise. Further, this particular study context is compelling in the way that everyone felt like an amateur, or outsider. In interviews, experienced teachers discussed feeling like first year teachers all over again due to the overwhelming novelty of mandated online teaching. This dynamic provided a space ripe for exploration as traditional boundaries of expert-novices in research were blurred.

Participants

The participants for this study were determined through theoretical sampling and convenience sampling (Gerson & Damaske, 2020). First, participants were strategically recruited from the PDO. According to an external evaluator's report, PDO teachers typically experience higher satisfaction with professional learning, greater retention, and stronger student survey and test results than a matched control group. PDO teachers are passionate about and committed to their work, collaborate regularly, reflect on their instruction, and are seen as leaders in their schools. Recruiting exclusively from this PDO ensured that the teacher participants would be experienced and well-resourced.

In May 2020, teachers from the PDO were given the option to volunteer to participate in the study. Of the 80 teachers in the PDO, 8 elected to continue to participate. Due to this participant selection, we conceptualize this study as a best case study (Yin, 2017) for several reasons. First, the eight teachers in this study were all experienced teachers with 15 years or more teaching experience. They were seen as leaders in their schools or departments and were highly-reflective, continually seeking out opportunities to learn. Second, these teachers had a strong community of support through the professional development organization. They all reported collaborating regularly with both school-based teacher teams and colleagues in the organization. Lastly, the teachers in this sample were members of a strong teachers union and feel supported by a data-driven district superintendent. By conceptualizing this sample as a best case sample, the findings from this study can be extended to consider the contextual circumstances that enabled participating teachers to develop adaptive expertise.

Data Collection

Data for this study included interview transcripts from all 8 participating teachers, fieldnotes from participant observations of 3 of the 8 teachers' department meetings, and content analysis of relevant announcements from the district and national media coverage of education during COVID-19 (Altheide & Schneider, 2012). In this semi-structured interview study, we conducted iterative cycles of data collection and

analysis, starting with Interview 1 in May 2020 (Emerson et al., 2011). While the study concluded with a final interview in June 2021, the data for this paper are drawn from four interviews across 8 participating teachers from May 2020 to March 2021, as well as content analysis (Altheide & Schneider, 2012) and participant observation (Emerson et al., 2011). In between interviews, data from previous interviews, content analyses, and participant observations were analyzed and used to inform subsequent interview protocols.

Data analysis

Across-teacher learning analysis

Aligned with our ethnographic approach (Emerson et al., 2011), data analysis centered participants' own meanings. After each round of interviews, we identified teachers' sensemaking via open coding, consolidating themes across the interviews (Charmaz, 2008). For instance, a common (and novel) dilemma emerged around engaging kids in synchronous online lessons: should teachers require that students' cameras stay on? On one hand, cameras leave students vulnerable, since peers see into their living spaces or screengrab awkward moments to post on social media; yet without students' faces, teachers struggle to gauge engagement. Discussing such dilemmas provided insight into developing adaptive expertise as teachers deliberated on what made the most sense for different teaching situations. Cross-case comparisons enabled me to identify clusters of responses (e.g., choosing primarily cameras off) and to extrapolate conditions in which different instructional responses make sense.

Within-teacher learning analysis

Alongside group-level analysis, we analyzed individual teacher interview data and fieldnotes from participant observations of department meetings to understand how each teachers' local, school-based contexts supported the development of adaptive expertise over time. We hypothesized that different teachers' constraints and affordances make identification or negotiation more sensible, thus shaping their learning. For each teacher, we coded for statements that provided insight into their pre-pandemic teaching identities. For example, when describing his reliance on humor during in-person teaching, Ezio described "I'll toss out a corny math joke and I'll laugh at my own joke, and then the kids will laugh… so that's how my classes normally are" (Interview 2, August 2020). When we coded for identification, we looked for evidence that teachers were integrating new understandings gained from mandated online teaching into their existing, or pre-pandemic, teaching identities. When coding for negotiation, we looked for evidence that teachers had shifted or modified their pre-pandemic teaching identities based on new understandings.

Comparative Case Analysis

Throughout the data collection and analysis process, we looked at the data across all 8 participants. For this paper, we focus on three of the teachers – Linda, Brad, and Ezio – because we found that they all adapted differently. By looking across these three cases, we can get a sense of how adaptive expertise is developed. Specifically, we will discuss how Linda limited her development of adaptive expertise by not engaging in meaningful identification or negotiation, how Brad developed adaptive expertise primarily through identification, and how Ezio developed adaptive expertise through negotiation.

Findings

To explore the ways experienced teachers developed adaptive expertise, we investigated the ways that teachers responded to the dynamic and novel context of online teaching during the COVID-19 pandemic, illustrated in the following three cases. In this study, we found that the teachers' learning and development of adaptive expertise was contextual and dynamic. Specifically, some teachers were able to develop adaptive expertise by engaging in identity identification or negotiation while others teachers' development of adaptive expertise was limited. For each case, we will describe the teachers' pre-pandemic, or in-person, teaching identity. We will then describe the teachers' engagement with identification or negotiation in their attempt to adapt their current understandings. We will conclude with a description of the ways each teacher developed adaptive expertise or was limited in their development.

Case 1: Linda, Limited Development of Adaptive Expertise

During the study, Linda did not engage in identification or negotiation because of discordance between elements of her pre-pandemic teaching identity and the demands of online teaching. In interviews, Linda often discussed how the physical space of her classroom contributed to her pre-pandemic identity: "I have built a very intentional learning space that has particular things on the walls. It has particular arrangement of the tables" (Interview 3, November 2020). She often referenced the importance of physical materials in her teaching – "I teach very driven

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by the stuff on the table kind of thing" (Interview 2, August 2020), referencing yardsticks, string, scissors, and other physical materials she typically had available on student desks. Her reliance on the physical resources in her classroom was rooted in her pedagogical commitment to learning being physical, embodied, and experiential. Being unable to access these resources during online teaching left Linda at a loss for how to negotiate the demands of online teaching.

In interview transcripts, we found no evidence that Linda engaged in identification by integrating new understandings into her existing pre-pandemic identity. Because the physical space and materials were no longer available to her in virtual teaching, she couldn't integrate new understandings into this element of her existing identity. This was evidenced when she said "I'm realizing how much they're not learning because they're not marinating in the environment" (Interview 3, November 2020), or when she discussed not knowing how to teach trigonometry:

> I am absolutely at a loss for what the heck I'm going to do. Really, really confused because for the last four or five years, we start trig by actually building a trig table on the board and they don't know that's what they're doing. But then, at their tables, they're given a bunch of index cards with different angle degrees marked on it, and they're going to mark that angle and then they build a right triangle. And they measure, and we just record all of these ratios and build this giant thing by hand up on the board and then start analyzing it. And it's like, I can't get kids to draw stuff because I don't know what equipment they have. They have no protractors. They have no rulers. (*Interview 3, November 2020)*

Linda described confusion about how to teach trigonometry because she didn't have the physical materials of protractors and rulers available to them.

When looking for data that supports negotiation, we looked for evidence that Linda modified her existing identity based on new understandings. However, Linda often framed negotiation as not worthwhile. For example, she expressed a lack of desire to invest time in learning new technologies: "I just don't care that much about it to invest umpteen oodles and oodles in learning like every new widget, whatever" (Interview 3, November 2020). Further complicating her dilemma, "the idea of having this co-constructed, giant thing that we do in person, right? … I don't want to let go of it entirely because trig is confusing" (Interview 3, November 2020). Her pre-pandemic identity was rooted in the physical materials in her classroom and tied to her conception of being a good math teacher. At the same time, it was incompatible with her online teaching practices. Therefore, Linda was unable to reconcile her pre-pandemic identity with the demands of online teaching by engaging in identification or negotiation, ultimately resulting in limited development of her adaptive expertise. She recognized this limitation when she explicitly described how unsuccessful she felt teaching online:

> I feel now that I know this is not me at my best, I know this is not- the Linda in the little box is not as good as Linda in person… I've never felt so incredibly inadequate and I don't, I don't know that I would go so far as to say a fraud but certainly so far from who I want to be as a teacher. (*Interview 3, November 2020)*

Case 2: Brad, Developing Adaptive Expertise through Identification

Before the pandemic, facilitating whole class discussions was a significant facet of Brad's identity. He valued conducting whole class discussions driven by students' current understandings, motivating his monitoring of student work and intentionality in guiding students' discussions. He was still able to act on this part of his identity during online teaching: "Kids… still feel like they still have a teacher in front of them, and still allow[s] the teacher to do teacher moves in terms of looking at their responses, filtering the ones that we can have a discussion about, pausing them, and then we're going to discuss it" (Interview 1, April 2020). While he was successful in incorporating new practices and adapting his discussion practices through identification, Brad did not engage in negotiation – he was able to adapt to online teaching without negotiating his pre-pandemic teaching identity.

To investigate the ways in which Brad engaged in identification, we looked for evidence that he had integrated new understandings into his existing identity of building and eliciting student understandings in whole class discussions. We found that Brad continually developed new understandings of a technology platform, Desmos, and integrated those new understandings to *maintain* his existing identity. Desmos is a free technology that hosts digital classroom activities designed for students to "explore [math] concepts more deeply, collaborate with their peers on problem-solving, and apply knowledge creatively as mathematicians" (Desmos.com). Teachers can also develop their own classroom activities catered to their specific students and content while utilizing the tools built into Desmos for student exploration and collaboration.

Brad's incorporation of Desmos during online teaching was notably different from his pre-pandemic teaching. In person, Brad reported only using Desmos for specific lessons that were few and far between. In interviews, Brad described the new ways he utilized Desmos to meet the demands of online teaching including enabling certain features like non-math check-ins and modifying the in-person curriculum to make it more accessible to students at home, spending 10-16 hours a week converting in-person lessons to desmos. For example, he said:

> What does it look like lesson planning is basically thinking from what my lesson would look like in class and they can get into Desmos and enabling features that I think would make it easier for students, cutting out questions that I think would only be able to be done with same manipulatives or say if they were in a group setting where I could be supporting them a little more or things like that. (*Interview 1, April 2020*)

He continued to explain the ways that Desmos connected his in-person teaching identity with the novel context of pandemic teaching: "that's been my mindset, is how can I keep my lessons engaging, make [the students] learn while also figuring out the best ways to allow me to still make it feel like a classroom" (Interview 1, April 2020). Brad's pre-pandemic teaching identity involved teacher moves like looking for, listening to, and discussing students' thoughts and understandings, and transforming all of his lessons into Desmos and learning how to utilize more features enabled him to preserve this existing identity.

Brad's engagement in identification contributed to the development of his adaptive expertise – he extended his knowledge to meet the demands of online learning. Namely, he spent time incorporating new understandings of the applications of Desmos to make it possible – even easier – to facilitate the type of discussion he valued in person:

> It's like when you're hovering around a class- Desmos is actually easier to facilitate discussion than when you have a clipboard and you're like, "Ooh. James, number two you said something really cool, that's really creative." I'll call on James for question number two. I can see it right in front of me at all times, all the things kids are not understanding and things that kids are understanding and things that kids are solving in unique and creative ways. That's why I think it's worth it.(*Interview 3, October 2020*)

Importantly, Brad developed adaptive expertise through identification but not negotiation. While he adapted his teaching practice, he did so in ways that left his existing identity intact. Supported by Desmos as a mediating tool, Brad was able to adapt his practice to meet the demands of online teaching in ways that aligned with his identity rooted in eliciting and giving feedback on student understanding.

Case 3: Ezio, Developing Adaptive Expertise through Negotiation

In our final case, we found that Ezio attempted to engage in identification and developed adaptive expertise through negotiation. Prior to mandated online teaching, Ezio deeply valued discovery-based learning. At the same time, his teaching identity included not being a technology person. He reiterated this many times in interviews, saying things like "technology is not my thing" (Interview 1, May 2020). For example, in Interview 3, Ezio says "I was never the tech person. I was the old school- I had no problem- give me a chalkboard, I feel perfectly comfortable with a chalkboard and chalk" (Interview 3, November 2020). Ezio was settled in who he was as a teacher, and salient to him, this did not include incorporating technology.

Initially, Ezio attempted to engage in identification by recording in-person style lectures and resisting incorporating new technology: "This virtual world is new to me, so it was just safer. Just stick with what you do. Go ahead, lecture the whole time, lecture the whole hour" (Interview 3, November 2020). However, he came to recognize that maintaining this aspect of his identity ultimately limited his ability to adapt to online learning in a way that made him feel successful:

> And even though it wasn't effective, I guess as the days or weeks wore on, then it started getting to me. Okay, this isn't working. You're not doing your job, you're just lying to yourself when you're doing that. (*Interview 3, November 2020*)

Ezio felt particularly unsuccessful in the ways online teaching did not meet his expectations rooted in his value of discovery-based learning – he did not feel like he was meeting the needs of his students or demands of online teaching.

In response to these feelings of dissatisfaction, Ezio engaged in negotiation, modifying his existing identity based on new understandings. He described taking an entire weekend to learn Desmos. He felt so successful that he has taken up the identity of being the 'tech pioneer' of his school. When asked how he felt being considered the 'tech pioneer' of his school, he explained "It feels good… on the one hand, I feel bad for our situation in general for our teachers, but on the other hand, I'm happy. I wanted to learn more for my own class" (Interview 3, November 2020). This shift in identity to becoming the technology resource in his school was also evidenced in a department meeting with colleagues. During an observed virtual department meeting, Ezio taught his 8th grade math team members a new feature of Desmos:

> Ezio's screen is still shared, and he now goes to the Desmos website and walks the teachers through an annotation ("sketch") feature. Ms. Guo says that she would like to come to Ezio's class (virtually) during her conference (planning) period to observe him so she can "come and learn from you." Mr. Iweala says that he would like to join Friday too as he pulls up his schedule. Ezio agrees they can observe, and Ms. Guo says "thank you so much for opening your classroom so we can learn from you." (*Fieldnotes, February 2021*)

After attempting to maintain his pre-pandemic identity of not being a technology person, Ezio gained new understandings of the demands of online teaching and *modified* his identity to meet those demands. Namely, he extended his knowledge to include new technology in response to his realizing that online teaching was making him feel unproductive. For example, he said "I'm using Desmos a lot more in my classroom… I just feel more productive now. I have something to build from. Not that I'm doing everything perfect in Desmos, but I'm learning as I go along" (Interview 3, November 2020). Initially, Ezio identified as "not a tech person" and attempted to engage in *identification* to adjust his practices in line with this identity. However, he then *negotiated* this aspect of his identity to become the "tech pioneer" of his school, further adapting and transforming his practice to meet the demands of online teaching.

Discussion

This study provides insights into how the field can better understand experienced teacher learning through the concept of adaptive expertise. Theoretically, this paper contributes to a richer understanding of adaptive expertise by examining its development through the lens of identification and negotiation. Practically, this study highlights the ways that supportive district leadership, strong union presence, and resources for collaboration provide a context for experienced teachers to reflect and adapt to new and novel situations. While we certainly hope that the findings are not used to inform teacher learning during a future international pandemic, we conceptualize this study as an extreme case (Yin, 2017) for understanding how teacher learning environments can be designed to support the development of adaptive expertise in less extreme, post-pandemic learning contexts. In this spirit, the findings contribute to the fields' understanding of teacher learning processes by investigating the different ways that Linda, Brad, and Ezio engaged in identification or negotiation in response to the dynamic and novel context of online teaching. Aligned with our situative view of teacher learning, each case highlighted the contextual and flexible nature of teachers' knowledge. Specifically, we have described how Brad and Ezio developed adaptive expertise by engaging in identification and negotiation while Linda's development of adaptive expertise was limited.

We found that all teachers in this study were supported to attempt adaptations to online teaching by the insulated support of district leadership as well as the influence and presence of the teachers union. By removing many external uncertainties, teachers were able to devote their focus on their teaching practice. This kind of support can be valuable in creating learning environments ripe for ongoing teacher learning; whether in a global pandemic or not, teachers negotiate countless institutional and local demands. We show that experienced teachers' sensemaking and learning can be better supported by alleviating these stresses.

There is also a lot to be learned from our focal teachers. Brad and Ezio both developed adaptive expertise in different ways as they incorporated Desmos into their online teaching practice. Although Desmos aligned with Brad's existing identity, supporting his identification, Desmos did not align with Ezio's existing identity. His attempts to integrate online teaching practices into his existing identity made him feel unsuccessful, motivating him to seek out something different and engage in negotiation. Similarly, Linda too felt unsuccessful in engaging in identification. Her lack of engagement in the process of negotiation indicated that this was a place in which she may have benefitted from additional support.

Taken together, our three focal cases illustrate how teacher learning can be studied and supported through the lenses of identification and negotiation and underscore the centrality of identity. On the one hand, when teachers' identities are thoughtfully considered, teachers can be supported by resources that align with their

identities to foster identification. On the other hand, teachers may also need to be supported to negotiate aspects of their identity that are incompatible or unproductive with their particular teaching context. It is important to note that the pre-pandemic identities described in this paper are not the teachers' only identities. Our conception of identity as socially and contextually constructed (Horn et al., 2008) suggests that the identities of these teachers are multifaceted and dynamic. Indeed, the teachers in our study both developed adaptive expertise and were limited in this development with respect to the identities described here, but they also exhibited entirely different adaptive practices with respect to other facets of their teaching identities. Further research is needed to explore the interplay of the multiple elements of experienced teacher identities and how they contribute to ongoing teacher learning.

Endnotes

(1) All proper names are pseudonyms.

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International Society of the Learning Sciences

A Learning Experience Design Approach: Investigating the Mediating Roles of Situational Interest and Mind-Wandering in Children's Online Engagement

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Abstract: Historically, learning for young students has occurred in formal, in-person classroom environments, but the distance learning context has opened a myriad of learning modalities. To this end, we aim to better understand how deploying learning experience design (LXD) approach supports or hinders children's engagement while participating in an online, video-based math course. This study operationalized LXD through the integration of evidence-based pedagogical instructional design and human-centered user experience (UX) design. Findings suggest that students' situational interest and mind-wandering significantly mediate the relationship between user experiences and online engagement. These results provide practical implications for how researchers, designers, and instructors can intentionally iterate the learning experience to reduce mind-wandering and sustain children's online engagement with learning theories as we consider the future of online teaching and learning modalities.

Introduction

The field of teaching and learning has rapidly undergone a major shift over the last two years of distance learning through the COVID-19 pandemic. The pandemic abruptly caused shifts in workflows across many sectors, and education specifically was required to fundamentally modify course delivery infrastructures. COVID-19 necessitated a systematic change in course delivery due to the nationwide orders of social distancing to mitigate spread, resulting in the suspension of in-person instruction (Ferrel & Ryan, 2020). For many educational institutions, transplanting the same in-person teaching through synchronous Zoom meetings may have been sufficient. However, it was always intended to be a short-term emergency solution that while facilitated the continuance of teaching and learning, is still distinctly different to online learning experiences grounded with evidenced-based pedagogical learning design.

Zoom certainly facilitated teaching and learning, but it also brought concerns of student disengagement, lack of interest, and validity from both the instructors and the student perspectives (Son et al., 2020; Unger & Meiran, 2020). At the same time, students described issues related to technical difficulties, increased distractions, and decreased motivation, with emergency remote distance learning through Zoom—all of which are critical contributors affecting the student learning experience (Agarwal & Kaushik, 2020; Fawaz & Samaha, 2021). As a result, this study documents the efforts to shift from synchronous Zoom courses to design, deploy, and document the impacts of an online math course grounded in the learning experience design (LXD) framework to examine children's frequency to mind-wandering and online engagement.

Learning experience design (LXD) refers to the creation of learning situations that extend beyond the formal classroom learning environment and which often utilize online and virtual technological formats (Ahn, 2019). LXD is the process of developing effective learning experiences that enable learners to reach a specified learning outcome in a human-centered goal-oriented method (Floor, 2018). Weigel (2015) further defines LXD as an interdisciplinary synthesis of instructional design, teaching pedagogy, cognitive science, learning sciences, and user experience design. As such, LXD broadens our definitions of what is to be considered a learning experience, affording instructors, designers, and researchers the opportunity to empathize with learners and develop experiences that expand our learning design toolbox (Ahn et al., 2019; Weigel, 2015).

In the context of our study, we operationalized LXD by grounding our online course in learning design frameworks and ensuring quality user experience design. We also explored the connection between students' situational interest and students' mind-wandering as a result of our LX designs within a learning environment, supporting or hindering students' online engagement. Courses designed with the LXD paradigm are relatively new, and this study provides insight into evidenced-based asynchronous online learning environments grounded in LXD as a feasible learning modality for children learning math. To this end, we aim to better understand how our design efforts foster children's' engagement while participating in an online grounded in the LXD paradigm.

Theoretical approach towards learning experience design

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The following sections provide an overview of the literature on engagement, mind-wandering, situational interest, and user experience examined, which ultimately serves to theoretically ground our analytic model. Situational interest was identified as a potential source of mind-wandering that may positively or negatively mediate the relationship of students' online engagement. Further, a critical factor influencing students' levels of situational interest is the medium of learning and the quality user experience that medium evokes. Limited studies have examined the interrelation of such specific constructs, even less so during a crisis learning context, warranting analysis. Reviewing these key bodies of literature thereby informs the basis of our hypothesized model to characterize the student learning experience by examining the effects of students' situational interest and mind-wandering mediating the relationship between students' user experience influencing their online engagement.

In education, student engagement is defined as the amount of student effort or active participation needed to complete a learning task (Richardson & Newby, 2006). In an online course, engagement can be further described as the attention, curiosity, interactivity, and interests students exhibit during an instructional unit, which further extends to the level of motivational traits students may have during the learning process (Pellas, 2014). Research in online learning attributes increased student engagement to quality instructional design (Pappas, 2015), student user experience with the interface (Hu, 2008), and student motivational factors (e.g., interest, self-efficacy) that can emerge as a result of the learning environment (Sun et al., 2012). When learning interfaces are difficult to navigate, uninteresting, or unengaging, studies have shown that this will likely lead to negative learning experiences such as increased mind-wandering, or the direction of attention away from a primary task (Desideri et al., 2019). Thus, we focus our design efforts onto ensuring quality instructional design to foster students' interests and strong user experience in order to maximize students' participation and degree of interactivity.

Mind-wandering or the colloquial term "zoning out," is defined as the shift of an individual's attention away from a primary task at hand and towards other internalized information (Smallwood & Schooler, 2006). Another way to describe mind-wandering is the human experience of drifting into thoughts away from the "here and now" (Smallwood & Schooler, 2006). Unlike being in a state of focus, mind-wandering is considered an off-task processing state such that the individual experiences an attentional lapse (Danckert, 2018). Mind-wandering is more likely to occur during monotonous environments (Eastwood et al., 2012) or long cognitively undemanding tasks (Smallwood & Schooler, 2015). Conrad and Newman (2020) conducted a mind-wandering study on students during the COVID-19 pandemic and found that students with greater instances of mind-wandering during long continuous Zoom class sessions had lower achievement scores. Considering that "Zoom" classes typically represent a low cognitively demanding task, often plagued by boredom, frustration, and lack of engagement (Katz & Kedem-Yemini, 2021) identifying potential detrimental factors that contribute to mind-wandering may be essential to better support students' learning (Randall, 2015; Smallwood & Schooler, 2006).

Since mind-wandering indicates a fault in information processing, where external task-related information shifts towards processing internal task-unrelated information (Smallwood & Schooler, 2009), this attentional shift is theorized to be a decoupling process between the task (external information) and the existing mental model (self-generated thoughts) of the individual (Mills et al., 2013; Smallwood et al., 2007). The Current Concerns Hypothesis suggests that mind-wandering occurs when intrinsic or extrinsic reinforcement where thinking about other personal goals outweighs the reinforcement for processing primary task goals (Klinger, 2009). Taking this into account, students' personal values in a teaching and learning context might be assessed by considering students' situational interests while engaged in a learning experience.

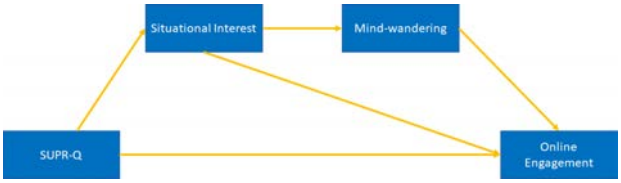
Situational interest (SI) refers "to the interest activated by the immediate learning environment" or the interest given the novelty aspect of a learning task (Schraw & Lehman, 2001). Past research indicates that situational interest is a powerful motivator in areas of math, reading, and history, when learner participation and interaction throughout the entire learning process is sustained (Chen et al, 2001). While situational interest and student engagement have been widely evaluated in the context of traditional in-person learning activities (Sun et al, 2012), less is understood about how to facilitate situational interest for young students in online learning environments while also reducing the onset of students' mind-wandering. We hypothesized that operationalizing the LXD learning design paradigm may aid in our juncture of supporting elementary students adopting an asynchronous online learning modality.

As SI refers to the interest activated by the learning environment, user experience can be seen as a measure linking the learner's experience of a specific learning interface and their interest in learning as a result of this utilizing this medium. Broadly defined, user experience (UX) is "the extent to which a product can be utilized by specified users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO 9241-11, 1998). In an online course, UX refers to the effectiveness of the learning interface and whether or not a student can successfully interact with the course platform to accomplish an intended task. Learning environments with strong UX redirect students' efforts towards the learning task, rather than learning how to access the content. This shifts the researcher and instructor's perspective from only focusing on instruction,

to also considering the deep understandings of learners, what they need, what they value, their abilities, and the limitations of the learning interface. As such, UX aims to create a positive student learning experience through content accessibility, interest, and design —all of which are significant predictors of student engagement in online learning environments (Thomson & Lynch, 2003).

The Situated Cognition Theory (SCT) instructional design framework was chosen to facilitate students' interests (Ghefaili, 2003) and inform the design of effective e-learning experiences while young students acclimate to distance learning. Centered around the notion that "learning" is inseparable from "doing," we adopted this framework so that learners could grasp the concepts and skills that are taught in the context in which they will be utilized (Brown et al., 1989). In practice, SCT emphasizes immersive learning environments, where new information is taught to learners in a way that simulates real-life settings. We operationalized this by using pre-recorded videos of a real-world math lesson taught by a teacher to students in a real classroom, and embedding interactive opportunities for modeling, coaching, scaffolding, articulation, reflection, and exploration (Pappas, 2015). Through this learning framework, students watched bite-sized video segments of real classroom interactions between a teacher and students, immediately practiced what they have learned through scaffolded problem scenarios, and provided written reflections on how they solved each math problem. As such, we implemented the SCT e-learning design framework to foster a deeply situated learning environment for students to actively develop interests, reduce instances of mind-wandering, and engage contextually within the online learning environment.

Figure 1. Hypothesized model for SUPR-Q (user experience), situational interest, mind-wandering, and online engagement.



Current study

Young students over the past two years have adapted to using a myriad of "edtech tools" to facilitate teaching and learning, in some cases adopting completely new modes of learning, facing new unforeseen learning challenges with the change in learning modalities (Agarwal & Kaushik, 2020). Building off the beta iteration of this online course deployed previously at the height of the pandemic (Wong et al., 2021), we gleaned the affordances and constraints identified by student commentaries to inform the design improvements of this current study to support children's online learning experience. One salient theme identified from our previous study was the notion of sustained engagement and mind-wandering while learning online (Wong et al., 2021). In this study, we employ evidence-based pedagogical LXD as a lever to support students' situational interest (SI) and ensure human-centered user experience (UX) design to alleviate technical worries related to distance learning. We then further explored the combination of situational interest and user experience predicting students' engagement, while considering the impacts of our design as a potential mechanism to reduce students' frequency to mind-wander in an online course grounded with learning experience design. This study is guided by the following research questions: (RQ 1) *To what extent do students' user experience, situational interest, and mind-wandering directly affect students' online math engagement?* (RQ 2) *To what extent do students' mind-wandering and situational interest mediate the relationship between students' user experience and students' perceived online math engagement?* (RQ 3) *To what extent does situational interest and mind-wandering sequentially mediate the path from students' user experience to online math engagement?*

Methodology

Course design context

We first worked with teachers to align with their existing Common Core State Standards (CCSS) math lesson plans. After understanding how we could best support teachers in the classroom, we then proceeded to co-develop the video lesson. Teachers, researchers, and course designers worked collaboratively to develop a script introducing ratio and proportions. Then, the instructional videos were recorded as a live, semi-scripted lesson on proportional reasoning taught by a teacher in a diverse class of fifth- and sixth-grade students. Utilizing multi-camera video production, one camera focused on the teacher, the second camera captured the teacher and the whiteboards, and the third camera captured only the students. These camera angles allowed for post-production

manipulations, directing students' attention to specific camera angles for increased engagement. During the editing process, we employed a reform-based instructional model in which the teacher first asks the students to solve a challenging proportional reasoning problem on their own, prior to receiving explicit instruction (Schwartz et al., 2011). Next, the teacher strategically chose students using the target solution strategies to describe their strategy to the class. Following each student, the teacher-led a discussion on the procedures and higher-level conceptual overview of each respective target strategy: the equivalent fraction strategy and the unit ratio strategy.

Cognizant of the research behind effective user experience (UX) and instructional design (ID) in self-paced courses, these online modules were designed to be flexible and learner-paced, enabling students to start on their own time and work through the course at their own speed (Richardson et al., 2016). In addition, intentional design choices were made to maximize digital interactivity, reduce mind-wandering, and learner engagement. More specifically, an hour-long video lesson was segmented into ten parts instead of one long continuous stream to reduce fatigue, cognitive load, and opportunities for students to mind-wander (Mayer, 2019). Scaffolded problem sets (worked examples) were specifically placed in between video segments for students to practice problems immediately after learning. These types of problems scaffold novice learners by drawing attention to the structural similarities in the lesson to ensure students attend to the key ideas, concepts, and relationships in practice (Begolli & Richland, 2016). For example, students were first asked to recall strategies they observed from watching the videos. Next, students plugged in the procedural steps to solve the math question. Then, students were asked to compare their procedural steps with model example strategy solutions. Video animations that displayed the sequential ordering of mathematical procedures called "worked examples" were added to enhance the visual representations and conceptual comparisons across solution types. This allowed students the option to review and crystallize the different solution strategies prior to moving on to the next problem. After making comparisons across problem types and strategies, students would solve the math problem by assessing their conceptual understanding. Lastly, solution reflections were embedded within each problem scaffold for students to explain, in their own words, how they solved each math problem with their chosen solution strategies. This design choice enabled students to actively engage in their own productive metacognitive judgments and reflect on "how and why" they arrived at their solutions, which has been found to foster learner responsibility, increased test preparation, and review and practice (Tullis & Benjamin, 2011).

Careful considerations were made to ensure that the course interface facilitated quality user experience design. For example, course roadmaps, course goals, and navigational instructions were clearly "highlighted" and "boxed in" to promote learner ease of use and findability within the online learning environment. Additionally, standardized vector icons were utilized before every instructional type, allowing students to differentiate between interface instructions as opposed to lesson specific instructions. A table of contents and progression bar was added to let learners know their progression within the course. Each video also had instructions clearly stating how to pause, play, and re-watch. These UX design choices were made to mitigate visual complexities, technical difficulties, and allow users to focus on the content most relevant for the task at hand. The ability to click backwards in the course was activated for students to freely navigate the course space with more autonomy. This design change was incorporated to account for students potentially making mistakes or clicking through the online course too quickly. Another recommended addition to the course was to include explicit breaks from the math problem sets by asking fun and engaging pop-up questions with GIFs that students could freely respond to. Since our math lesson was immersed within the theme of cooking recipes, these GIFs and accompanying questions asked students about what they might be baking or cooking at home and how these proportional reasoning concepts might be applied in their everyday lives. While maintaining the theme of our lesson, this presented break opportunities for students to share what they were doing during shelter in place and express how these math concepts might be applied in a non-academic context. Through these iterations, an array of design decisions grounded in LXD principles were implemented to co-develop this online-video math course, with the goal of integrating elements of a real classroom and interactive features of an online learning environment in order to maximize students' online engagement while reducing the frequency of students' mind-wandering through the rapid co-design of an online math course.

Data collection and analysis

We recruited 5th and 6th grade teachers from two school districts in the Orange County area. A total of three 5th grade teachers, six 6th grade teachers, and one 5th/6th grade combination class teacher agreed to be a part of the study. There was a total of 12 classes and each classroom had between 26-33 students. Of the (N = 303) students who participated, 56.1% of the participants identified as female and 42.6% identified as male. Student ages ranged from 10 to 12 years old, with a large majority of students being age 10 (42.6%) and 11 (55.7%). This sample consisted of children from a variety of racial/ethnic backgrounds (22.6% White, 3.8% Black, 1.1% Native American, 17.7.1% Asian, 1.1% Native Hawaiian, 21.0% Latinx/ Latino, 27.19% other, 4.8% Mixed).

We administered five questionnaires during Part 2 of the study. This included the Situational Interest Scale (Chen et al., 2001), which measured students' levels of interest in the specific online mathematics lesson we distributed, the Standardized User Experience Percentile Rank Questionnaire (SUPR-Q) (Sauro, 2015), which examined students' experiences with the online platform, and the perceived online engagement scale which measured students' engagement within the online learning experience (Rossing et al., 2012). These three measures were 5-point Likert Scales ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Lastly, students' mind-wandering was measured using the Mind-wandering Questionnaire (Mrazek et al., 2013) designated on a 6-point Likert scale, 1 (almost never) to 6 (almost always).

Data were analyzed using SPSS to conduct scale reliabilities, descriptive statistics, missing data analysis, correlations, and AMOS 26 for structural equation modeling. Scale reliability checks were conducted to verify the Cronbach's alpha coefficients for all of the validated instruments used in this study. Cronbach's alpha coefficients greater than $\alpha = 0.70$ were considered acceptable levels of reliability (Nunnally, 1994). Measured variables were analyzed by first recoding the Likert questions followed by computing descriptive statistics of the items associated with each instrument. Full information maximum likelihood (FIML) was utilized as the missing data estimation approach to account for data missing at random, maximizing the case-wise likelihood of the observed data (Carter, 2006). Preliminary analysis tested assumptions of sample size, multivariate normality, linearity, and multicollinearity of the variables of interest. Bivariate correlation analysis evaluated the linear relationships between the different study variables. Lastly, AMOS was used to conduct a path analysis using the maximum likelihood estimation (MLE) in order to analyze the hypothesized research model (See Figure 1). More specifically, we conducted a covariance-based path analysis, a subset of structural equation modeling (SEM), to examine a simple mediation and sequential mediation within the same model to investigate our research questions with measured variables (Lleras, 2005). Fit indices such as the goodness of fit test conformity (Chi-square statistic), the goodness of fit index (GFI), comparative fit index (CFI), normed fit index (NFI), and the root mean square error of approximation (RMSEA) were calculated (Kline, 2012). Lastly, unique direct and indirect effects were analyzed to examine the factors influencing students' mind-wandering and online engagement.

Findings

Descriptive statistics and correlations for the measured data (Perceived Learning Engagement, Situational Interest, Mind-wandering, and SUPR-Q scores) are provided in Table 1. In addition, the reliability estimates (Cronbach's alpha) of all the adapted scales are shown in Table 1. All of the measures were reliable based on the widely accepted recommendation of a Cronbach's alpha of .70 (Nunnally, 1978).

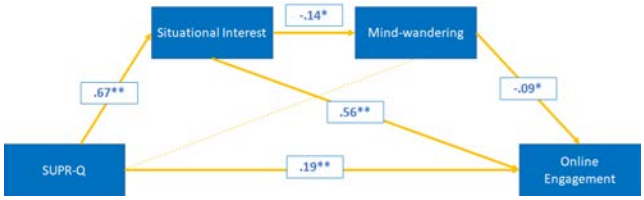
Table 1: Descriptive Statistics and Correlations for Study Variables (N = 303) **. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed).

Scale	1	2	3	4
SUPR-Q	—			
Situational Interest	.67**	—		
Mind-wandering	-.18**	-.14*	—	
Perceived Engagement	-.58**	-.70**	-.20**	—
Cronbach Alpha (α)	.87	.92	.83	.72
Mean	3.91	3.47	1.65	3.23
SD	.68	.74	.82	.89
Skewness	-.93	-0.69	1.66	-.02
Kurtosis	-2.45	.76	5.94	.14
Tolerance	.54	.55	.97	—
VIF	1.86	1.83	1.03	—

In the initial examination of the path analysis, we tested a fully saturated hypothesized model, analyzing the conformity indices and direct effects of user experience, situational interest, and mind-wandering influencing students' online engagement. The $\chi 2$ conformity index of the model was significant $\chi 2$ (1, N = 303) = 4.419, p = 0.036. A non-significant p-value is typically required to prove a high level of conformance; however, this is highly sensitive to large sample sizes (Hoyle, 1995). As such, the Root Mean Square of Approximation (RMSEA) was calculated to accommodate for the slightly significant chi-square statistic due to the large sample size. In this initial model, the RMSEA was 0.061 where values of < 0.08 indicate a good fit, with values closer to 0 representing a perfect fit (Kline, 2015). To determine the square root of the difference between the residuals of

the sample covariance matrix and the hypothesized model (Kline, 2005), the SRMR was calculated to be 0.028, with the recommended cut-off value of less than 0.08. Lastly, the GFI, CFI, TLI, and NFI was calculated to be 0.992, 0.992, 0.950, and 0.989, respectively. Index values of 0.95 or greater represent acceptable conformity (Schumacker & Lomax, 2004). Estimating the structural β coefficients of the model provided the statistically significant pathways on all variables measured. As such, a model re-specification was not necessary, and the hypothesized model was selected as the final model.

Figure 2. Standardized structural regression model for SUPR-Q (quality of user experience on website), situational interest, mind-wandering, and online engagement for sample (n=303). *Note*. **.Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed). Dotted lines represent non-significant path.



After determining the model conformity indices, the standardized beta coefficients of the direct effects were further examined. A summary of the effects can be found in Figure 2. The standardized coefficients can be interpreted as a change in units of standard deviations. For example, a 1 unit change in SUPR-Q is related to 0.193 increase in standard deviations for online engagement. Consistent with our predictions, we found that both students' SUPR-Q (user experience) ($\beta = 0.193$, $p < 0.01$) and students' situational interest ($\beta = 0.558$, $p < 0.01$) had significant positive direct effect on students' online engagement. Furthermore, students' mind-wandering ($\beta = -0.088$, $p < 0.05$) had a significant negative direct effect on students' online engagement. Altogether, students' user experience, situational interest, and mind-wandering together accounted for 51.7% of the explained variance in students' online engagement ($R^2 = 0.517$). We also found that students' situational interest ($\beta =- 0.136$, $p < 0.01$) had a significant negative direct effect on students' mind-wandering, accounting for 1.9% of the explained variance in students' mind-wandering ($R^2 = 0.019$). Lastly, we found that students' SUPR-Q ($\beta = 0.674$, $p < 0.01$) had a significant positive direct effect on students' situational interest with it accounting for 45.5% of the explained variance ($R^2 = 0.455$)

As the aforementioned direct effects were significant, the simple and sequential mediating effects of students' situational interest and mind-wandering were examined. To evaluate these mediation effects, we first examined the significance of the simple (mediated) indirect effects of students' situational interest on (1) students' SUPR-Q and students' mind-wandering and (2) students' SUPR-Q and students' online engagement. Next, we examined the significance of the indirect effects of students' mind-wandering on students' situational interest and students' online engagement. The standardized indirect (mediated) effect of students' SUPR-Q on students' mind-wandering was ($\beta = -0.092$, $p < 0.05$). In addition, the standardized indirect effect of SUPRQ mediated by situational interest on students' online engagement was ($\beta = 0.384$, $p < 0.01$). Next, we evaluated the significance of the simple mediation effect of mind-wandering on situational interest and students' online engagement. The standardized indirect (mediated) effect of situational interest on online engagement was ($\beta = 0.012$, $p < 0.05$). Lastly, we examined the cascading relationship of students' user experience indirectly related to students' online engagement through the sequential mediating effects of situational interest and mind-wandering. The standardized direct effect of students' SUPR-Q on SI ($\beta = 0.674$, $p < 0.05$), SI on MW ($\beta = -0.136$, $p < 0.05$), and MW on Engagement ($\beta = -0.088$, $p < 0.05$) were all significant. As a result, the standardized indirect (mediated) effect of students' SUPR-Q on students' online engagement was ($\beta = 0.008$, $p < 0.05$). The standardized total effect of SUPR-Q on SI was ($\beta = 0.674$). The standardized total effect of SI on MW was ($\beta = -0.136$). The standardized total (direct and indirect) effect of MW on PLE was ($\beta = -0.088$). The standardized total effect of SI on PLE was ($\beta = 0.570$). The standardized total (direct and indirect) effect of SUPR-Q on MW was ($\beta = -0.092$). The standardized total effect of SUPR-Q on PLE was ($\beta = 0.577$). These results suggest the partial mediation of the association between students' user experience and online engagement through situational interest and students' frequency to mind-wander.

Conclusion, implications, and limitations

During this unprecedented time, LX designers have the challenge to not only develop learning environments that increase conceptual understanding by drawing on theories of learning sciences, but also create experiences that

are interesting, engaging, and human-centered to support a broad range of learners given the disruptions to teaching and learning. This affords a unique opportunity to deploy online courses that are grounded in evidence-based pedagogies to further validate the utility and efficacy of online learning as an effective mode of learning in its own right that may have been plagued by Zoom teaching methods. As LX designers, educators, and researchers, we must be conscientious of students' dynamic learning contexts and the impacts of their surrounding environment to empathize with young students' needs while developing educational interventions (Seymour, 2020). Thus, by collaborating with teachers directly, codesigning the online video lessons to fit the classroom curricula and assessing the needs of teachers and their students while distance learning, we co-developed a video-based online math course to explore how best to support students' engagement through LXD.

More specifically, this study operationalized LXD through the combination of instructional design as a lever for promoting students' situational interest (SI), emphasis on human-centered design to support students' user experience (UX), and the combination of situational interest and user experience to reduce students' mind-wandering and foster student engagement in an online learning environment. Interestingly, our analyses suggest that students' situational interest and user experience while interacting with the online learning interface were significant predictors of students' online engagement. The results also reveal that situational interest and mind-wandering were significantly corelated to students' online engagement. Thus, when analyzing the indirect pathways, we confirmed our hypotheses that students' mind-wandering and situational interest as significant mediators explaining the relationship between students' user experience in the course and their online engagement. Furthermore, we identified sequential mediating effects of students' user experience to engagement through situational interest and mind-wandering.

These findings illuminate our understandings of the application of LXD, suggesting a potential underlying mechanism explaining our LX design impacts on learners' course experience and course engagement. On average, we documented that students who experience high user experience within the learning environment, show greater situational interest within the math course, and ultimately show greater instances of course engagement. The results also suggest that students' situational interest positively effects their level of engagement, when factoring in how much students' mind-wander. By preserving the ecological validity of the classroom environment in the instructional videos, students were able to follow along with the teacher and immediately practice the math concepts. This may be one factor in the course design that increases students' situational interest and reduces students' mind-wandering, as it provides a similar in-person learning context of the classroom while also utilizing the key affordances of asynchronous online learning (Begolli & Richland, 2018). Careful attention to the course usability aimed to promote quality user experience design by facilitating ease of use, findability, and navigability (Simunich et al., 2015). Additionally, to maximize opportunities for engagement, knowledge checks, scaffolded problem sets, math animations (worked examples), and math reflections were embedded within each math problem to guide students through sustained participation and interactivity. These user experience design decisions afforded students the opportunity to recognize their initial understandings of the math concepts and allow students to review and practice by navigating backwards or replaying a video. As such, students were able to actively take control of their learning pace and adapt their learning behaviors to mind-wander less and stay engaged in the course content. Thus, quality user experience and the degree of interaction between learners and the online learning environment are consequential to supporting students' engagement in an online learning environment. These findings suggest that the LXD paradigm of combining evidenced-based pedagogical learning design and human-centered user experience design as a feasible approach to generate interest, reduce the onset of mind-wandering, and increase engagement in asynchronous teaching and learning with children.

While the results of this study are correlational which serves as a limitation, there are important theoretical underpinnings and practical implications that support children's motivational, cognitive, and behavioral factors that can be applied to online teaching and learning immediately. As referenced earlier, emergency remote online learning is fundamentally different from online courses designed with evidence-based theory and practice. However, this presents a unique opportunity to further research and identify how instructors can better support their student's learning experience, as the remote learning context has paved the way for alternative learning modalities. Based on our study findings, we have learned that students' engagement is, in part, explained by their user experience with the learning platform, and mediated by situational interests and mind-wandering. These results are important as it affords instructors to consider the LXD paradigm to better attend to factors that positively impact students' mind-wandering and online engagement. Thus, our study makes an important contribution to building and clarifying learning theories with educational technologies, as it suggests design factors contributing to students' user experience and situational interest together with mind-wandering mediates students' online engagement. Moreover, these results add to our understandings of students' learning experience during emergency remote distance learning, which will serve as a foundation for future experimental research iterations to implement online LX design principles. As the landscape of teaching and learning continues

to evolve with expanded learning options, this research provides insights into LXD as a feasible pedagogical model and suggests design facets that may be implemented in-person and through hybrid modalities in the future.

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Epistemic Games with Emergent Systems Microworlds

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Abstract: This paper is about designing learning environments that support students' epistemically agentic participation in a science classroom. We use Collins and Ferguson's idea of *epistemic games* to investigate students' participation and learning with an Emergent Systems Microworld (ESM)-based learning environment. ESMs are computational models that are designed using agent-based representations and constructionist design principles. Qualitative analysis of student responses to embedded curricular questions reveals different epistemic games they engaged in using the ESM. An in-depth analysis of an epistemic game demonstrates how agent-based representations supported student investigations of a phenomenon related to natural selection. The findings illustrate how ESM-based learning environments can support students' agentic participation in epistemic games to make sense of emergent phenomena.

Introduction

Science educators, science education researchers, and designers of learning environments have argued that student participation in science classrooms should go beyond 'knowing about' disciplinary ideas in science and the practices of scientists and include authentic participation in scientific inquiry practices to 'make sense of the world' (Chinn & Malhotra, 2002; Miller et al., 2018; Scardamalia & Bereiter, 1991; Schwarz et al., 2017). To design for such authentic and epistemically agentic participation, we build on two design theoretical frameworks, constructionism (Papert, 1980) and agent-based models to investigate and learn about emergent systems phenomena (Wilensky, 2001; Wilensky & Rand, 2015).

We use 'epistemic games' as a theoretical construct in this paper to analyze students' participation in the learning environment that we designed. The notion of epistemic games is inspired by Collins and Ferguson's conceptualization of epistemic games (Collins & Ferguson, 1993). Another commonly used conceptualization of epistemic games in the field of Learning Sciences is Shaffer's framework of epistemic frames and games (Shaffer, 2006). Though there are similarities between these conceptualizations at the fundamental level - both are about strategies related to knowledge construction - their operationalizations differ. Collins and Fergusson define epistemic games as strategies and rules that practitioners of science use for constructing knowledge about natural phenomena whereas Shaffer's work is about educational role-playing games which are framed as epistemic games (Arastoopour & Shaffer, 2013; Collins & Ferguson, 1993). In our work, we use Collin and Fergusson's definition in the context of science education. We frame students' epistemic games as strategies that they use to investigate and construct knowledge about natural phenomena in a learning environment designed for this purpose.

In this paper, we study students' epistemic games in a type of learning environments, which we call *Emergent Systems Microworlds (ESM)-based learning environments* (Dabholkar et al., 2018). These learning environments use ESMs which are agent-based computational models that are designed as interactive constructionist microworlds (Edwards, 1995; Papert, 1980). We use the term ESM-based learning environment to include an ESM, curricular activities, and pedagogical practices. We investigate how students engaged in different epistemic games and how that engagement supported their learning of disciplinary ideas. We also investigate how agent-based representations used in the ESM supported learning of an emergent phenomenon modeled in the ESM. We first discuss theoretical and design frameworks that informed this work, which we see as our contributions to approaches for designing learning environments. Then we present our findings and discuss how they demonstrate the effectiveness of our design approach for supporting students' agentic learning.

Theoretical Frameworks

Epistemic Forms and Games

The theoretical framework used in our analysis is inspired by Collins and Ferguson's notion of epistemic forms and games (Collins & Ferguson, 1993). Epistemic forms are the target structures that guide a scientific inquiry, and epistemic games are the rules and strategies that researchers use to generate epistemic forms. A metaphor that Collins & Ferguson (1993) use is the game tic-tac-toe. The nine squares form a target structure to be filled and thus determine the epistemic form. The rules that players follow and the strategies they use to place crosses and noughts (Xs and Os) are part of the epistemic game. Epistemic forms are generative frameworks with slots and

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constraints regarding filling those slots. The desired result of an epistemic game is to complete a target structure that corresponds to a particular epistemic form. For example, making a list of invasive species in a particular habitat is an epistemic game and the target epistemic form is *the list* itself. In this paper, we use these notions in a novel approach to inform the design of learning environments and analyze student learning with those curricula.

Agent-based restructurations

Another theoretical framework that is used for the design of the ESM-based learning environment is called the theory of restructurations (Wilensky, 2020; Wilensky & Papert, 2010). The theory of restructurations is about investigating how new representational forms reformulate knowledge in various disciplines often with dramatic effects. Agent-based modeling of emergent systems is an example of restructuration and consequently one of the central design features of an ESM. Dynamic computational agent-based representations are restructurations of emergent phenomena. While these are typically taught with differential equations or static models (Wilensky & Papert, 2010), the power (the analytical power to express and investigate an emergent phenomenon) and learnability (cognitive, social, affective, and diversity) properties of agent-based representations make them effective for investigating and learning about emergent phenomena.

Design Framework

Emergent Systems Microworlds

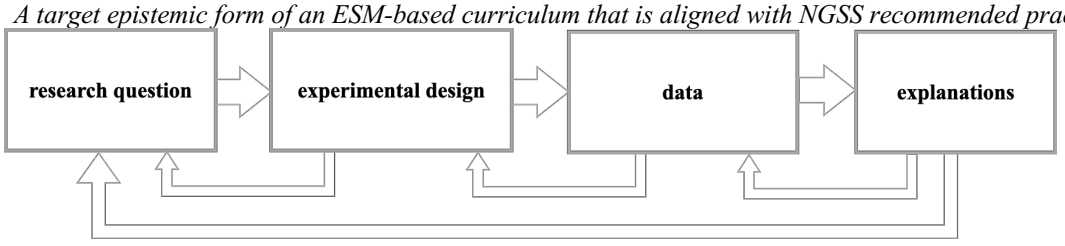
The ESM design framework combines agent-based modeling and constructionism and is inspired by similar prior work (for example, see Wilkerson-Jerde & Wilensky, 2010) and a related design framework called Emergent Systems Sandboxed (ESS) (Brady et al., 2015). The framework for design of ESMs and ESM-based curricula draws its theoretical foundations from Wilensky and Papert's theory of restructurations (Wilensky, 2020; Wilensky & Papert, 2010). In addition to using agent-based restructurations, ESMs are designed as interactive microworlds for students to explore and investigate phenomena (Dabholkar et al., 2018). A microworld, which is a constructionist design concept, is an encapsulated open-ended computational exploratory environment in which a set of ideas can be investigated that lead to knowledge construction (Edwards, 1995; Papert, 1980).

Epistemic form and epistemic games with an ESM

We use the Epistemic Forms and Games theoretical framework to analyze an ESM-based learning environment designed for students to engage in epistemic games to generate a desired epistemic form (Collins & Ferguson, 1993). The Next Generation Science Standards (NGSS) pushes for the learning of practices in disciplinary contexts, which can take various epistemic forms (NGSS Lead States, 2013). We developed one such form for pedagogical purposes, which we have used to design an ESM-based curriculum (Figure 1).

Figure 1

A target epistemic form of an ESM-based curriculum that is aligned with NGSS recommended practices.



This target structure in an ESM-based curriculum often takes the form of what Collins and Fergusson refer to as process analysis (Collins & Ferguson, 1993). Process analyses attempt to characterize behaviors of dynamical systems. ESMs are models of a dynamic complex system that provide easy access to visualization and investigation of emergent patterns that arise from agent interactions. Users have visual access to agent-level interactions and system-level emergent patterns. As evidenced in the data that we present later in this paper, when students use an ESM to engage in this epistemic form (Figure 1), their explanations about emergent properties of a system (such as a change in a population because of natural selection) are often based on the mechanistic details of agent integrations in the system (such as inheritance, predation, reproduction).

Research Context

Participants and setting

Evolution of Populations is a ten-day ESM-based biology unit designed by the lead author in consultation with high school biology teachers. Ms. Lydia (pseudonym), a biology teacher in a large Midwestern city's public

school, taught this unit in 2018 to freshman students in four classes (n = 88). 100% of the participating students were on a free lunch program (an indicator of belonging to an underserved population). Students were predominantly of Hispanic or Latino (75%) and African American (11%) ethnicity.

ESM-based Curriculum

The ESM-based curriculum was designed to introduce students to population dynamics, prey-predator relationships in an ecosystem, and natural selection. Activities were delivered through an online curriculum portal (https://ct-stem.northwestern.edu/curriculum/preview/681/) and were split into lessons. Each lesson consisted of 3-4 pages. Typically, on each page, students read a prompt with a description of a computational model and suggestions for exploration. Then, students answered 2-5 embedded assessment questions on each page. The ESMs in the unit are built using NetLogo (Wilensky, 1999), an agent-based modeling platform that is intentionally designed to foreground emergent systems modeling for educational and research purposes.

An ESM in this unit was designed as a computational experimental system for students to investigate phenomena related to population dynamics, population genetics, and natural selection. The design of the ESM was inspired by a short film designed by Howard Hughes Medical Institute (HHMI)[1] about natural selection and adaptation in populations of rock pocket mice. The HHMI film gives a geological history of the American Southwest and discusses the research about changes in populations of rock pocket mice. Rock pocket mice belong to a species of mice *Chaetodipus intermedius*, which are mainly found in rocky outcrops in the deserts of the southwestern United States and Mexico. Mice that camouflage well with the surroundings have a higher chance of surviving predation by avian predators. The mice that are found in sandy areas typically have a light fur-coat, whereas the ones found in rocky areas have a dark-colored fur-coat. Evolutionary biologists and molecular geneticists who have studied these populations in New Mexico have attributed this adaptive variation in the color of fur coat primarily to mutations in a gene called the melanocortin-1-receptor gene, *Mc1r* (Nachman et al., 2003).

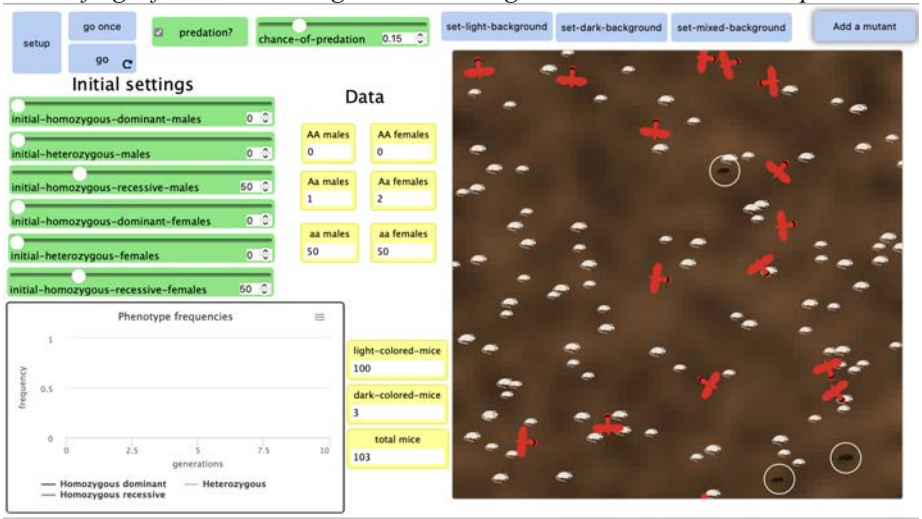
We designed the curricular activities to scaffold students' use of the ESM to design and conduct investigations using the ESM (Figure 2). The curricular activities included - (a) students watching the HHMI video and deciding research questions they want to investigate about rock pocket mice, (b) students' open-ended explorations of the ESM, (c) refinement of the research questions such they can be answered using the ESM, (d) scaffolded activities to understand specific aspects of the ESM such as inheritance or predation, (e) final refinement of research questions, self-driven experimental investigations of those research questions.

Possible Epistemic games with the ESM

The Rock Pocket Mice ESM was designed for students to investigate how populations of different initial compositions change in response to different environmental conditions. Students could choose different settings to investigate different aspects of the phenomenon (see Figure 2 and Table 1).

Figure 2

Rock Pocket Mice ESM in which users can engage in many different epistemic games by deciding initial population composition, predation rate, background colors, and whether to introduce mutant or not. In this figure, a user has introduced three mutants (heterozygous dark-furred mice) into a population of light furred mice living in a dark background environment with a predation rate of 15%.



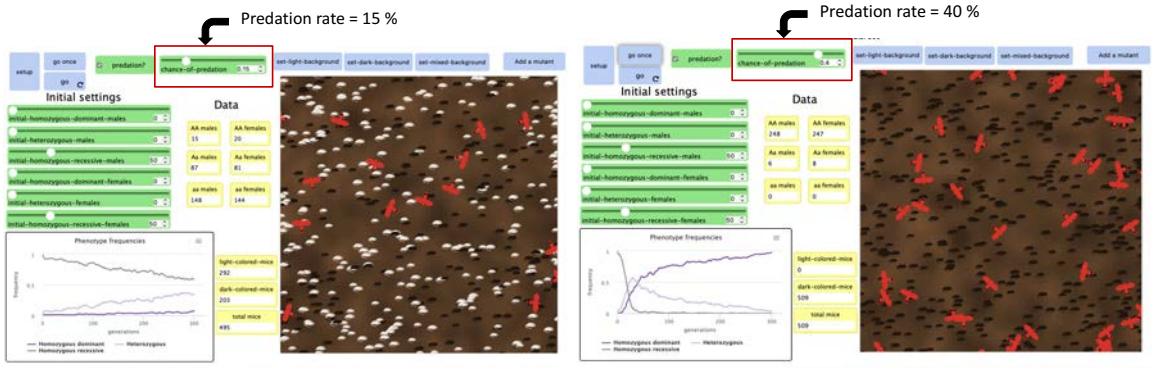
[1] https://www.biointeractive.org/classroom-resources/making-fittest-natural-selection-and-adaptation

For example, one of the students in the class wrote her final research question as follows:
If we have a population of mice with light fur coats only living in a dark background, and we add 3 mutant mice, how will the population change after 300 generations with a 0.15 chance of predation?
For this research question, the experimental setup would look like what is shown in Figure 2. Students could use this ESM to set up their experiments by changing one or more of the four conditions – initial population, background color, predation, and introduction of mutants (See Table 1). Combinations of these experimental conditions allowed students to investigate various aspects regarding how populations change because of natural selection such as the effect of camouflage for survival, predatory pressure, etc.

Table 1
Different experimental settings in the ESM that users can decide to design computational experiments for investigating their research questions

Initial population composition	**Background**	**Introduction of mutant/s**	**Predation**
Light (homozygous recessive), dark (homozygous dominant, or heterozygous), or mixed	Light, Dark or mixed	Yes, or no	Low, high or no predation

Depending on how experimental conditions were set, students saw different experimental outcomes. For example, with a 15% of predation rate, which was mentioned in the research question, three hundred generations are not enough for the dark fur phenotype to become predominant in the population, whereas predation rate of 40% causes elimination of light fur phenotype in the population after 300 generations (See Figure 3).
Figure 3
Experimental outcomes after 300 generations with different predation rates



In the first part of our analysis, we investigate different kinds of epistemic games that students played using the ESM. In the second part, we present in detail an epistemic game of a student and discuss student engagement in an epistemic game to help us investigate their learning with the ESM. Our research questions are:

1. What were the different kinds of epistemic games that students played using the rock pocket mice ESM?
2. How did agent-based representations support learning of an emergent phenomenon as students participated in epistemic games?

Methods

We performed a qualitative analysis of student responses to the questions in the ESM-based curriculum to investigate their epistemic games (Miles et al., 2014). Student responses to the following question were coded to identify their epistemic games:
Come up with a question about natural selection in the case of the pocket mice, which can be answered using this model. One example of a question that could be answered using the model: If we introduce a mutant (with a dark-fur-coat) in a population of mice with light-fur-coats that are living in a mixed background environment, how will to population change after 500 generations?

Note that this question in the curriculum provides students with an example question, which is likely to have guided framing of student responses. Nevertheless, as seen in the data presented in the findings section, students designed several different kinds of epistemic games. Based on the conditions that students could vary in the ESM to investigate their research questions, we created the following codebook to code students' epistemic games.

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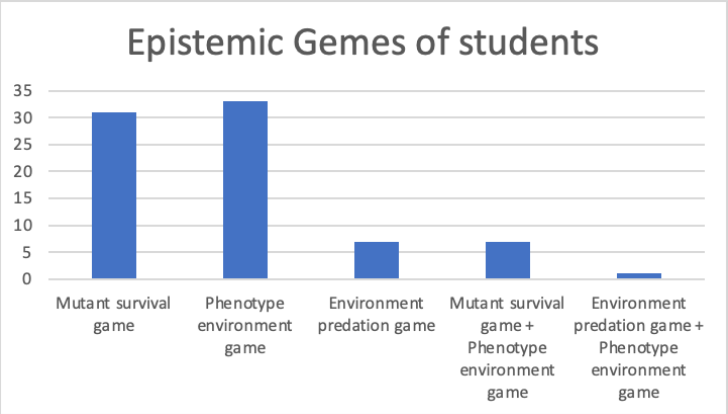
Table 2
Codebook used to code for students' epistemic games

Epistemic Game Code	Explanation	Example
Mutant survival game	An epistemic game of investigating how mutant mice survive in a population of specific composition living in specific environmental conditions.	*If we have a population of mice with light fur coats only living in a dark background, and add 3 mutant mice, how will the population change after 300 generations with a 0.15 chance of predation?*
Phenotype environment game	An epistemic game of investigating how specific phenotypes survive in specific environmental conditions	*If we have a few with light fur coats in a population of homozygous dominant (dark fur coat) mice that are moving in a mixed background environment, how will the population change after 200 generations?*
Environment predation game	An epistemic game of investigating how different predation rates affect survival	*If we have a normal amount of heterozygous mice on different backgrounds how will they react to a high and low predatory rate?*
Mutant survival game + Phenotype environment game	An epistemic game of investigating the survival of specific phenotypes and mice with the mutant phenotype in specific environmental conditions	If we decrease the population of dominant dark-colored mice to 30 and increase the population of light-colored mice to 150 that are living in a mixed background but add about 10 mutants, how will the population of dark-colored mice look over 300 generations?
Environment predation game + Phenotype environment game	An epistemic game of investigating how the predation rate affects survival of mice with specific phenotypes living in specific environmental conditions	If we change the predation percentage to .15 in a population of mice with both light and dark fur colors (heterozygous) that are living in a dark environment, how will the population change after 250 generations?

Findings

The ESM supported designing and conducting experiments to engage in various kinds of epistemic games. Students participated in five kinds of epistemic games. The majority of students participated in mutant survival (n= 31) and phenotype environment (n = 33) games (See Figure 4). The mutant survival game is the same as the one mentioned in the example research question provided to the students. This game involves introducing mutant mice in a specified environment and studying their survival. A phenotype survival game is about investigating the survival of mice of a specific phenotype (dark fur or light fur) in a specific environment (dark/light/mixed background, predators present/absent). Environment predation game is a more sophisticated game, which 7 students participated in. This game involved investigating the effects of predation rates on the survival of mice. 8 students played combinations of games – 7 played mutant survival + phenotype environment game and 1 played environment predation and phenotype environment game.

Figure 4
Frequencies of students participating in different epistemic games



Each type of students' epistemic game attempted to investigate different kinds of research questions. For example, in the *mutant survival* games, the research questions were about introducing specific kinds of mutants in a specific kind of environment and investigating their survival (See an example question in Table 2). In each epistemic game the specific details of the investigations – the experimental conditions, data collection and analysis strategies – were different. These differences show how they exercised their epistemic agency in performing scientific investigations. In the next part, demonstrate this further by performing an in-depth analysis of an epistemic game of a student.

Emma's epistemic game

In the second part of the analysis, we discuss the epistemic game of a student, Emma (pseudonym). We argue how agent-based restructurations in the ESM facilitated Emma's investigations of the emergent phenomenon related to the change in the population of rock pocket mice because of natural selection. Emma participated in the ESM-based curriculum as a part of a group of five students. That is the reason why in Emma's responses she uses 'we' instead of 'I'. Emma's group participated in the mutant survival game. Their game involved introducing mutant agents in populations of specific agent characteristics (homozygous recessive) and observing system-level changes in the population after 400 generations (see Figure 5). Emma's responses about their hypothesis and the experiment design help us understand their epistemic game better. They added 10 mutant mice with dark-colored fur to the population of homozygous recessive mice (light-colored fur), in a light background with a predation rate of 35%. Their hypothesis was about the survival of dark-colored mice. They hypothesized that the population of dark-colored mice will be less and less. In their experimental design, they system-level settings related to the environment - predation rate and background color and agent-level properties of the population of mice and how they would change the initial population composition by adding 10 mutants.

Figure 5

Emma's research question, hypothesis, and experimental design

Research Question -

If we introduce 10 mutants in a population of homozygous recessive mice that are living in a light background environment, how will the population change after 400 generations?

Hypothesis -

If we add the 10 mutants with dark colored fur to the population of homozygous recessive mice that are living in a light background environment then the population of the dark colored mice will be less and less because [because] they will be the ones standing out in the light enviroment [environment] not being able to camoflauge [camouflage].

Experimental design -

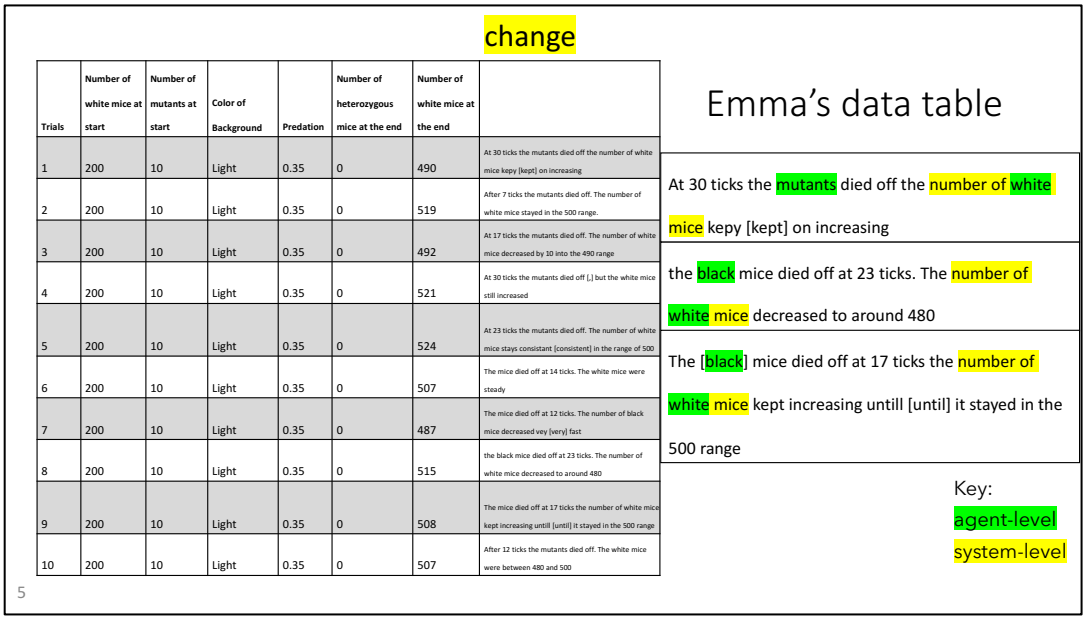
we kept the predation on at 0.35	Environment - predation
we set the background environment color to light	Environment - background
we set all the other sliders to zero except for homozygous recessive males and homozygous recessive females.	Genotype/phenotype
we set the homozygous recessive males and homozygous recessive females sliders to 100	Genotype/phenotype
we then would add 10 mutants	change
we would keep the number of mutants the same in each experiment.	Multiple trials

Key:
agent-level
system-level

Emma's response to a question about data collection (See Figure 6) shows the experimental settings and outcomes that they recorded in each of the ten trials conducted. They also wrote their observations at the end of each of the trials. We have enlarged three observations in the data table to show how the students noted agent properties and system-level changes at the end of each trial.

Figure 6

Emma's data and observations: Emma conducted 10 trials and noted number of *white mice at start, number of mutant at start, color of background, predation, number of heterozygous mice at the end, number of white mice at end* and qualitative observations at the end of each trial. three observations are enlarged as examples.



change

Trials	Number of white mice at start	Number of mutants at start	Color of Background	Predation	Number of heterozygous mice at the end	Number of white mice at the end	
1	200	10	Light	0.35	0	490	At 30 ticks the mutants died off the number of white mice kepy [kept] on increasing
2	200	10	Light	0.35	0	519	After 7 ticks the mutants died off. The number of white mice stayed in the 500 range.
3	200	10	Light	0.35	0	492	At 17 ticks the mutants died off. The number of white mice decreased by 10 into the 490 range
4	200	10	Light	0.35	0	521	At 30 ticks the mutants died off [,] but the white mice still increased
5	200	10	Light	0.35	0	524	At 23 ticks the mutants died off. The number of white mice stays consistant [consistent] in the range of 500
6	200	10	Light	0.35	0	507	The mice died off at 14 ticks. The white mice were steady
7	200	10	Light	0.35	0	487	The mice died off at 12 ticks. The number of black mice decreased vey [very] fast
8	200	10	Light	0.35	0	515	the black mice died off at 23 ticks. The number of white mice decreased to around 480
9	200	10	Light	0.35	0	508	The mice died off at 17 ticks the number of white mice kept increasing untill [until] it stayed in the 500 range
10	200	10	Light	0.35	0	507	After 12 ticks the mutants died off. The white mice were between 480 and 500

Emma's data table

At 30 ticks the mutants died off the number of white mice kepy [kept] on increasing

the black mice died off at 23 ticks. The number of white mice decreased to around 480

The [black] mice died off at 17 ticks the number of white mice kept increasing untill [until] it stayed in the 500 range

Key:
agent-level
system-level

5

Finally, Emma wrote her conclusion as follows:

In conclusion or [our] hypothesis was correct. We asked about how adding 10 mutants to the population of mice would chnage [change] it . We thought that the black furred mice would decrease in population because they would be the ones tanding [standing] out in the light environment. We were right becuase [because] in all of our trials the black furred mice ended up dieing [dying] off after a couple of generations. The mutants did not affect the population of light furred mice because [because] probably predators would eat them before they got a chnace [chance] to reproduce and produce mixed offspring.

Emma's response in her conclusion shows how she and her group considered agent properties and agent behaviors to explain a system-level change in the population. They also discussed that the dark-furred mice could not survive beyond a few generations because they did not camouflage and got predated before they could breed with the light-furred mice to produce mixed offspring.

Discussion

The findings of our study demonstrate how the ESM-based learning environment supported student engagement in different kinds of epistemic games, which helped them learn about disciplinary ideas by engaging in science practices in epistemically agentic ways. Characterization of students' epistemic games revelated that they played five different kinds of epistemic games using the ESM. Each type of game is helpful to study different aspects of the natural phenomenon being investigated and develop mechanistic explanations regarding the phenomenon. The epistemic games that students played were not assigned to them or even pre-decided in the curriculum. These games were identified and characterized based on students' research questions. The ESM served as an experimental system or a playground for students to devise and play their epistemic games to investigate those research questions. These findings demonstrate that the ESM design and ESM-based curriculum supported investigations of different aspects of a phenomenon by encouraging self-driven agentic learning.

The qualitative analysis of Emma's case demonstrates how agent-based representations and constructionist design features of the ESM supported her participation in her epistemic game. Emma's experimental design was aligned with her research question. It involved manipulation of the composition of the initial population by specifying agent properties and system-level environmental conductions. Her experiment was meticulously designed, which included ten trials. The data analysis helped her develop mechanical explanations regarding natural selection. Her answer shows how she considered the effect of agent properties and system-level environmental conditions in determining their survival and reproduction, which would in turn affect the passing of traits in the next generation and survival of those traits in the population. This analysis demonstrates how Emma's epistemic game using the ESM for creating the epistemic form (Figure 1) helped her learn about some of the fundamental ideas regarding natural selection.

In the future, we want to focus on how student groups in an ESM-based learning environment can learn from the epistemic games that other student groups in the class play. In this study presented in this paper, sharing across student groups did not happen as much as we wanted. The teacher asked students to share their research questions, however, student groups were not asked to share their claims and evidence that they used to verify their

claims. Our future work will involve designing specific scaffolds in the curricula that will facilitate sharing across groups so that students learn different kinds of epistemic games that can be played to learn about a phenomenon (practices) and conclusions from those games (disciplinary ideas).

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Mediating elementary students' mechanistic reasoning in collective embodied modeling activities

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Abstract: This paper explores elementary students' mechanistic reasoning about states of matter during a series of collective embodied modeling activities. Recognizing students' mechanistic reasoning in a collective embodied space can be challenging since students' reasoning is often deeply - yet implicitly - embedded in their interactions. In this paper, we use Russ et al.'s (2008) mechanistic reasoning framework as a guide to identify moments of mechanistic salience for students and draw upon the learning in embodied activity framework (Danish et al., 2020) to map the mediators within the environment that contribute to the production of such mechanistically rich moments.

Introduction

Mechanistic reasoning is a reasoning ability about the causal process that underlie natural phenomena (Russ et al., 2008). Prior studies have explored the potential of embodiment as a way to explore and understand mechanisms (Danish et al., 2017; Dickes et al., 2016; Mathayas et al., 2019). In the present study, we seek to elaborate the potential connections between mechanistic reasoning and embodiment by examining elementary students' embodied sense-making around mechanism in collective embodied modeling activities using the Science through Technology Enhanced Play (STEP; Danish et al., 2015; 2020) mixed reality (MR) environment.

Students who are participating in a collective embodied model are often moving continuously. Thus, while teachers and experts may recognize mechanisms embedded in those actions and movements, those embedded mechanisms are not always attended to by students who shift their attention and movements from moment to moment. For example, students may move slowly to represent a liquid state of matter without intentionally aiming for an intermediate distance between their enacted particles, nor noticing this as relevant to producing that state of matter. As such, the present analysis focuses on moments when mechanisms are visible in students' interactions to understand how students' attention to those mechanism is mediated by their interactions. We then ask: how do mediators in a collective embodied modeling activity affect students' understanding of mechanism within states of matter?

Theoretical framework

Mechanistic reasoning

Mechanistic reasoning, particularly its use to account for dynamics within the natural world, is foundational to the development of students' scientific inquiry skills (Koslowski, 1996; Russ et al., 2008). In such contexts, mechanistic reasoning is conceptualized by Russ et al. (2008) as the development of ontological and causal descriptions of underlying structures based on prior knowledge, expertise in a domain (diSessa, 1993), and everyday experiences (Keil et al., 1999). While scholarship has proven the value of creating explanations for how a cause brings about an effect (Schauble, 1996), Kuhn (1997) expands on this conception, drawing attention to understanding the 'broad cause' of a phenomenon. This framing encompasses not only the association between agents and sequential effects but also the underlying processes of that association thus enabling students to make predictions (Russ et al., 2008). Furthermore, mechanistic reasoning integrates students' explanations of how unobservable structures and components at the micro-level of a system account with observable changes at the macro-level (Schauble, 1996). Although mechanistic reasoning is considered a high-level reasoning ability, prior studies have demonstrated that young children can be scaffolded to construct and explain the mechanism of natural phenomena in different domains, such as biology (Danish et al., 2017) and ecology (Dickes et al., 2016).

Mediated collective embodied activity

This study is guided by the Learning in Embodied Activity Framework (LEAF; Danish et al., 2020) which expands upon Cultural Historical Activity Theory (CHAT; Engeström, 1999) for embodied learning contexts. LEAF synthesizes individual and sociocultural theories of learning and highlights the role of the body as a

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valuable learning resource; within LEAF, each mediator in Engeström's CHAT framework (subject, object, division of labor, community, rules, and tools) is analyzed for its role in transforming embodied learning at both individual and collective levels. To privilege the body as a sensemaking resource, LEAF draws on situated simulation theories (Alibali & Nathan, 2012) and body cueing (Lindgren, 2015) at the individual level, merging them into sociocultural context to understand students' engagement in a joint embodied activity. Individual students' embodiment needs to be understood through alignment with others. The present study design was heavily guided by these principles, situating the various elements present as *mediators* of the activity.

Vygotsky (1978) defines mediators as material and/or ideal cultural tools that transform the relationship between a subject (participant) and the object (goal) of their activity. These mediational means are socioculturally situated and have associated constraints and affordances. In our analysis, we view students' experiences in STEP through the lens of *mediated action* (Wertsch, 1981) where students engage in meaningful action and may as a result appreciate the value of the cultural mediators for their action and apply them in later activity. Our goal is to explore what mediators are present in moments when students identify aspects of mechanism and how these mediators contribute to students' mechanistic reasoning. In the present study, an individual student (subject) embodies a water particle (rules) in a space that is tracked and visualized by a simulation (tool) to inquire particle behaviors (rules) through modeling different states of matter (object) with other "particle" students (community). Some students (community) observe their peers' embodied modeling and make inferences (a division of labor) about the impacts of embodiment on the state of matter based on the simulation feedback. Facilitators (community) scaffold students' embodied modeling and regulate students' classroom behaviors.

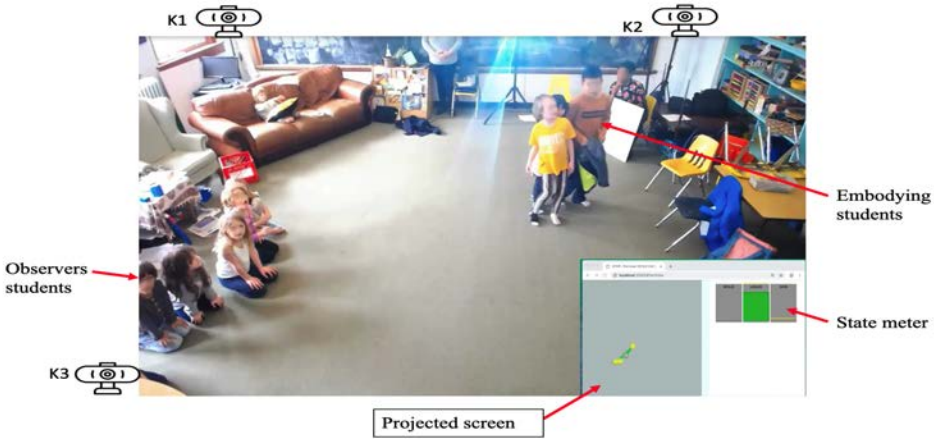
Methods

Design

The present modeling activities occurred using the STEP system, a MR environment for students to explore complex science phenomena (Danish et al., 2015). This curriculum featured 22 first and second-grade students from the Midwest engaging in seven thirty-minute class sessions to explore particles' behavior in three states of matter (Danish et al., 2020). As illustrated in Figure 1, there were three Kinect cameras (labeled K1, K2, and K3) tracking students' movements and projecting them as digital water particles on a projected screen. As students move and interact with each other as particles, their movement and interactions are simulated into different states of matter and displayed through the state meter on the screen.

Figure 1

Students in the STEP MR environment



Data source

This analysis focuses on how mediators in a collective embodied modeling activity contribute to students' collective mechanistic reasoning. We reviewed and contented logged video data across the seven days of the implementation. Next, we identified days three and six as offering the clearest contrast in how students explored mechanisms in exploratory versus more structured activities. During day three, students attended the state meters to indicate how their behavior and collective configurations produced different states of matter. During day six, facilitators asked students to demonstrate their understanding of mechanism by acting out the behavior of particles within predetermined environments as made visible on the projection (pond, ice world, and dessert).

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These two class sessions offer us insight into how students engage with mechanistic aspects of states of matter through embodied representations.

Applying Russ et al. (2008) mechanistic reasoning framework to STEP: Particles

In the present study, we draw Russ et al. 's (2008) mechanistic reasoning framework to understand students' reasoning on mechanisms in the context of the state of matter. Russ et al.'s (2008) framework arranges aspects of students' reasoning in a hierarchy based on logical connections and scientific sophistication. These components include (1) description of the target phenomenon, (2) identification of setup conditions, (3) entities, (4) entity activities, (5) entity properties, and (6) the organization of entities that followed mechanistic processes such as (7) chaining, (8) use of analogies, and (9) the use of animated models. We use this framework to characterize students' engagement in mechanistic reasoning through collective embodiment.

In the case of states of matter, we view *the target phenomenon* as the particle behavior that led to the three states of matter (solid, liquid, and gas) in the context of water. An example would be students' commenting on the appearance of a particular state of matter (i.e., "there is a solid") during the embodied activities. We coded *setup conditions* as the moments where students identified the necessary conditions in the environment to produce the phenomenon. For example, students might note that the environment needed to be hot to achieve a 'gas' state. *An entity* in this context was an individual water particle. Students' representations of *properties of entities* included identification of the different speed and attraction strengths of particles in different states. We coded *identifying the organization of entities* when students attended to the difference in distances between particles. *Activities* were coded as an acknowledgement of the various things that an entity engages in; and when students commented on particles' actions (i.e., the use of phrases such as "do," "go," or "move"); for example, when a student commented "let's go into a circle." We coded students' reasoning about changes in a phenomenon as a result of other events elsewhere/at a different scale as *chaining.* An example of (backward) chaining would be students' reasoning that "to make gas, we should move fast."

Data analysis

Two authors collaboratively and iteratively watched video data of the two class sessions through the lens of Russ et al. 's, (2008) framework to identify episodes where aspects of mechanistic reasoning were most salient in students' interactions. Two seven-minute episodes of video data were then selected because they depicted in-depth discussion of mechanism. These were then analyzed to explore how the activity design mediated those discussions. To accomplish this, each video was first segmented into 10-second segments. Authors then jointly coded all of the segments using Russ et al.'s mechanistic reasoning framework as a coding scheme. Next, the first author transcribed the moments with the highest number of mechanistic codes applied into multimodal transcripts. Finally, all authors used interaction analysis (Jordan & Henderson, 1995) to identify how mechanism was being represented through students' interactions, the mediators that contributed to this mechanistic reasoning, and other emergent patterns through iterations of collaborative data sessions.

Findings

The following three cases represent episodes during days three and six of the states of matter unit in which students collectively engaged in mechanistic reasoning about how particles produce states of matter using their bodies. We argue that as mediated action is situated in a particular time and space, that the mediational means present in the classroom function differently in different moments as demonstrated by the ways students do and do not appropriate them. Case one illustrates an episode early in the implementation in which students explored how their bodies could be used to represent particles of a state of matter. Here, verbal and visual cues functioned to productively constrain students' efforts; students realized that appropriate embodiment required attending to particular mechanistic properties of particles. Case two depicts an episode in which students' embodiment did not produce the intended state of matter; facilitators' verbal cues functioned to remediate the activity by shifting students' attention towards why their movements were not working and how to correct them. In case three, we focus on how the STEP system, as a mediator, functions (a) as an instructional organization tool and (b) to simultaneously orient students toward multiple aspects of mechanism at the microscopic and macroscopic level.

Case 1: Early explorations of state

The following episode was taken from a day three activity in which students are introduced to the concept of particles as related to the state of matter. The activity is exploratory and open-ended; students were not explicitly told that their movement were being mapped onto those of particles; however, through the use of simulation feedback (visual mediation), students came to the conclusion that (a) they were particles and (b) that

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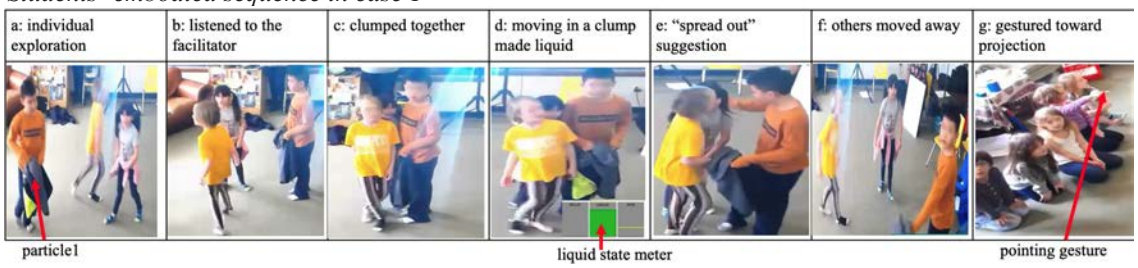
their proximity to each other was integral to which state of matter was being produced. Table 1 and Figure 2 illustrate this episode.

Table 1
Case 1 transcript

	Actor	Talk	Embodiment
1	Particles		(Fig 2a) Students wander around individually.
2	Facilitator	What happens when you move together, try to notice something?	(Fig 2b) Three students stop, look at the facilitator, and listen.
3	Particle 1	OK	(Fig 2c) Particle 1 pull other particles together into a tight clump.
4	Facilitator	Instead of running around crazily.	(Fig 2d) All particles move in a tight clump.
5	Observer	Oh, it makes more liquid, the particles go closer together	
6	Facilitator	What happens when they are closer?	
7	Observer	Liquid, more liquid	
8	Particle 1	((hard to hear))	(Fig 2e) Particle 1 points to a farther place and gently pushes the other two students back.
9	Observer	Are they particles?	(Fig 2g) An observer points to the simulation.
10	Observers	They are particles!	All students look at the simulation.
11	Facilitator	Nice, Observer!	

Figure 2
Students' embodied sequence in case 1



Line 1 and Figure 2a shows how students moved around the embodied space individually with few observable indications that they recognized the importance of their movement relative to their peers. The facilitator offered a suggestion (Lines 2 &4) which students accepted as evidenced by how they moved closer together (Lines 3 & 4 and Figures 2c & 2d). This acceptance of the facilitator's suggestion signals that students' conceptions of 'moving together' was heavily related to proximity (speed has been a side-effect). The projected simulation responded to this change in movement by increasing the 'liquid meter' on the graph (Figure 2d) and the observing students shared their realization that this change in movement produced liquid (Line 5 &7). One of the embodying students (labeled 'Particle 1') attended to entity proximity (coded as *the organization of entities*) (Line 8 and Figure 2e) by suggesting that the other embodying students spread out; this suggestion was also accepted as evidenced by their peers moving away (Figure 2f). An observing student inferred that their peers were embodying particles (Lines 9 & 10 and Figure 2g) by gesturing towards the projection of the particle avatars. The rest of the observing students shifted their gaze towards the projection (Figure 2g), exclaimed in agreement (Line 10), and the facilitator expressed approval (Line 11).

This episode demonstrates how facilitators' verbal input and simulation feedback honed students' attention towards mechanistic aspects of the states of matter phenomenon. The combination of facilitator prompts, embodying students' movement as response to the prompt, and real-time projected simulation feedback increases the salience of these mechanistic aspects for students. First, this episode illustrates how students realized that their movements as particles (microscopic *entities*) are connected to which state of matter (the *target phenomenon*) is present. Furthermore, students acknowledged how the phenomenon was determined by the group's collective embodiment rather than individual movement; in this episode, collective embodiment was interpreted as particles distance from one another (*entity organization*).

Case 2: Acting as particles to produce target states of matter

This excerpt portrays a moment from day six (near the end of the unit) where students were tasked with embodying particles at a microscopic scale based on a visualization of the environment at a macroscopic level. A newly introduced mediator - the toggling of a background depicting an icy, pond, or desert environment (Figure 3h) – was disregarded by embodying students despite the target state of matter being continuously mediated by facilitators' questions (Lines 2 through 8). Observing students responded to the failure to embody the target phenomenon by offering a series of recommendations (Line 9). Here, we shift our perspective towards the observing students; we frame embodying students' movement as mediating observing students' engagement with aspects of mechanism such as speed (as a *property* of particles) and distance (*organization of entities*). We offer the following transcript (Table 2) and video sequence (Figure 3) to exemplify the use of students' embodied performances as a mediator for observing students' learning.

Table 2

Case 2 transcript

	Actor	Talk	Embodiment
1	Facilitator	I am going to take particles and transform them into a space, to a setting. And their job is to act like the particles in that setting.	
2	Facilitator	So, what should you guys be?	(Fig 3a & 3b) Particle 1 shows a shivering gesture. Particle 2 holds hands with Particle 1 and Particle 3. Particle 4 wanders in a circle.
3	Particle 2	Uh let's be...solid	
4	Facilitator	So, where are you? Can someone tell me where you are	
5	Facilitator	One of the particles where do you think you are looking at the screen?	(Fig 3c) Particle 4 accepts an invitation to hold hands from Particle 2 & 3.
6	Facilitator	So, Particle 2 said you're going to be solid, why?	(Fig 3d) Particles look at the screen. Particles 1 & 3 walk to the circle center.
7	Particle 2	Uh, we just wanted to be solid	(Fig 3e) Particle 3 leads a "circle dance."
8	Facilitator	You just want to be solid? What setting are you in right now?	(Fig 3f) All particles gaze towards the projection.
9	Observers	You need to be slow and close together	
10	Particle 2	We need to be slow and close together	(Fig 3g) Particles move slowly and closer to each other, accepting Observers' suggestion.
11	Facilitator	How are they doing observers are they making solid? When they are slow and close together?	
12	Observer	Yes, for a second	(Fig 3h)

Figure 3

Students' embodied sequence in case 2

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This episode opens with facilitators' attempts to direct embodying students' attention towards the background of the projected simulation (an icy environment as the new *setup condition*) in order to clarify the target state of matter (solid) to the larger group (Line1). Although an embodying student answered (Line 3) with the correct state of matter, it becomes clear that there is a disconnect between why students should be embodying solid water particles; there is no student response to the facilitators several probing questions regarding 'where' the particles are. We interpret this instance (Lines 1 through 8) as embodying students' failure to connect the behaviors of microscopic *entities* (particle movement) to the larger macroscopic *phenomenon* (state of matter): the core causal relationship (coded as *chaining*) within the states of matter content area (as discussed more in Tu et al., 2022). While this failure is indicative of a gap in embodying students' understanding, it functions as a mediational cue for observing students' learning. An observing student proceeded to instruct their embodying peers to be "slow" (a *property* of solid particles) and "close together" (in reference to the *organization of entities*). The embodying students echoed this instruction (Line 10) as an indication that they would accept the suggestion, and the observing students confirmed that a solid was produced (Figure 3h). Here, we see how students' talk and embodiment function as bi-directional mediators for each other's learning. Whereas embodying students' failure to recognize the connection between the simulation's projected background and particle behaviors led to observing students articulating insights regarding the target particle behaviors, observers' verbal scaffolds had a re-mediating effect on embodying students' actions.

Case 3: Embodying the mechanisms linking movement and state

Embodying students continued to explore and began noticing the link between their movement and the simulation's depiction of state. This continued into case three in which students were challenged to quickly adopt the movements of and iterate on their embodied representations to model solid, liquid, and gas states as determined by the background currently visible in the projected simulation (Figure 4). Unlike case two in which embodying students struggled to understand the causal (coded as *chaining*) relationship between microscopic particle behaviors and macroscopic states of matter, case three demonstrates students understanding of not only the relationships between microscopic behaviors and macroscopic states, but the importance of drawing on a multidimensional understanding of particle movement to appropriately represent the target phenomenon.

Table 3
Case 3 transcript

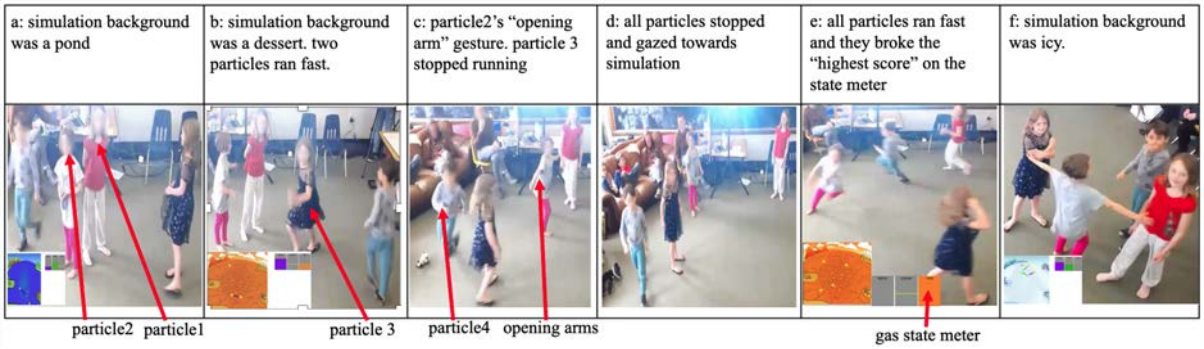
	Actor	Talk	Embodiment
1	Facilitator	I am going to transform you to one more place.	(Fig 4a)
2	Observers	Oh!	(Fig 4b&4c) Two particles begin running fast. Particle 2 suggests "spread out" with an opening arms gesture
3	Particle 2	No, no, no. Spread out	(Fig 4c) Particle 3 stops running and accepts Particle 2's embodied suggestion. Three particles spread out. Particle 4 runs fast.
4	Observers	Run fast!	(Fig 4d) Particle 4 stops running. All particles gaze towards the projected simulation.
5	Observers	Go to gas! Make it go!	(Fig 4e) All particles run fast.
6	Observers	They break the high score ((State meter reached to the top))	(Fig 4e)
7	Particle 2	Wait, let's try to go in a circle ((the facilitator changed the environment back to be icy))	(Fig 4f) All particles stop moving. Particle 3 hugs her arms. Particle 2 organizes students to go back into a circle.

This activity is split into two phases as differentiated by which environment (*setup condition*) was being projected as the simulation background and thus which macroscopic state (*target phenomenon*) students should have been emulating. During the first phase, a group of students embodied particles as the projected background of the simulation changed from a pond (indicating the target state to be 'liquid') to a desert (where the target state is 'gas') (Line 1). Immediately, students responded to this change, however there was a disagreement in which aspects of particle movement were currently relevant; two students started to run to indicate an attention to speed (a *property*) (Figure 4b) whereas another student made a gesture (Figure 4c) to indicate that the group should spread out (*organization of entities*). While both interpretations are appropriate

for the desert setting and gas state, the simulation's state meter did not indicate successful representation of gas particles. This failure prompted the embodying students to pause their activity and look towards the state meter (Figure 4d). An observing student suggested that the embodying students all "run fast." The group accepted this suggestion as indicated by their movement, and the state meter indicated the successful representation of gas (Lines 4 -6 and Figure 4e). While the observer's suggestion to "run fast" initially seemed to require that some students compromise on their idea to spread out (attend to distance) in lieu of their peers' idea (to move fast), the outcome of this interaction involved the integrated recognition of multiple aspects of mechanism. In accepting the suggestion and adopting a 'fast' speed, they demonstrated how the embodiment of gas requires that particles both move fast (*property*) and be far apart (*organization of entities*).

Figure 4

Students' embodied sequence in case 3



The next phase of the activity started immediately afterwards and was indicated to the class by a change to the background environment (to icy Figure 4f). As with the prior phase, students immediately acknowledged the change in environment (the *setup condition*) and recognized that they should be embodying solid particles (the *target phenomenon*) by adopting a new set of movements. They stopped running (to represent slow movement as a *property* of solid particles) and decreased their distance from one another (to represent solid particles as being *organized* closely together) (Line 7 and Figure 4f). The alternating environment (the simulation's background) mediated the activity by functioning as an instructional organization tool; it prompted the entire group to reconsider the requirements of the environment and thus their individual and collective movements. Observers' suggestions scaffolded embodying students' activity by directing attention towards an aspect of particle movement which was currently missing from the embodiment. Here, mediation functions to organize activity based on the macroscopic conditions and make students aware of the multiple intersecting aspects of the phenomenon and particle behavior to successfully represent the target state.

Discussion

This paper explores students' mechanistic reasoning related to states of matter in three collective embodied activities. Mediating students' exploration of different mechanistic properties is an essential part of how classroom teachers and activity systems support this complex reasoning. We notice how mediational means function differently across three different cases; in case one, we see the use of visual and verbal cues to productively constrain students' exploratory movements toward a common objective. Case two illustrates how observing students' talk can be used to scaffold their peers' embodiment as they articulate connections that may not be visible to those 'in' the simulation in a sort of bi-directional mediation. Case three exemplifies how mediation in the form of peer observation and real-time simulation feedback can support students in making connections between mechanistic aspects at both microscopic and macroscopic levels.

We have demonstrated that mediation of collective embodied sense-making to represent scientific phenomena affords students opportunities to engage with aspects of mechanism at both the macroscopic and microscopic levels. Our analysis also indicates the importance of teasing out moments where mechanism is being enacted versus where mechanism is understood. From a teachers' perspective, we suggest that attending closely to students' actions and offering real-time feedback as informed by students' actions can lead to the productive constraining of students' attention towards aspects of the mechanism. From an activity design perspective, we recommend organizing activities to allow for students' embodiment of the target phenomenon in addition to activity observation. This will enable students to articulate the patterns they are noticing in their peers' embodied modeling while their embodied peers leverage this observational talk as verbal mediation. The above cases demonstrate how as students are confronted with various aspects of mechanisms through embodied

modeling, mechanistic aspects are compounded and thus simultaneously engaged with during more conceptually difficult activities. Once aware of these multiple aspects, students can more explicitly and maturely attend to the causal relationships and processes that underlie phenomena.

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International Society of the Learning Sciences

A Student's Access to Practice-Linked Resources in an Elementary Unplugged-to-Plugged Computer Science Unit

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Abstract: This paper presents a case study of a student's participation in an expansively-framed unplugged computer science (CS) instructional unit that leverages activities and materials not typically associated with CS: playing an "unplugged" tabletop board game and designing a paper prototype of a new game level. We use the practice-linked identity framework as a lens to characterize resources available in our instructional design and how they afforded or hindered the student's participation across the instructional activities. Our findings highlight the importance of relational resources in influencing participation, both positively and negatively, and provide implications for the design of future CS learning environments.

Introduction

One approach to making computer science (CS) instruction more accessible to those who are historically underrepresented in the field is to change the materiality through which CS ideas are encountered. This is an approach that has been used to some degree of success with craft materials, such as electronic textiles (Searle & Kafai, 2015) and paper circuitry (Lee & Recker, 2018). Presumably, this also is part of the appeal of "unplugged" approaches to CS instruction that do not involve an actual computer in order to enact. By moving CS away from the screen, it seems possible that the standard pathways for participation can be disrupted. New participants can gain entry when the barriers associated with traditional media are removed.

Taking seriously the idea that encountering CS through different media has promise in changing who can participate in and become proficient with computing, we have been engaging in iterative design-based research that introduces CS through an unplugged medium but, in lieu of stopping once those ideas are initially encountered, attempts to facilitate transfer to the more canonical computing medium (e.g., a screen-based programming environment) (Lee et al., 2020). The specific form of unplugged computing from which we begin is the computing involved in board game play (Berland & Lee, 2011). Students then transition to using Scratch to play the same game and program new game levels.

The present study examines, by way of case study, the student experience of participating in this unit. We sought to understand if and how this strategy of beginning with unplugged materials and then shifting to plugged materials enabled participation and identification with CS over the course of the unit. To do this, we strategically identified a specific student success case from one iteration of the designed and enacted unit and then reviewed all video records of that student's participation. We found, and describe in this paper, that materiality contributed to this youth's self-reported positive identification with CS. However, the case was more complex than simply concluding that new materials increased access. There were also important social interactions that we identified as being likely contributors to the case student's positive identification with CS. Through iterative review and coding, we found that viewing this case study as the product of a combination of material, relational, and ideational resource availability yielded the most insight for us. This case study was formed around the question of, *how do material, relational, and ideational resources combine in cultivating a positive identification with computer science in the context of an unplugged-to-plugged unit?*

Theoretical framing

The focal case in this study is a fifth-grade student, Ella, who showed a positive change in her identification with CS after participating in a research-designed unplugged-to-plugged unit. Because the change we observed in Ella was connected to participation in an activity and involved developing positive identification with CS, we chose a theoretical lens that explains identity construction through activity, specifically practice-linked identity resources.

Practice-linked identity resources refer to supports that were made available and accessed during participation in social activities. Through a study of how positive identities were constructed through participation in a track and field team, Nasir and Cooks (2009) identified three practice-linked resources found in learning settings: material resources, ideational resources, and relational resources. Material resources are physical artifacts in the settings and "the way in which the physical environment, its organization, and the artifacts in it support one's sense of connection to the practice" (Nasir & Cooks, 2009, p.47). Second, "relational resources refer to the

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positive relationships with others in the context that can increase connection to the practice" (Nasir & Cooks, 2009, p.47). Finally, "ideational resources refer to the ideas about oneself and one's relationship to and place in the practice and the world, as well as ideas about what is valued or good" (Nasir & Cooks, 2009, p.47). While Nasir and Cooks originated this theory from naturalistic study of intact social practices, we believe that it has potential for looking at researcher-designed activities, such as a curriculum. Indeed, through its use, we noticed some unintended but influential relational resources that were provided to our case student by members of our research team. While these were not intentionally designed as part of the curricular unit as resources, they appeared to counteract some other interactions that restricted resource access for the case study student. Before describing how that transpired, we first turn to a description of the designed unit.

The designed elementary computer science unit

With the potential of alternative media for providing different forms of access to CS in mind, we developed our unit based off of a commercial paper-based board game. Board games have been both studied and designed as computationally rich environments; a number of computational ideas can be instantiated through game play, whether or not the players are aware that what they are doing is computational. Some board games where this had been explored include one on disease spread simulation and another that represented a wolf-sheep predation model (Horn et al., 2012). However, there are now board games that explicitly present their game play as computing and their value to players as supporting learning of CS (Poole et al., 2021). These games vary in structure but can instantiate CS in the form of actions presented as written code, algorithmic sequences represented as player moves, and or solutions as being derived through application of Boolean logic.

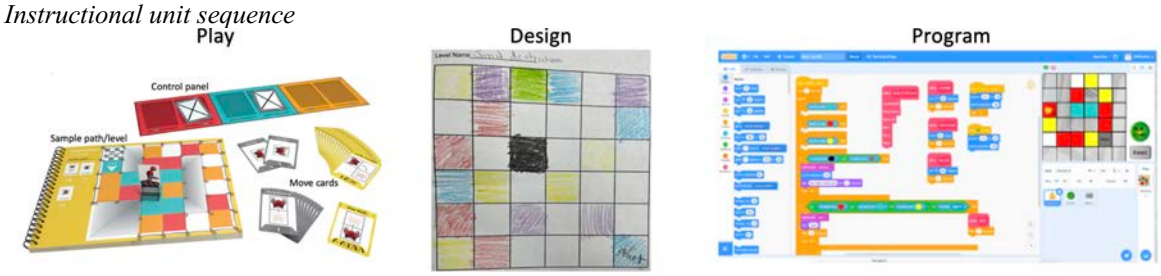
After review of several options, we created our designed unit with the commercial board game, *//Code: On the Brink,* published by ThinkFun, as the initial unplugged entry point. The board game is comprised of levels, or puzzles for players to solve. Each level has a path within a grid through which a player needs to 'program' an agent (a robot token) to move from a 'Start' square to 'Finish' square. The Start and Finish are separated by colored spaces. Landing on a colored space means executing the commands associated with that color. Players need to figure out the procedures for each color such that the robot token can execute the commands from the colored starting space and then whichever colored spaces it lands on so that it will eventually, without any changes to the player-specified procedures, land on the 'Finish.'

Players use move cards ('Move Forward', 'Turn Right', 'Do Nothing' etc.) that they place on a control panel to make procedures for each color (see Figure 1). For example, if a player puts a 'Turn Right' in the first spot and 'Move Forward' in the second spot of the control panel for blue, each time the robot lands on a blue it will rotate right and then move forward one square.

The designed unit consists of seven weekly lessons that span the classroom and school library. This was done because the partnering schools were exploring the school library as a setting for implementing CS instruction. Our unit design was an effort to support both the classroom teachers and school librarians in providing CS instruction. In separate work, we found that the use of the board game and the unplugged-to-plugged structure served as a support for the teachers and school librarian to learn new ideas about CS (Stephens et al., 2021).

Figure 1

Instructional unit sequence



The general lesson structure involved a portion that began in the classroom (for up to 20 minutes) and was led by the classroom teacher. Then students went to their scheduled weekly library time and, for the next 30 minutes had CS instruction. At the library, the school librarian introduced and then helped facilitate student work in pairs to: ***play*** the physical board game; play a Scratch version of the same game; ***design*** their own level of the game on paper using colored paper pieces and then colored pencils; and then ***program*** their level in Scratch for their classmates to try. As this was a research endeavor, research team members were present to set up cameras and microphones. However, they provided assistance as needed with the unit, helping to distribute materials or answer questions as needed. As we will show later, this proved consequential for our case student's participation and identification with CS over the course of the unit.

Methods and data

This project was conducted with a rural elementary school in the western United States. Seventy-four fifth graders (girls = 35) across three classrooms participated in this iteration of the project. Ten of those students were randomly selected (girls = 5) to be focal students. While all students completed pre-post surveys, the focal students were interviewed before and after the unit. They were also videotaped throughout the unit.

As we were interested in understanding if and how the unit worked as intended, we identified the focal student who started the unit with low affect and knowledge in programming, yet showed the largest growth, based on the pre-post surveys. This student was Ella (a pseudonym). We then reviewed all video records we had collected with Ella featured in them. This occasionally included full class activity in the classroom, but very minimally. The bulk of our analysis leveraged a total of two hours of video footage of her and her partner, Astor, in the library. This footage included the pair: playing the game, designing a level, and programming their level in Scratch. Analysis consisted of a combination of open and In Vivo coding. We coded interactions around her use of materials across the different activities and identified themes around how the activities shaped her access to identity resources. We then collapsed them into two contrasting categories of support/access/affordances and constraints/limitations/barriers. We focus our analytic findings on how the constraints and affordances shaped her participation. Table 1 shows examples of the identity resources that were available to Ella across activities.

Table 1

Identity resources afforded by the unit

Identity resource	Examples of resource use
Material resources	In the play activity, material resources consisted of the board game components: move cards, control panel, and a robot marker (see Figure 1). In the design activity, resources were paper, color pencils, and the robot marker (see Figure 3). In the programming activity, resources were a Chromebook, a computer mouse, Scratch, and their paper design.
Relational resources	Relational resources consisted of the interactions: Ella's interactions with her partner, other students in the classroom, and researchers in form of asking questions, providing feedback, and negotiating access to materials.
Ideational resources	Examples of this resource include instances when Ella showed her understanding of a concept, took ownership of her work, or showed excitement related to the activity.

Findings

As discussed earlier, our expectation was that the choice of materials can positively shape one's participation in learning activities. Through analysis based on practice-linked identity resources, we found that the use of materials, one's relationship to others, and one's view of self were indeed all linked and shaped Ella's participation in the unit and identification with CS. However, we found that these interacted in ways that both constrained or afforded participation. We describe these constraints and affordances below.

Constraints to participation

In this section, we offer examples of the constraints that hindered Ella's participation in the instructional unit. We found that constraints were often related to relational resources such as negotiating access to materials, negotiating decisions around materials, or seeking information from peers.

Negotiating access to materials

In terms of negotiating access to materials, whether the activity was *unplugged* or *plugged* further shaped how Ella and her partner participated. As partners, Ella and Astor shared control of materials between them. Since students were working in pairs, a student could assume one of two roles: a driver or a navigator. The driver controlled the materials, whereas the navigator gave instructions to the driver. Students were encouraged to switch roles between them but the switching was not enforced. During the board game play, the driver physically controlled the movement of the robot on the puzzle. In the design activity, the driver moved the colored paper pieces on the grid to design their puzzle. In the Scratch programming, the driver controlled the computer mouse and keyboard to make changes in Scratch (see Figure 2). Ella had more control of the materials in proportion to Astor during the *unplugged* activities (game play and design) than in the *plugged* (computer-based) activities (see Table 2). During the plugged activity they continually fought for control of the mouse and keyboard. During one fight for control, Ella was using the computer mouse to work on the digital version of the game board in Scratch. Astor wanted to do something else, so he tried to get control by moving his finger on the touch pad of the laptop. Astor said in a loud voice, "why don't you let me do anything?" Hearing this, the librarian walked over to them.

Astor told the librarian, "… she won't let me do anything…" The librarian told Ella to "take turns" and that she does not "get to just do it all" as she walked away. This example illustrates how Astor's fight for the materials constrained Ella's participation during the plugged activity. However, Ella remained engaged in programming and continued to negotiate for control of the materials. Ella's control of the materials and fewer instances of conflict during the unplugged activities show that the sequence of activities in the unit afforded her participation.

Table 2
Counts of Ella's and Astor's control of the materials

Instance type	Number of instances coded in data					
	Board game play		Design		Computer activity	
	Ella	Astor	Ella	Astor	Ella	Astor
User in control of the materials	40	31	37	21	28	33
Refused to give up control	2	3	5	3	11	4

Figure 2
Examples of Ella and Astor controlling the materials in the three activities.

Negotiating decisions around the materials

In terms of decisions around the materials, Ella had to negotiate decisions with Astor in all settings (playing, designing, and programming). When they were not able to reach agreement, Ella often got out of her seat and asked a researcher for help.

In the following excerpt, Ella and Astor had just started designing their game on paper. They started their board with a blue square. Students had the option to use up to 3 individual movements for each color. She asked Astor "what should blue do" three times and he did not answer. Ella decided to make the first movement 'move forward three.'

E: "So let's do… Move… Three.." (She said it while she wrote on the paper)
A: "No, you can only do.. move forward once."
E: "She said we should make some up."
E: "So… One two three" (She moved the robot three steps on their paper game board)
A: "That's not what she meant."
E: "Ok, I'm gonna [unintelligible]" (She got up from her seat and walked up to a researcher, and talked to her, their conversation was inaudible, she then returned to her seat)
E: "Yea we can, we can move.." (She sat down and took the robot out of Astor's hand)
E: "Ok, so.. one, two, three" (She put the robot on the blue square and moved it forward three squares)

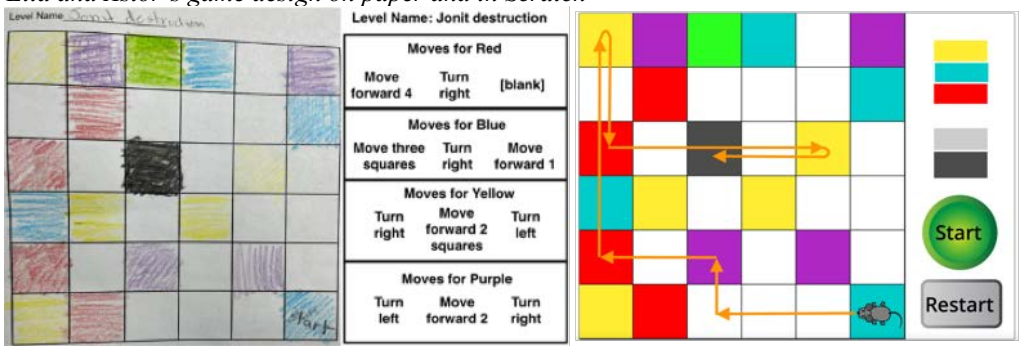
As shown in the example above, Astor challenged Ella's decision so Ella accessed a relational resource, a researcher, to get feedback. We saw other instances of Ella seeking feedback from researchers while students were learning how to play the game, while designing their game on paper, and while programming it in Scratch. Ella may have interpreted being questioned by Astor as him undermining her expertise and a potential barrier to her participation. She sought recognition from a more knowledgeable other in moments of conflict with Astor. By seeking help from the researchers Ella confirmed her decision and received recognition. Accessing a relational resource in this example led to her practicing her creative choice and personalizing the design of their boardgame.

However, Ella did not always seek help and sometimes conceded to Astor. For example, after they completed the design of their game on paper and wrote their procedures for landing on Red, Blue, Yellow, and Purple squares (see Figure 3), Ella decided to color some of the blank squares as distractors to make their board more challenging. This strategy makes it harder to identify the pattern or correct path when looking at the board. Astor insisted on coloring one of the squares green, even though they didn't use green in their game. A disagreement ensued because as Ella told him that they did not have any instruction set for green so people would

know it was not part of the path: “No, because then they can tell, there are no greens” (she gestured to their sheet indicating the red, blue, yellow, and purple squares). After a few minutes of Astor begging, she finally relented and let him color a green square on their board. By conceding and letting Astor put a random green square that served no game purpose on the board, Ella was also conceding to participation on Astor’s terms. According to Nasir and Cooks (2009), material resources are artifacts in the environment that support one’s sense of connection to practice. For Astor, adding the green square may have created a personal connection for him, because according to him it was “the color of his favorite transformer”, but its purpose undermined Ella’s connection to the practice of designing the board. Ella’s actions of coloring in squares as distractors and her concern that “they can tell” suggest that she wanted to express her ideas in their design and wanted to make their game challenging.

Figure 3

Ella and Astor’s game design on paper and in Scratch



Requesting feedback from peers

Students were given the ability to develop their own procedures for moves. Ella’s decision to ‘move forward three’ for the first step of blue was an example of her making up a procedure. When programming their game in Scratch, two nearby boys, Cody and Brian, had been trying to create a procedure they called “shimmy” in which the robot moved and rotated. When they finally got their procedure to work, they cheered and caught Ella’s attention:

Ella: “You made it do it?”
Brian: “What? Yea we got it! [unintelligible]”
Ella: “Wait how did you get that?”
(Ella stood up and started walking towards their computer to take a closer look at their code)
Brian: “We’re not gonna give you the code”
Ella stopped, turned and went back to her seat.
Astor stood up and leaned forward and looked at Brian and Cody’s computer screen.
Ella: “I know. How did you make it shimmy like?” (She moved her body possibly mimicking the shimmy)
Astor: “Uh. It’s just moves”
Cody: “Yea it’s moves”
Astor: “Move something. Move right or move left”
Cody: “Yea, you can also do move back”

In this example, we see how her peers and partner constrained Ella’s participation. By refusing to show their code to Ella but showing Astor, her peers undermined her place and participation in learning. These examples around constraints illustrate ways Ella’s relationship to place, practice, and CS was challenged. Relational resources are a way for people to connect to practice (Nasir & Cooks, 2009). While Ella was able to make connections to the researchers and seek help and confirmation of her CS knowledge, her partner and boy peers often functioned as barriers to her participation. Relational resources can often function as a source of motivation for participation and learning (Nasir & Cooks, 2009). By hindering her relational resources, i.e., interpersonal connections, her peers were deciding who could participate and how.

Affordances to participation

Participation in the unit involved students working in pairs, thus it is not surprising that relational resources shaped Ella’s participation in many ways. As we saw in the previous section, her interactions with her partner and peers often created constraints and barriers to participation. In this section, we focus on her interactions with researchers

that shaped her participation and connection to practice in positive ways. In particular, we focus on the interactions that happened during the unplugged activity of designing their board game level. The structure of this activity led to researchers walking around the room and asking students about their design and their procedures. As we saw in Table 2, Ella had more control of the materials than Astor during this activity and seemed engaged in the design. At one point, Ella and Astor were working on their board when a researcher looked at their moves:

R: "Move forward four and turn right?" (Referring to the procedure for red, see Figure 3)
Ella nodded her head.
R: "Oh man, you got some crazy blocks"
E : "Yeah, I do!" (She said excitedly with a big grin)

This excerpt shows how Ella took ownership of her design and recognized her place in the practice. She showed excitement upon someone else noticing the complexity of their design, recognizing what others value, which is a type of ideational resource.

When Ella was done with the board and coloring in the distractor squares, a researcher walked up to her:

R: "Look at that beautiful board. Wow"
E: "Yea it's.. a hard board "
R: "Is it?"
E: "Very hard [laughs]"
(Later in the conversation)
R: "Oh, do you think this is gonna work?"
E: "Yea, we tried it many times"

In this example, Ella once again took pride in her ability to create a complex design. She also showed confidence in her knowledge of the activity when she said "Yea, we tried it many times" when questioned by the researcher on whether it was going to work or not.

These examples show that when someone took notice of Ella and Astor's game's design, Ella was the first one to respond. She showed excitement about others noticing their design and took pride in it. In the interactions Ella had with her peers, they did not recognize her competence. In her interactions with researchers, however, she received recognition for it. In other words, Ella was accessing her ideational resources during her interactions with the researchers. Her interactions with the researchers appeared to make her feel good about her design. Her agreeing that her blocks were "crazy" and adding that her board was "hard" showed she knew what was valued and good in terms of the practice of designing the game level. This also could explain why she resisted Astor's efforts to add a green block to their board because it took away from what was valued (e.g., being hard).

We found that Ella's participation in the unit changed her ideas around what programming was and what participating in it meant. In the post-interview, she told us that:

> "[this project]...got me more interested in programming. Because at first, when I thought about it, I thought this was gonna be the most boring project ever. Now I really want to do computer programming."

Changing the materials and activities in Ella's computing class changed how she participated. The activities afforded different identity resources which further shaped her participation. When asked about how this project compared to what she typically did in her computer class, she said: "You weren't just sitting on your computer the entire time; you were actually designing your game." A common stereotype that can negatively affect girls' interest in programming is that it involves sitting at a computer all day (Pantic et al, 2018). Ella's preference for the unplugged activity of game design illustrates the importance of changing the activities and materials associated with programming and or CS in order to broaden participation.

It is important to note that Ella had a positive experience despite the barriers to participation she experienced. Another student in Ella's shoes may not have persisted. While we can design curricula that empowers participation for individuals, like in the case of Ella, we need to also ensure the classroom culture and environment enables all students to participate. Without making any causal claims about Ella, we assert that the design of media is not sufficient for enabling participation of everyone. Ella needed 'others' in the setting to access her practice-linked identity resources. In case of Ella, she sought recognition of her ability to create a complex design. She did not find this recognition from her peers, but she did find it from the researchers present in the room. We assert

that in order to further the goal of broadening participation in CS, more effort needs to be put in engendering values in learning settings that help students feel supported and recognized by others.

Discussion and conclusion

The study explored how one student, Ella, participated in a CS unit that was specifically designed around activities and materials not typically associated with CS: playing board games and designing a game level on paper. Using Nasir and Cooks' practice-linked identity resources framework as a lens, we discussed how the design of the unit influenced student participation. Our findings showed how others in the setting afforded as well as constrained Ella's participation in the unit.

Relational resources are one's relationship to others in the environment. Our findings showed how Ella's partner and her peers constrained her participation and restricted her access to material resources. The findings also showed how this lack of support mediated access to ideational resources. Ideational resources constitute one's relationship to the place, practice, and the world and one's ideas about themselves (Nasir & Cooks, 2009). In one example, we saw how Ella's peers refused to share their 'shimmy' code with her, but shared it with her (boy) partner. By excluding Ella, her peers undermined her place and participation in the learning setting. Challenging someone's place can also have an effect on their ideas about themselves and who they consider themselves to be. Research has shown that subtle cues that suggest students don't belong can weaken motivation to participate and that women leave STEM because the social climate undermined their motivation (Cheryan et al, 2009). On the other hand, receiving public recognition for one's competence from more knowledgeable others can lead girls to identify themselves as expert coders (Hughes et al., 2021). Our findings revealed that Ella actively sought recognition from more knowledgeable others, e.g., researchers, on multiple occasions. In one example, she sought feedback from a researcher to resolve a conflict with Astor when he challenged Ella on creating a new move for a blue square. Ella also sought recognition for her ability to create a complex design. She was elated when a researcher commented on her "crazy blocks". In another example, a researcher commented on how beautiful their board (board game design) was. Ella's response was "Yea it's a hard board," indicating that she was seeking recognition despite the lack of recognition from her peers. The recognition Ella received from the researchers helped her view herself as a competent coder. Ella's persistence in learning and taking part in activities as an equal participant is also evidenced by her refusal to give up control of the materials in the plugged activity. Despite the barriers she faced in the form of a lack of recognition from and restrictions from accessing material resources by her peers, Ella persisted. However, it is important to note that not all students will.

Implications

Our findings have implications for researchers, designers, and instructors of CS curricula. The first implication relates to the design of the CS unit. We assert that in order to appeal to a broader set of participants, the media used for learning should be designed to afford participation from a variety of learners. Consider the example during the plugged (computer-based) programming activity in which Ella asked her peers (boys) to teach her how they had programmed their sprite to do a shimmy and they refused. Similarly, Ella and Astor continued to fight for the control of computer mouse and keyboard. One possible explanation for Ella's tension with them can be explained by the prevailing gendered cultures in CS education. Studies have shown that boys are less likely to share control of the resources during coding activities (Gray & Leith, 2004), while girls are likely to have a lower sense of belonging in computing activities than boys owing to perceived stereotypes (Master et al., 2016). In contrast to plugged activities, unplugged activities of playing the board game and designing the new game levels provided students with tangible materials. Ella was much more in control of the materials during the unplugged activities, while she struggled to keep control of the materials in the plugged tasks. We also argue that the sequencing of our activities encouraged Ella's participation. In our unit, CS concepts were introduced in unplugged media and then revisited in the plugged media. Ella appeared to have a high level of engagement during the unplugged activities. Her participation changed during the plugged tasks owing to Astor seizing more control of materials. In spite of that, Ella sustained a high level of engagement and persisted to keep control of the materials. We thus see how the use of unplugged materials to introduce CS concepts, before transitioning to the use of plugged materials may have helped Ella to assert herself during the computing tasks, and to go against the stereotypes embedded in the discipline of CS (Master et al., 2016).

The second set of implications of this study relates to the role of others present in a learning setting. Studies suggest that girls perceive CS as a stereotypically male discipline (Master et al., 2016). Thus, in order to engage girls in CS learning, the 'others' in the learning setting should recognize expertise of girls. Recognition of one's expertise can transform one's view of the field (Keune et al., 2019) and help girls become more confident in their abilities to code (Hughes et al., 2021). As we saw in Ella's example, 'others' meant researchers in the

room, her partner, as well as other students in the classroom. In a more naturalistic classroom, the class teacher should play a similar role as the researchers did for Ella.

We thus highlight that educator should be aware of the role their recognition can play in encouraging girls to participate in CS classrooms. The second part of our assertion relates to creating environments where girls are also recognized by their peers for their expertise. Even though Ella received recognition she sought from the researchers, we saw examples in which Ella lacked support from her partner and her peers. In their study of three girls in a code camp, Hughes et al. (2021) found out that public recognition of girls by their teachers in a CS classroom can lead other students to perceive the girls that receive recognition as expert coders. In our study, however, Ella did not receive recognition from her peers. In sum, CS curriculum design should foreground how activity structures and materials shape who participates and how they participate. Further, the design of learning settings should include strategies that help a broader array of students feel supported as well as recognized by others.

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International Society of the Learning Sciences

A comparison of refutational and rhetorical aspects in science arguments by grade level

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Abstract: Engaging students in the process of argumentation supports student understanding of scientific knowledge. We present a comparison of arguments from 7th and 11th grade biology students from modeling tasks using an argumentation framework to investigate differences in student approaches during two comparative tasks. While students at both grade levels constructed arguments that contained multiple reasons and epistemic ideals, we identified differences in rhetorical statements and refutational strategies by grade level. High school students attended to the underlying model-evidence relationship to explore differences between competing models and to make comparisons and refute the competing model at higher instances than middle schoolers. Refutational strategies by high schoolers connected multiple pieces of evidence, or made connections between provided models and evidence, while middle schoolers made use of epistemic ideals to refute a competing model. These differences are discussed in conjunction with implications for design.

Argumentation engages students with constructing and critiquing claims about phenomena using appropriate and sufficient evidence (e.g., McNeill & Krajcik, 2011). Students can leverage evidence in arguments in multiple ways to make sense of phenomena and to articulate evidentiary relationships of the natural world (e.g., Nussbaum, 2021). Sometimes to increase the challenge of the task, students are presented with models in lieu of claims. These models include mechanisms and serve to explain some phenomena. Students can be tasked with constructing, evaluating, or revising such explanatory models (e.g., Passmore et al., 2009). Scientific argumentation plays a central role in evaluating competing models based on evidence, or identifying the best model or explanation (e.g., Krajcik & McNeill, 2012; Nussbaum et al., 2019). Research on student argumentation relies on argumentation frameworks to provide insight about how students evaluate and use evidence to articulate claims and revise their own and others' claims.

These argumentation frameworks tend to focus on argumentation structure with less focus given to the role of epistemic knowledge about what qualifies as a good argument, a good model, good evidence, or the relationship and interaction of models with evidence. Some of these frameworks focus on a specific aspect or aspects of arguments in order to conceptualize student understanding. Paying specific attention to these structural aspects is critical but tends to hide other aspects such as the rhetorical nature of arguments. To better bridge this gap we use the *Integrative Argumentation Framework (IAF)* which examines arguments as a series of argument moves (Cavera et al., 2018a). This framework attends to structural aspects of arguments (e.g., capturing the claims made, supporting or refuting statements), appeals to epistemic criteria of model quality, and rhetorical nature of arguments as argument *moves*. These moves serve to capture how students convince a reader of a standpoint as they move through the pieces of their argument.

Scaffolding and task structure play a major role in the kinds of arguments that students can construct and critique (e.g., McNeill & Krajcik, 2012). These arguments tend to contain increasingly robust aspects of arguments (e.g., a refutation, more reasons) when explicit scaffolds help students attend to those features of arguments. While we know that students tend to construct increasingly robust arguments as they move through different grade bands particularly with scaffolding (e.g., Kuhn & Udell, 2003; Nussbaum et al., 2019) we know less about the nuance between those differences. This paper intends to address the impact of scaffolding on student argumentation and evaluate the kinds of complexity and nuance that students develop at two grade levels (middle school and high school) using the same argumentation framework, *IAF*.

Theoretical Framework

Argumentation is the process of using data to defend or refute a standpoint (Toulmin, 1958; 2003), and is a critical knowledge-building process that appears in science classrooms as a way to support student understanding of science concepts (e.g., Driver et al., 2000). Students can be presented with claims that describe scientific phenomena or scientific models that include an underlying mechanism, but students find evaluating competing mechanistic models to be cognitively demanding (e.g., Krist et al., 2019; McNeill & Krajcik, 2012). Scientists

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make these kinds of evaluations about complex arguments of phenomena (Popper, 2014). Students can critique and argue about why one argument is better supported by evidence oftentimes by demonstrating that more evidence supports evidence over another. This kind of weighing strategy has been described before (e.g., Nussbaum et al., 2019) as a way of either counting the amount of supporting evidence in support of a chosen model or by integrating evidence into the argument or by integrating evidence into the model and showing how that evidence relates to the chosen model, either as warrant or backing for a chosen model (Cavera et al., 2018a).

However, we know that students find difficulty in constructing and critiquing competing claims and models of competing phenomena, often developing supporting statements of their chosen claim without discussing a competing idea. This idea of discussing the opposing side, or refuting competing claims, evidence, or discussing the contra argument, is often considered one of the more difficult aspects for students to attend to in argumentation. This process of identifying differences between competing ideas is central to the argumentation process. Osborne and colleagues (2016) discuss arguments that include a *counter claim with justification* as one in which a student can explain why the competing claim is wrong by leveraging a warranted comparative argument. This kind of sophisticated reasoning pattern is a difficult move for students to tackle and appears at the highest level of their argumentation learning progression. McNeill & Krajcik (2012) discuss scaffolding students' rebuttals last in class as part of their claims, evidence, reasoning, and rebuttal (CERR) framework in order to reduce cognitive load. Successfully navigating and discussing their own argument as well as the counterargument in both of these instances is seen as an achievement. Often the idea *rebuttal* and *refutation* are used interchangeably in the literature but are distinct ideas. Toulmin (1958) defined rebuttal as "conditions of the exception", whereas refutation is a contradictory idea to the chosen claim (van Eemeren & Grootendorst, 2001). When students identify juxtaposing ideas between comparative models, they are refuting such as in the case, *I believe in model 1. It is better supported by the evidence unlike model 2 which is supported by less, low quality evidence.* A rebuttal could be posed as, *model A is always right except when it is supported by less evidence.*

We know that students struggle to form refutations and without sufficient scaffolding struggle to form refutations on their own. For example, Nussbaum and colleagues encouraged students to juxtapose competing arguments as part of a scaffold known as the argument vee diagram (AVD) at the middle school and college level which supports students to make comparisons to integrate competing arguments (Nussbaum, 2021; Nussbaum et al., 2019). This kind of comparative strategy allowed students the planning space to identify flaws in the counterargument. Essentially, refutation in this case was defined as the identification that the conclusion of the counterargument is false or that the premises of the competing argument is flawed. By allowing students the space to build an integrative solution, or a *design claim*, students can identify flaws and explore both an argument and counterargument using the AVD scaffold.

These and other approaches attempt to capture the nuance and complexity of student argumentation at the middle or high school level (e.g., Grooms et al., 2018; Nussbaum, 2021; Nussbaum et al., 2019) though these often focus on analyzing *how* students construct and critique arguments and the kinds of structural and epistemic ideas that students have about a topic. In this, we focus on argumentation moves across two grades (7th and 11th grade) in order to understand more about the differences in argumentation across middle and high school. We apply the Integrated Argumentation Framework (*IAF*) which focuses on an analysis of nuance of arguments through the lenses of structural, epistemic, and rhetorical perspectives of arguments (Cavera et al., 2018a). These moves aim to capture how students articulate their standpoint by capturing three lenses of argumentation: structural aspects (e.g., supporting claims, refuting claims), appeals to epistemic criteria, and rhetorical features. We applied *IAF* to student arguments to identify the kinds of arguments that students develop in middle and high school. We developed similar assessments about a topic in biology that aimed to evaluate students' competencies and reasoning with models, and the construction of evidence-based arguments about core science topics. Our research questions are: What are the kinds of arguments that students develop at the middle school and high school levels? What are the types of refutational and rhetorical features identified in student arguments?

Methods

Study Context

The study took place in two suburban schools in the United States—a middle school (7th grade) and a high school (11th grade) in which students were learning biology topics in the same school district. The schools were considered academically average in mathematics, language arts, and science performance. The district served 79% White, 9% Hispanic, 6% Black, 1% Asian, and the remaining students identify as mixed race. Approximately 34% of the students were classified as economically disadvantaged, with 27% of students qualifying for free or reduced lunch in the middle school while 34% qualified in the high school.

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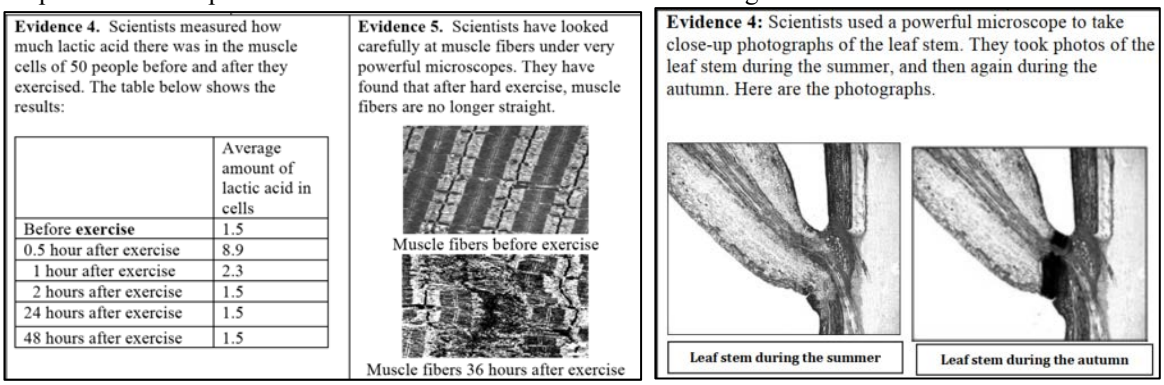
In both grades, students participated in a modeling-based biology curriculum which engaged students in the development, evaluation, and revision of models of scientific phenomena, and provided students with multiple opportunities to develop evidence-based arguments in support of a chosen model (from 2-3 competing alternative models and multiple pieces of evidence that varied in quality). In both high school and middle school levels, students were assigned either a task called Falling Leaves (*FL*) or Muscle Pain (*MP*) at the close of instruction.

Instrument Design & Data Collection

Students were provided with 60 minutes to complete the task. The assessment tasks included five pieces of evidence that varied in quality and two competing explanatory models, and students were asked to build an argument in support of the explanatory model they thought best explained a phenomenon they had not studied in class around the topics of muscle pain (e.g., Why do you think muscle pain occurs after heavy exercise?) or leaves falling off trees (e.g., Why do you think leaves fall off trees in the fall?). We will be discussing posttest arguments written by students at both grade levels. The evidence provided to students were either of high quality (e.g., scientific studies), provided information on the phenomenon (e.g., description of the phenomenon), or was an anecdotal account.

Figure 1

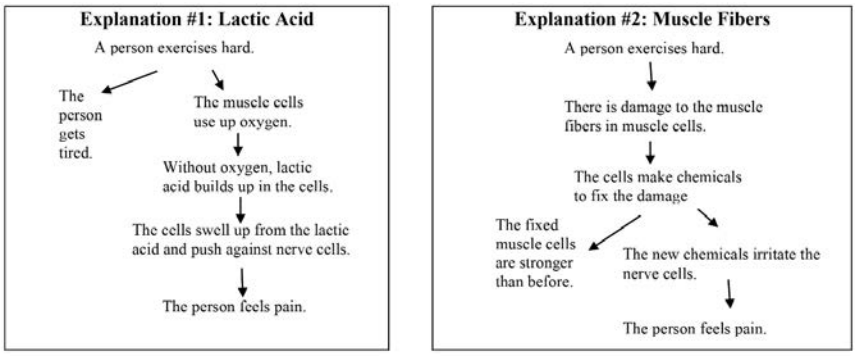
Example of evidence provided to students in the Muscle Pain and Falling Leaves assessments



For space purposes, we provide two sample evidences from the Muscle Pain (MP) assessment, and one from the Falling Leaves (FL) assessment (Figure 1). Evidence 4 (left) describes that right after exercising lactic acid levels rise but that approximately two hour later, levels drop to their initial level. Evidence 5 (right) shows the damage to muscle cells that comes from exercising but does not show the mechanism. These evidences are designed to support or contradict one or both of the models. Evidence 4 from FL shows photographs of leaf stems.

Figure 2

Explanatory models presented in the Muscle Pain assessment

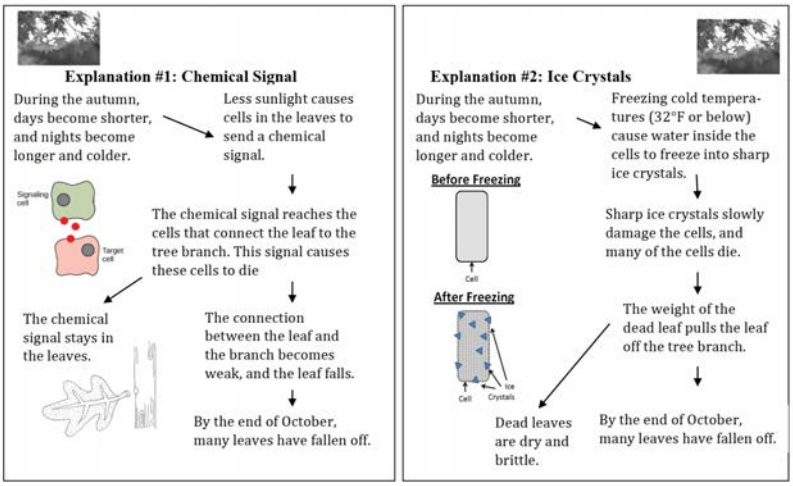


In the MP task, students were presented with two competing explanatory models about the mechanism of muscle pain (Figure 2). One explanation suggested that when a person works hard oxygen is used up causing a buildup of lactic acid in cells causing cells to swell and push against nerve cells causing pain (which is incorrect based on the provided evidence). The other explanation hypothesizes that the cells are damaged during exercise

leading to fiber damage which causes cells to fix the damage. These chemicals cause irritation which causes pain. The key distinction here is the underlying damage causing irritation to the nerve cells as opposed to the buildup of lactic acid. This idea is not supported by the provided evidence. Once students were presented with all five pieces of evidence and the two explanatory models, they were asked to write an argument that explored which model best explored why muscles hurt 24 to 72 hours after exercise, the *lactic acid explanation* or the *muscle fibers explanation*? They are asked to provide reasons and to write to someone may disagree with you, but who has not seen the evidence.

Similarly, in the FL assessment, students were provided with five pieces of evidence and two competing mechanistic models. One explanation suggested that in autumn shorter days resulted in less sunlight and the release of a chemical from leaf cells, which in turn causes the connection between the leaf and the branch, making the leaf fall. The competing model suggested that the shorter days resulted in cold temperatures which resulted in the production of ice crystals inside the leaf cells and causing damage and increasing the overall weight of the leaf cells. The key distinction is the impetus for the underlying mechanism—shorter days resulting in the release of a chemical or colder temperatures causing ice crystal to build up in the cells. The first hypothesis, shorter days resulting in the release of a chemical is correct based on the provided evidence.

Figure 3
Explanatory models presented in the Falling Leaves assessment



We report data from students who completed the argument in the MP task (n = 92 at the middle school level, n = 119 at the high school level) and the FL task (n =107 at the middle school level, n = 112 at the high school level). Each was given to students at the end of instruction which was approximately 20 weeks for middle school and 10 weeks for high school. Any students who did not complete the argument (e.g., blank essays) were removed from data analysis.

Data Analysis

We analyzed student arguments using the *Integrative Argumentative Framework (IAF)* (Cavera, 2018a). This argumentation framework analyzes student arguments by segmenting student arguments into coherent propositions or *argument moves*. These moves are categorized into three major perspectives: *structural*, which captures the presence of a *Claim statement* (e.g., *I believe model A is best*.) which can either open or close the argument, and *Support* and *Refute* statements which provide credence (e.g., *I think the model is correct because evidence 1 and 2 support it.*) or demonstrates how the competing model is false (e.g., *The only evidence that supports model B is evidence 4 and that isn't a good quality piece of evidence*.). *Epistemic* moves are those in which a student appeals to epistemic ideals to satisfy an epistemic aim (e.g., *The model has good pictures. It shows a step-by-step process.*). *Rhetorical* moves include the *Setting the Stage* moves, which are those that provide a strategic organization of the argument. We identified two major types of *Rhetorical* moves: (a) Overview moves where students identify differences between models (e.g., *Model B talks about damaged cells which Model A doesn't even mention.)* and (b) Preview where they provide a summary or layout their argument (e.g., *I think [the] lactic acid [model] is better. There are more evidence in support of it and it's clearer organized*.).

We took this framework and expanded the *Refute* move category based on a prior coding scheme (Cavera, 2018a) in order to capture the kinds of refutational strategies that students applied during their arguments. We

identified three major refutational strategies: (a) refutation based on congruence with existing theories, (b) refutation based on evidence credibility, or (c) refutation by evaluating the quantity of evidence that supported each model in conjunction with (a) or (b). Three independent coders coded 22% of the middle school data and 38% of the high school data. Interrater reliability was 86% and 91%, MS, HS respectively. All disagreements were discussed.

Results

We begin our analysis by discussing the kinds of argumentation moves those students displayed at each grade level, then discuss the refutational moves and rhetorical moves more specifically by grade level. By starting with discussing the arguments more generally and then moving to examples we explore the trends displayed by each group and then can explore what these argumentation moves look like in practice.

Composition of student arguments at the middle school and high school levels

When comparing each of the groups of arguments (Table 1), students at the middle school level on average wrote shorter arguments than students at the high school level across assessments. This was captured both by the average number of words as well as the average number of argumentation moves. While students at both grade levels selected the model supported by evidence (Explanation B: the muscle fibers model in MP and Explanation A: Chemical Signal in FL) at approximately the same rate, we note differences in the amount of *Support, Refute, Epistemic*, and both types of *Setting the Stage* moves. We also note that a percentage of students at the middle school level did not select between the two provided explanatory models in their claim statement while all of the students at the high school level chose between the two models. We also note that students in both grades did not provide rhetorical set ups in the FL task.

Table 1: *A comparison of arguments at the middle school and high school levels*

	Middle School-MP	High School-MP	Middle School-FL	High School-FL
Model Selection	Explanation A: 47% Explanation B*: 51%	Explanation A: 46% Explanation B*: 54%	Explanation A**: 49% Explanation B: 46%	Explanation A**: 55% Explanation B: 45%
Avg. moves	3	4	4	4
Avg. word count	70±15	177±12	79±8	144±11
Support Moves	44%	34%	53%	47%
Refute moves	9%	14%	7%	12%
Epistemic moves	21%	16%	23%	17%
Setting the Stage moves	Overview: 3% Preview: 4%	Overview: 9% Preview: 5%	Overview: 1% Preview: 1%	Overview: 2% Preview: 1%

*Model B is better supported by the evidence provided in MP
**Model A is better supported by the evidence provided in FL

Rhetorical Strategies & Appeals to Epistemic Quality

Rhetorical and epistemic strategies were evaluated at both grade levels in terms of the identification of our *Setting the Stage* and *Epistemic* moves (Table 1). An example MP middle schooler provided both a preview of their argument, *It is supported by more, higher quality evidence than explanation A is*, as well as an overview of their argument by juxtaposing the evidences in conjunction with each of the models. This student wrote, *evidence 2 supports model B because it mentions the nerve cells. Evidence 3 supports model B because it explains how the muscles get swollen which is in model B not A.* MP high school students alerted readers of important features in their argument, for example, *One reason why I think model B is better is because out of the 5 evidences, [the] majority of them support model B.* The student guides the reader through how the majority of the evidences support their model instead of the competing model and provides a 'roadmap' to follow and be aware of aspects the student deemed important. Towards the end of their argument the example high school MP student states, *Overall, we can see that model 1 has more evidence contradicting it than supporting it than model 2. Model 2 has the best pieces of evidence supporting it and more evidence supporting it than model 1 does. Comparing the models directly, they are constructed in an identical fashion, so they both meet the same model criteria. Thus, model 2 is the better explanation.* By attuning the reader to this rhetorical strategy—discussing each evidence and its relation to each of the models, the student is then able to then juxtapose the models again once they have evaluated each

of the evidences. The high school example sets up and relies on the relationship between the quantity and quality of supporting evidence for their selected model throughout the entirety of the argument. This student also addresses states that there are differences between the two provided models, addressing the epistemic appeals of the model criteria and relying solely on the relationship between model and evidence to make a decision between the models.

In the FL task, middle school students focused on sense-making epistemic features like: *it* [model B] *makes more sense because when it gets colder, the leaf freezes, and forms ice crystals.* High schoolers similarly described the quality of evidence provided and connected it to the provided models in such cases as, *The best explanation is explanation 2. This is because it has the strongest piece to go with it which is evidence 5. 5 is the best because it shows you a detailed graph of exactly how much of the leafs [SIC] are left other then that there's a blurry picture and some common knowledge about trees. So the best explanation with the best form of evidence will obviously be the best.* Overall, in the FL task regardless of grade level students attended to the rhetorical aspects of arguments at a lower level than students completing the MP task. Some students provided an overview of their argument like this high school student, *I believe explanation 1 is the best explanation of why leaves fall from trees because the act of a chemical signal being sent to the leaf and causing the leaf stem to weaken from the branch makes more sense. Explanation 2 makes no sense because cells in the leaves are full of water and get frozen and ice crystals form and the weight of the leaf pulls it off the tree right? Then how do they become dry and brittle instantly before falling if there frozen and autumn leaves are already dry as is on the tree?* This rhetorical set up is a great opener to help set the reader up to juxtapose the content of the two explanatory models.

General trends were noted in both assessments, some students also discussed the epistemic qualities of the evidence and models as a way of determining their model selection. Middle school students tended to favor explicitly pointing out how their chosen model connects to common class criteria lists for good models (e.g., the model describes the phenomenon, the model is good, clarity of the model, etc.,). High school students did this as well, though more often pointing out the communicative features (e.g., clarity, large sample size) and the role of the evidence in supporting each of the models.

Refutational approaches at the high school and middle school grade levels

Discussing the competing model is a difficult task for all students and like others, students in both groups could produce refutations at a rate of 9% and 14%, and 7% and 12% (middle school, high school, MP to FL, resp.). Parsing the kinds of refutations that students attended to in their arguments (Table 2) students at the middle school level focused on the credibility of the competing evidence as a means of refuting the competing model. Students employed this strategy 36% of the time on its own and all but one student used it in conjunction with the *quantity of evidence model that supported each model* strategy. When high school students refuted, they often combined strategies in conjunction with the *quantity of evidence that supported each model* with more students focusing on the *credibility of evidence* than *congruence with existing theories*.

Table 2: *Refutational strategies by grade level*

	Middle School-MP	High School-MP	Middle School-FL	High School-FL
Credibility of evidence strategy	39%	28%	45%	31%
Congruence with existing theories strategy	23%	24%	18%	22%
Quantity of evidence that supported each model strategy	38%[α]	48%[α]	37%[α]	47%[α]

[α] Represents all students who chose this refutational strategy with either the credibility of evidence strategy and congruence with existing theories strategy.

In practice, students who refuted heavily favored the *quantity of evidence that supported each model strategy* combined with one of the other strategies or the *credibility of evidence strategy* alone to refute the competing model as compared to the *congruence with existing theories strategy*. Middle schoolers were more likely to focus on the credibility of evidence. For example, a middle school student completing the MP task organizes their argument by discussing how several evidences support their chosen explanatory model (Model A, the lactic acid model). Throughout their argument, the student demonstrates that several evidences (evidences 2,

3, and 4) all provide support only for their model and not the competing model by describing how specific statements only appear in the text of one model, *model A is supported by evidence 4 because it mentions lactic acid which is obviously only in model A, the main idea of model A [it's] even in the title.* This, tied with their credibility of the evidence that supports their chosen model, such as in the case: *model A is better because it has a chart explaining before and after exercise meanwhile model B only has pictures that to me don't help the reader*.

High school students tended to have a different approach. For example, a high school student completing the FL task stated that their model is supported by more, high quality evidence, such as evidence 4 and 5. They state that the picture (evidence 4) contradicts model 2 because *ice would be throughout the leaf to support the model*, *but model 1 shows that the damage is in just the stem. So this supports model 1 and contradicts model 2.* Evidence 5, a graph that depicts the number of nights below freezing and the percentage of leaves still on trees fully disproves model 2 because *there were no below freezing nights until December but the trees are bare!*

Discussion

Prior to students completing the post argument assessment, which was examined in this study, students were provided with scaffolds that were embedded into the curriculum. Due to students' use of these scaffolds, we have found that students developed extended arguments that contain rhetorically complex ideas and refutations. Not only do students generate these kinds of arguments at each grade level they attend to different kinds of strategies to refute the competing model. Students at both grade levels are also able to attend to the rhetorical nature of arguments and appeal to epistemic qualities of evidence and models.

Refutational strategies and complexity

Appeals to epistemic ideals, rhetorical ideas, and refutations are evident, identified here as argumentation moves, both middle school and high school students developed arguments that contained features but did so in different manners. Previous researchers have identified that with scaffolding students can take the tactic of refuting a competing argument by evaluating the amount of supporting evidence for competing arguments (Nussbaum, 2021; Nussbaum et al., 2019). This approach is similar to the strategy discussed here though many of our students additionally combined this approach with an additional appeal to epistemic quality. Middle school students who refute tend to focus on the epistemic qualities and features of the evidence in order to refute the competing model. High school students tend to focus on the relationship between the models and evidence, attacking the connection as compared to middle schoolers who attack *qualities* of the model and evidence. In each instance students are refuting; however middle schoolers tend to focus on their model quality criteria list and describing how each of the evidence support their own model and not the competing model based on the provided scaffold. This demonstrates the difference in what is important to tackle and differentiate between—the model evidence connection or the epistemic qualities of the evidence. Students can evaluate the quality of the evidence that support their own model or claim or the quality of the connection between the model and evidence.

Arguments written by high schoolers contained more variation in argument moves and were more likely to contain both types of *Setting the Stage* move in the MP task. These rhetorical moves were noted at a much lesser degree in the competing FL task. High school arguments were, on the whole, longer than the arguments written by middle schoolers which lends themselves to the increased level of nuance. However, at both grade levels students could include a *Setting the Stage* move, often cueing the reader of how their argument was organized or of what features they would discuss throughout the argument. This idea of setting up the argument is an important rhetorical strategy that alerts the reader of important features of the competing argument but also tied into a refutation it demonstrates a powerful approach to argumentation.

The role of scaffolding on argument complexity

A major contributing factor to the development to the nature of the arguments that students developed was a feature of the task design. During instruction, students were provided with the Model-Evidence Link (MEL) matrix scaffold and expected to discuss the competing models and relationship between the models and evidence. For the assessment the scaffold was removed, and we found that at both grade levels students struggled to discuss the competing models, a finding consistent with previous work (Cavera et al., 2018a; 2018b).

This work further supports the idea that students can argue in robust ways with respect to rhetorical and refutational aspects of argumentation. Previous researchers have demonstrated that taking students to make comparisons between competing claims is difficult, challenging students with competing multistep models increases the difficulty—even with sufficient scaffolding. This work contributes to the body of work that has shown that students at both the middle and high school levels can form refutations; this work demonstrates that students at each of the grade levels go about the process in different ways dependent on task and grade level. We also find task dependent differences with respect to rhetorical approaches. We hypothesize that students responded

to each task differently because this assisted in how they made sense of each task. As these tasks were completed by student populations that seen the phenomenon of leaves falling off trees before this, coupled with the provided evidence may not have required the set up for the underlying mechanism. Comparatively, the complexity of muscle pain (a phenomenon students have experienced but cannot physically see) may have required more mental effort to unpack and explain lending itself to more rhetorical maneuvering.

Students at both grade levels can argue rather complexly especially when it comes to refuting. They just need to be provided complex tasks that ask them to develop extended evidence-based arguments. The refutations attended to are powerful but the strategies at each level were different with more attention at the high school level paid to the connection between the model-evidence connection while middle schoolers paid more attention to the qualities of the evidence that support their own model. These approaches differ from what Anderson and colleagues (2001) and Nussbaum and colleagues (2019) have previously found. We also know from previous work and others in the field that discussing the communicative features of arguments (e.g., pictures, titles, etc.) are what students' value *before* instruction (e.g., Pluta et al., 2011; Cavera et al., 2018b). Even with scaffolding students at the middle school level rely on these communicative features to refute the competing model and its evidence. Students at the high school level begin to tackle that relationship between the model and evidence noting the strength of the model is only as good as the evidence that supports it.

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Towards a "Slowed Down" Pedagogy: An Emergent Youth-Led Practice of Politicized Care

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Abstract: We discuss how youth "slowed down" an online STEAM makerspace during the COVID-19 pandemic, opening up new ways of being and doing together. The practices youth enacted in slowing down arose from their politicized care for one another. Adult mentors, through moments of slowing down, were given an opportunity to rethink how to listen to youth's desired ways of doing STEAM. To discuss the implications of slowing down, this article features two instances in which Black youth "slowed down" in sessions to demonstrate their desired ways of being together/doing together within the STEAM context. Highlighting youths' moves has implications for how educators think about co-designing programs with youth and how to enact politicized care in the face of rapid social, environmental, and political change.

Introduction

The typical pandemic Green Club (GC) meeting began with the images of the adult mentors huddled on a computer screen in individual tiles on a black background, chatting and waiting for youth to file into the Zoom room. The regulars usually joined before the allotted after-school time: Lulu and Shadow (sister and brother), Finn, and May appeared in their tiles one by one, though their rectangles typically featured their screen names instead of their faces. One of them, without fail, started us off with their usual question: 'Can I show you guys something I drew?' This question always elicited positive responses to the tune of "YEEEEESSSSS" and "please do!" in the chat from the mentors and the other youth. The youth who were regulars during the in-person STEM-Rich program integrated their recent art during each virtual Wednesday session with updates on what they had been drawing in their free time.

This ritual that developed is just one example of how youth "slowed down" (Shahjahan, 2015) our engagements in the virtual space of GC. Sharing artwork was eventually institutionalized in the agendas mentors created, allowing for more time to appreciate each other's work that had taken place when we were not together. In this example of youth-led practice, youth show that "being with" (Villenas, 2019) each other is not precluded by being physically apart. Rather, there are ways to "be with" one another that center relationships, processes, and expressing critical discourses of the "multi-pandemic" (Calabrese Barton & Greenberg, 2021) that can emerge when youth have space to enact it.

We therefore discuss how youth helped adult mentors make space for their desired ways of engaging with each other and STEAM through slowing down in the virtual club. Slowed down pedagogy emerged during the peak of physical distancing practices and uncertainty of the future of the pandemic, when vaccines could not come fast enough and terms like "Zoom fatigue" (Schroeder, 2021) and "learning loss" (Merrill, 2021; Calabrese Barton & Greenberg, 2021) proliferated throughout educational discourses in the U.S.. We therefore emphasize the relational nature of the learning that took place in this year of GC. We argue that slowed down pedagogy has relevance to multiple educational contexts wherein educators are invested in being responsive to the ways that youth can reshape normative engagements/discourses. To support this argument, we explore how Black youth sought to reorganize practice in the remote STEAM makerspace, the "Green Club" (GC), by collaboratively engaging in a practice of *slowed down pedagogy* (Shahjahan, 2015) that built over the COVID-19 multi-pandemic. We position this slowing down as stemming from GC members' *politicized care* (McKinney de Royston et al., 2017) for one another. We answer the questions: **How and why did youth "slow down" the learning environment through their discourses and practices? What impact did youths' relationship building have on their opportunities to learn and become in STEAM?** In answering these questions, we begin to illustrate what "slowing down" can look like, and how it can be responded to by adult educators in order to transform learning environments towards equity.

Background

We start from the premise that youth are constantly developing, demonstrating, and sharing expertise in many different subjects, with STEAM being one of those, and that STEAM-rich making in a community oriented youth makerspace is a site for this sort of learning to occur (Calabrese Barton & Tan, 2018). Foregrounding youths' moves to "be with" (Villenas, 2019) each-other in the online format, we build on work that views STEAM learning

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as a constellation of relationships, practices, and discourses that ultimately position them as knowledgeable and creative STEAM makers. We also position it within work that aims to reimagine why we teach STEAM in the first place. Instead of centering labor and the projects of STEAM, we aim to center the relationships and alternative discourses that can take place within these contexts (Sengupta-Irving & Vossoughi, 2019). This is what we refer to as the "relational" aspects of learning; how youth and adults came together to co-create the experience of GC.

Much effort was required from families to reorganize time, priorities, and resources due to the pandemic (Jalongo, 2021). Our remote program took place during larger "community infrastructuring" efforts (Greenberg et al., 2020) which focused on "build[ing] capacity for disrupting injustice and supporting each other during the COVID-19 crisis" (Greenberg et al., 2020, pg 1). GC continuing into a socially distanced program held online was part of this move towards infrastructuring, in that it served as a space for youth to come together to create work and discuss the pandemic as it unfolded. The youth discussions and practices that are highlighted in this paper are part of "disrupting injustice and supporting each other" in the context of learning more about STEAM.

Theoretical frameworks: Slowing Down & Politicized Care

It was essential that the space of GC reflect caring relationships which recognized the multiple pressures on families and youth during the height of social distancing (Thompson et al., 2021). Slowed down pedagogy emerges from the nexus of politicized care and slowing down. This particular mixture creates a lens through which we can understand youths' projects, relationships, and interactions that does not center the end products of their work.

Politicized care encompasses the ways that adults of color care for youth of color, bringing attention to the politicized dimensions of their needs (McKinney de Royston et al., 2017). We build on the concept of politicized care to show not only how teachers or adult facilitators enact politicized care for their students, but how, in a setting where youth are co-constructors of the program, youth enact politicized care for each other. Politicized care can be seen in the relations between members of the learning community, such as when they affirm/build on/push on critical discussions about their lives that are often politicized (such as climate change or police brutality), or when they uplift each other as knowers and doers of STEAM who also carry vital community knowledge and ways of knowing.

Often, youth enacted moments of politicized care for one another, ***slowed down*** the GC agenda, often times to a point where it was changed entirely. We refer to 'slowing down,' initially conceptualized by Shahjahan (2015), as practices/moves that focus on the embodied nature of learning and "being with" (Villenas, 2019) each other, placing an emphasis on the bodily, emotionally, and socially shaped dimensions of youths' learning experiences. 'Slowing down' was one way that youth invited all participants to put aside learning expectations and norms that had developed over time in previous years as a way to care for each other. Occassionally, this meant that preexisting agendas would be thrown out in favor of youths' needs in the moment. We claim that 1) these efforts to slow down the STEAM program were led by youth, through discourses and practices that affirmed each other, and 2) this process of slowing down made space for critical and political discourses on substantive concerns about the world we live in, while also re-orienting their maker program/experiences/projects in ways that more explicitly reflected these forms of caring.

Methods

Context

GC has been a fixture for over a decade, in-person, at a local Great Lakes City, Midwest youth center. During the 2020-21 academic year, GC went virtual due to COVID-19 physical distancing guidelines. The virtual sessions were held on Zoom and lasted approximately one hour at least twice a week. The purposes of these meetings varied: one meeting (Monday) was dedicated to adult and youth researchers co-designing the topics, goals, and timelines of projects and sessions, while the other meeting (Wednesday) focused on making and working through the focal project for the semester. We had two semester-long projects (the "focal projects") where youth collaboratively planned, designed, and created projects that engaged both STEAM and their community, both widely construed. These were "2020 stories," where youth told their stories of the multi-pandemic using a broad array of materials, including anything from their homes and materials that could be distributed from the makerspace. Youth were encouraged to be imaginative and open-minded when thinking about what they could use to tell their stories, leading to a variety of project mediums such as paint on canvas, a written story, a coding project, and videos. The winter project was a podcast where youth talked about their collective interests and learned how to use audio editing software. Each week youth ideated on new topics to discuss with each other and recorded it. They also broke into groups to work on other necessary projects for the podcast, such as creating the cover art and deciding how to edit.

Participants

The youth in this program are predominantly Black middle schoolers of various gender identities who live in GLC. Throughout the year, participation ebbed and flowed, but there was a core group of 5-7 youth that would consistently join in on the Monday and Wednesday meetings, though there could be anywhere from 2-10 youth in the session on a given day. There were 5 adult mentors, 2 of whom were White women, 1 Black woman, 1 Latinx woman, and 1 White man. Of this group, 3 of the adults are from or have lived for a while in the GLC community, and taught for many years in this program. All of these mentors are authors of this paper.

Data Generation

We engaged in data co-generation through critical ethnographic methods, which included writing field notes, video-recording sessions, saving Zoom meeting chat logs, collecting artifacts from sessions, and facilitating participatory, long-form interviews with youth twice throughout the school year. Data were analyzed as analytic memos of moments that stood out to adult researchers. In a second round of analysis, researchers debated-towards-consensus what types of "slowing down" were happening in different identified moments. Finally, we organized these types into analytic claims, mapping them to empirical evidence of how our shared youth-adult engagement forms shifted and transformed, and what that shifting/transforming revealed to us about slowed-down pedagogy in our program. All names mentioned here are pseudonyms chosen by the participants.

Findings

We return to our original research questions to structure the findings. First, how and why did youth "slow down" the learning environment through their discourses and practices? We zoom into moments where they enact politicized care for one another by slowing down. In the introduction, we shared an example of youth creating a ritual that made space for sharing work and affirming one another. This ritual was one of an arrangement of practices that youth engaged in that showed politicized care for one another in a way that was developmentally appropriate and emphasized the importance of the quality of attention that we allow for the youth to enact.

Second, we answer the question: what impact did youths' relationship building have on their opportunities to learn and become in STEAM? During the COVID-19 pandemic, youth's relational learning took center stage in their work. We privilege this relational work while also drawing attention to the STEAM learning that they demonstrate through their practices. These enactments of politicized care productively slowed down GC and opened up new spaces for engaging in STEAM. Making explicit how youths' relational development mattered in the space is important not only for understanding this in the context of the pandemic, but for designing future learning environments in which relational learning is valued. The two vignettes support our view of the importance of relational learning. In the first, we see how one of the youth calls attention to silence and uses it to spark critical discussion. In the second, we see how leaving space open for redirection can still lead to substantive learning while honoring the ways in which youth want to engage.

Negotiating the initial slowing down through calling attention to silence

Finn, a Black non-binary youth, has found a video relevant to what GC members would be interested in, and wants to share it. We show how Finn's action of calling attention to "silence" and using it to make space for critical political discourse about both the environment and their futures is one way youth sought to slow down and re-orient their program around new directions and relationalities. In this first example, we describe a moment where an adult educator negotiates the activity with youth to slow down and support youths' relationship building in STEAM.

In the moment, Luz, a Latinx femme adult mentor, is trying to engage the youth in their chosen project, creating a podcast. At the start of the session, during the time when youth shared updates about their work, Finn asked if they could share a video they saw online. Luz tried to keep the group on a schedule for the podcast, and asked if they could save it for later. She then started sharing platforms for editing a podcast to ask youth which one they would want to use. Between her explanations and sharing of websites, there were a handful of times where no one was talking or responding. During a particularly long pause, Finn called attention to it, saying "Question." Luz invited them to ask, though it was hard to hear through the glitching of Finn's audio.

"Why is it so quiet?" Finn asked, laughing. "I'm like, 'uh oh, what happened?' [...] it seems like we, kind of, don't have anything else to talk about…" They said this slowly, knowing they were about to offer a subject change back to the video. Here, Finn does not reject the project, but puts forth a new idea for the group to think about. None of the youth outright rejected the idea of working on the podcast at that time, yet they were trying to tell the adults something through their inaction/non-response. In this moment, Finn 'broke' a silence that came out of working on a project that they and the other youth were not engaging in at the moment. The silence

created a space for taking a different direction than working on the podcast. Silence was a necessary first step as part of "slowing down," which youth created and Finn stewarded.

In response to Finn trying to change the subject, Luz then asked the group if they should try to record something before listening to the video. Finn responded that it would be fine, but then proceeded to talk about "Dear 2045," (SugarDaisy, 2020), which is "about all the stuff that happened last year [...] Technically, it's about the pollution and all that stuff, and about how Donald Trump did all those [inaudible] things." While they were explaining, Luz started sharing her screen, in an attempt to draw attention back to the podcast. During this time, Finn's audio cut out, and Luz asked them if they could paste a link to it in the chat. She attempted for a few more minutes to engage the youth in the podcast. Luz's audio went out for a minute, and Finn asked if they could share their screen. At this point, Luz recognized that this is important to Finn, and that the other youth are interested in what they have to share, so she stops pressing the project.

However, this was not without some collaborative efforts by the youth. For example, in moments when Finn's audio would cut out, other youth would let them know in the chat they cannot hear Finn, with short messages like "I can't hear you." This was in tension with Luz's moves to focus on the project, which used those moments when Finn's audio would cut out as opportunities for redirecting back to the "main" project, such as sharing her screen when Finn was talking then asking them to paste it in the chat. When the other youth would actively support Finn's idea of sharing the video through keeping their attention on them, Luz recognized their quality of attention for the podcast was and would not be good without first hearing Finn out. Recognizing and leaning into the quality of learners' attention on a project was crucial for "slowing down," and was a way that youth could show how they wanted to engage with each other and STEAM.

After Finn shared the music video for "Dear 2045" (with some technical hiccups), they told the group "exactly why [they] wanted to share it": they thought it was a "great description of what's happening in the real world" and they "love how these people, like, care about what's going on." Finn pointed out that people "think [climate change]'s a joke," and sometimes "bully" people for caring about the environment. Finn said that this song might help people realize that climate change is a serious issue and that they should support people who care about it instead of bullying them. This song "inspires [Finn] to be more careful about what is going on around everybody else." Finn shares why it is an important message for others to hear, remarking on the video's ability to reach people in an emotional and "real" way. This demonstrates political clarity, which is an important aspect of politicized care, and was a necessary precursor for Finn to want to share with the group to begin with.

Negotiating the initial slowing down through calling attention to silence

We show how youth take up slowing down to collaborate and demonstrate their relationships with one another and continue to express critical discourse of the environmental crisis. This example takes place a few weeks after Finn shared the Dear 2045 video, during our updates time in the Wednesday session. Finn shared that they have been learning to sing the song "Snowman" by SIA. We all, youth and adults, encouraged them to sing it. After some technical issues, they sang it and it was beautiful. Lulu, another youth, was inspired to sing the same song. The session, similarly to the Dear 2045 session, was meant to be for working on our collective project. However, the youth wanted to sing and write music. This time, instead of trying to divert the youth to the plan, the adult mentors responded by supporting the writing of a "rap." However, even though Lulu and Finn had shared out loud, writing the rap was quiet. The majority of the work took place in the chat. Any verbal contributions were to either support what was being said in the chat or to ask questions about the project to check in if they wanted to work on it.

Below, the final rap was edited in format to show the contributions between youth and adults. In the passage below, the adult contributions, primarily from Maria and Starr, are completely left aligned. Every other line has a different number of tabs which differentiates each youth: Lousie, Finn, Tris, and Lulu. This format is meant to give an idea of who contributed what, how, and when, while also emphasizing the artistic nature of the work the group engaged in.

Green Club investigators…. We like snakes and alligators!
	i am a dog, you see this tree? it is a log
		le bark bark.
I'm dog, but I like me fish.
		I eat food in my dog dish.
			i have a pet fish, her name is miss she lives in a dish.
			i ate her she delish.
	My dog has a wish,
		to eat YOUR fish!

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Wait that's too violent, tisk tisk!
When green club tries something, we never miss!
Normally when I count time, I rhyme, not only that but I count dimes
These things keep our earth alive, most things we need to survive
like plants and water, like food and shelter
I like dirt,
the sun's our ice melter!
When they see us they say hi but when we is mad they run and hide
I water Kiri, he turns into a shark, when I go near Kachan he goes Bark Bark
we all have superpowers, we just need to use them…angel
I live in Space, I eat some grapes, and when I get tested I always Ace
we don't stand down, we empower
till my guinea pig bit. he devour.
I feel betrayed. I've been attacked.
i can only type with one finger and a half.
---gets holy bible and shouts S t a y b a c k!
should i put hand sanitizer on the bite?
it might burn but that is OK
not finna become todoroki due to a sanitizer…
we'll share more next time, so please stay!
And
help fight for the earth
so it doesn't go away

At the end of the 30 minutes it took to write, the rap was performed by Tris, Lulu, and Shadow individually. During this time, they hyped each other up to sing it and when someone would stop midway, they would encourage each other to keep going. These practices are part of what they did to enact politicized care; they demonstrated communal bonds by being encouraging and writing together as a group. It was also a developmentally appropriate way for them to demonstrate their knowledge of STEAM while also expressing their views over the future of the environment.

We also see that the slowed down work extended over time and brought up ways for youth to engage with one another. The GC raps session happened because youth wanted to share their ability to sing/rap, which is something that has been done in different forms in the past but was brought back in an organic way. This rap was collaboratively produced in a way that was mostly quiet. For example lines such as "till my guinea pig bit. he devour. // I feel betrayed. I've been attacked. // i can only type with one finger and a half" were developed as youth talked about Lousie's guinea pig. We see how youth centered silence/listening in the creation of the rap because of how the chat influenced this. In the audio, we hear mostly the GC members saying positive things to each other and laughing along as we write. Youth/adults invite each other to share their thoughts by asking open questions or calling on each other for responses, recognizing when other people want to be able to speak so they listen and support them.

Learning across the examples

To discuss learning across these examples, we emphasize how youth learning took the form of relational work that supported how they engaged with STEAM. For instance, they demonstrate their knowledge production around the environment in both examples, both through their discussions of the future in the Dear 2045 example or through their invocations of needing to protect the earth. Youth share a powerful video about climate change, and illustrate the points where politicized care and slowed down pedagogy appear in their moves to make space for STEAM engagement by and for the other youth. This brings in critical political discourses about the world, their futures, and the environment.

Discussion

The featured vignettes are examples of how youth "slowed down" STEAM making through their politicized care for one another. Finn's experience as a youth and a long-time member of the group allowed them to enact politicized care for their peers in a way that Luz did not recognize at first. Finn's moves to "slow down" were oriented around sharing the "Dear 2045" video, which opened up a conversation on the role of STEAM in society and how youth play a role—displaying political clarity. Luz, recognizing how silence and youths' quality of attention were shaping the session, stepped back for Finn to take an active role in the moment. This points to the

need for creating spaces for youth to slow-down as a way to support them in naming and enacting their desires for their program and their lives.

The whole group vignette where the youth co-wrote a rap together showed how from making space for slowing down there can be productive disruptions that take a different path to get where we want to go. Though the rap was not part of the plan, it was still part of what we envision as participating in STEAM. We were able to do this because we let go of the agenda and went with what youth showed us how to do in the moment. This points to how it is possible to find a balance between participating in STEAM in "traditional" ways while being responsive to youth. The implications of these points have reach in how we think about co-designing programs with youth and how we consider learning in general.

Implications for co-design with youth

We posit that slowing down can be a form of in the moment co-design with youth that seeks to maintain an overall vision of the learning that the space is designed for, while being attentive to the ways that youth want or need to interact with one another. While our Monday sessions featured explicit co-design time, where youth and adults came together to plan our projects and the overall timelines, in the moment co-design was equally as important for the overall implementation. Being able to negotiate the plan in the moment via slowing down is crucial to recognizing how youths' relational work is playing into STEAM learning.

Implications for learning

We situate this form of learning within the narratives of "learning loss" that pervade pandemic educational discourse. We argue that youth are showing us in this space that they are actually learning much about subjects that are not often emphasized in schools. Youths' work in this case sits at the margins of "learning loss" discourse, because what they are doing matters in profound ways yet is not recognized or valued. However, relational work is more important than ever in this time of isolation and social distancing. Further, the effects of the pandemic on entire generations of learners has yet to be seen. Research in the area of relational learning will continue to be important, and slowing down afforded a space to see this youth work.

Conclusion

This paper presents examples of how slowed down youth-led pedagogy, stemming from their politicized care for one another, contributed to youth's STEAM learning and presented adult mentors an opportunity to rethink how they listen to youth. We share two vignettes, one featuring Finn, a Black youth in an informal STEAM program, who "slowed down" a session, and in doing so was able to share a powerful video about climate change and insights on the power of youth. We also shared an example of how a group of youth embodied this by collaborating on a rap that was written entirely in a chat on our online platform.

These examples show us that slowed down pedagogy allows for a shift in how we approach STEAM making so that it is less tied to neoliberal logics of production, innovation, and competition in favor of developing relationships, exploring new processes, and collaboration. Throughout this paper, we have illustrated the points where politicized care and slowed down pedagogy take precedence in youth's moves. This lens offers us implications for both how we think about co-designing programs with youth, and how we work to de-center normative engagements with STEAM learning.

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Students' Ideas About Evidentiary Fit and Its Role in Modeling Practice

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Abstract: A core aspect of scientific inquiry is developing and revising models. This practice is supported by shared epistemic criteria to evaluate the "goodness" of models (and other epistemic products). A prominent criterion used by scientists is evidential fit. The use of epistemic criteria is gaining traction in science education; however, there is a gap in the research about the extent to which students view evidential fit as a central epistemic criterion of scientific models and what sense they make of the role of evidence in modeling. Using the *Grasp of Evidence* framework, we examined how students reasoned about evidential fit and its relationship to model goodness. We found that students understood that evidential fit confers accuracy and considered nuances of evidential reasoning, such as relevance and sufficiency. We discuss educational implications of these findings for advancing students' evidential reasoning with scientific models.

Introduction

Recent reforms in science education in the US have emphasized engaging students in knowledge production practices (NGSS, 2013; NRC, 2012). Knowledge production practices, such as modeling, have therefore increasingly been a focal point in science curricula. Giere (2004) defined models as, "…idealizations that scientists use to represent aspects of the world for specified purposes" (p. 742). Examples of models include the Copernican and Ptolemaic models of the solar system (Frigg et al., 2020) and Darwin's model of natural selection (Passmore & Stewart, 2002). The practice of modeling involves creating, evaluating, and refining models to explain and predict phenomena (Ke & Schwarz, 2020; Kenyan et al., 2008; Schwarz et al., 2009).

Scientific models are created and evaluated based on shared epistemic criteria for what counts as good models in science (Kuhn, 1977; Longino, 2002). Examples of epistemic criteria are fit with empirical evidence, explanatory power, fit with other established theories, conceptual consistency and coherence, and parsimony (Kuhn, 1977; Longino, 2002). Fit with evidence is considered as a central, perhaps the most important, criterion (Longino, 1996). Scientists create, evaluate and revise models in light of new evidence and even discard them if the model fails to fit a growing body of evidence. Fit with evidence is important because models with good evidence fit are more likely to resemble the world in desired respects (Bonjour, 2009; Strevens, 2020). In this study we used the term *accuracy* to mean how closely the model resembles reality in the desired respects.

Although evidential fit is a central criterion for making and evaluating scientific models, scientists often need to make tradeoffs among criteria (Kuhn, 1977). For example, a complex model that fits the evidence might not be parsimonious. A simpler model might offer greater explanatory power but not fit the available evidence as well as a more complex model (Longino, 1996). Scientists consider the tradeoffs between evidential fit and other criteria such as explanatory power, complexity, and conceptual coherence in pursuit of an aim. For example, models that will be shared for use by the public might need to be parsimonious; however, models that will be shared with scientists who have expert domain knowledge can be complex. Therefore, a complex model that fits all available evidence might be altered to fit the most relevant evidence and still be understandable.

Although scientists grasp the connection between evidential fit and accuracy, there has been little research on how science students understand the relationship between these ideas. Prior research has not yet investigated how students view the connection between evidential fit and accuracy; whether students see evidential fit, and accuracy as connected, and further, whether students see evidential fit as conferring accuracy. We also do not know how students prioritize criteria in instances when criteria need to be weighed against each other; for example, whether models should fit the evidence and be complex or whether they should fit less available evidence but be simple and easy to understand.

Prior research has shown that fifth-grade students were able to develop normative criteria for scientific models as a class community (Murphy et al., 2021). These included the criteria that models should be

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understandable and that they should be supported by relevant evidence. Students are also able to prioritize criteria and provide justifications for why criteria are important including meta epistemic justifications about criteria importance in relation to each other (Murphy et al., 2021). Av-Shalom et al., (2018) found that all class criteria lists that were developed during the intervention included some form of fit with evidence, which shows that students are aware of the importance of the criterion fit with evidence (Av-Shalom et al., 2018). Further, Av-Shalom et al., (2018) found that students are able to reason that scientific models should fit most of the evidence and it is preferable that there be no counterevidence. Ryu and Sandoval (2012) found that upper elementary students were able to construct and evaluate arguments according to evidential criteria; however, Sandoval and Millwood (2005) found that although students stated that fit with evidence was important, 73% of students did not provide sufficient data to support a claim and failed to explain how data supported claims.

Although prior research has shown that students prioritize evidential criteria, less is known about what fit with evidence means to students, how fit with evidence relates to other criteria, and how students would reason about tradeoffs between different criteria (in instances when criteria compete). To address these issues, we conducted an interview study with fifth graders following a five-week inquiry project in which students frequently used and discussed criteria for good models. Our specific research questions were as follows:

1. How do students conceptualize the relationship between evidence fit and accuracy?
2. How do students navigate the tension between potentially competing criteria? (e.g., when more understandable models are simpler but don't fit the evidence)?

Theoretical framework: Grasp of evidence

To guide our thinking and analysis, we used the *Grasp of Evidence* framework (Duncan et al., 2018). To *grasp* evidence means to understand how experts construct, evaluate, and use evidence and how lay people can adequately use evidence themselves. Part of being able to engage with evidence involves meta-awareness of how evidence is constructed and how to adequately critique evidence which can be guided by ideals (epistemic criteria). Therefore, understanding how epistemic criteria guide evidence construction and critique can help to develop sophisticated evidentiary reasoning. The Grasp of Evidence framework unpacks five dimensions of expert and lay evidentiary reasoning: evidence analysis, evidence evaluation, evidence interpretation, evidence integration, and laypeople's use of evidence. The first four dimensions capture *experts' evidentiary practices*, which are the processes that scientists engage in when using evidence to further scientific knowledge. The fifth dimension, *lay peoples' evidentiary practices,* captures the ways that laypeople can reason about evidence themselves. Although experts and lay peoples' evidentiary practices differ, it is helpful for laypeople to understand scientists' evidentiary practices so they can understand how scientific knowledge is produced. Gaining exposure to experts' evidentiary reasoning skills can enable laypeople to better assess the science they encounter in their everyday lives by giving them insight into appropriate methods and validity of conclusions. Further, laypeople can develop an understanding of the cognitive division of labor as they see that scientific knowledge is produced by many highly specialized credible experts which might engender trust in science.

We were interested in how students conceptualize evidence in relation to scientific models therefore the dimension of the GoE framework that helped to guide analysis was dimension four, *evidence interpretation* which looks at how evidence gains significance in relation to a claim, argument, or theory. Before we explain this dimension more fully, it is useful to consider how we define evidence. We lean on Walton et al's., (2008) definition: data becomes evidence when it is used in support of a claim. Looking at evidence in relation to models considers how evidence is explained by a model and how well the evidence supports the model. The aim of evidence interpretation is seeking strong evidence to determine model validity. Ideals (criteria) guide attainment of the aim; in this case, seeking strong evidence to determine model validity. Laypeople can assess whether evidence is strong by considering the following ideals: *relevance*: how relevant the evidence is to the model; *core support or refutation*: whether the evidence supports core (versus peripheral); parts of the model; *diagnosticity*: precise fit with the model; *comprehensiveness*: the extent to which the evidence addresses multiple components of the model; and *directness*: how direct is the chain of reasoning. Engaging in an assessment of the aims and ideals when interpreting evidence means that students can understand how scientists interpret evidence which should help guide them to interpret evidence in relation to models and decide between competing models.

Therefore, in this study we considered how students interpreted evidence in relation to scientific models by analyzing how students saw evidence as supporting models in terms of conferring accuracy. We were also curious how students would reason about the interplay between evidential fit for scientific models in terms of how much evidence is deemed sufficient to support a model and how contradictory evidence would impact model accuracy. We also wondered whether students saw evidential fit as the eminent criteria or, like scientists, they would make tradeoffs between other criteria depending on the aim. We will explore these questions in the results.

Methodology

Context and participants

Data from this study came from an implementation of a five-week model-based inquiry unit in a public charter school in the Northeast of the United States. Two fifth-grade classes (termed 5A and 5B) participated, with a total of 50 students. The demographics of the school were 60% White, 22% Asian, 9% African American, 7% Latinx, and 2% other; 5% of students were eligible for free and reduced lunch. The school performs above average on standardized state tests on Mathematics, Language Arts and Science.

In the unit, students developed models to explain the phenomenon of eutrophication, which is the process by which an excess of nutrients causes an increase in plant growth which depletes the oxygen supply and causes fish to die by suffocation. Students built an understanding of eutrophication through analyzing reports of empirical studies and interacting with a simulation. Based on these two types of evidence, students created models in a new modeling software called [MEME] (Danish et al., 2019) to explain why fish were dying in a local pond. The models consisted of components (parts) that were linked by mechanisms (processes) to create a causal account of why the fish were dying. The evidence was stored in [redacted], and students could link the evidence to the parts of the model to support the components and mechanisms.

The evidence consisted of reports of empirical research and NetLogo simulations. Students sought to account for both types of evidence as they developed their models of eutrophication. Examples of reports given to students were an autopsy report explaining why the fish died, graphs showing the amount of sunlight and nutrients in the pond, and a fertilizer label to show the chemical ingredients accompanied with reports of how fertilizer increased plant growth in a pond ecosystem. The agent based NetLogo simulations (Tisue & Wilensky, 2004) showed how the variables sunlight, fertilizer, and oxygen impacted fish death on a micro and a macro scale.

Model creation and evaluation were guided by a list of epistemic criteria that was developed by each class. The class criteria list was made by analyzing pairs of models about scientific processes, such as fossilization and life cycle of the frog, and coming up with a list of agreed and shared upon criteria. Half-way through the unit the students revised their class criteria lists based on observations and critiques to their models during a gallery walk. The final class criteria list featured normative criteria such as models should make sense; each component (part) and mechanism (process) should have a clear explanation supported by reasons and evidence; be organized, clear, and explain what is happening; and models should include relevant evidence (Murphy et al, 2021).

Data collection and analysis

At the end of the unit, seventeen students were interviewed in dyads. The data for this study was taken from interviews with all nine dyads from class 5A. The data from this study specifically focused on a task that assessed students' conceptions of model evidence fit. In the task, students were asked a series of questions that probed students' conceptions about the relation between evidence and models.

In the first part of the interview task students were asked the following questions to probe the relationship between evidential fit and accuracy: *1) What does it mean for a model to be accurate? 2) What is more important, accuracy or fitting the evidence?3) Can a model be accurate but not fit the evidence 4) Can a model fit the evidence but not be accurate? 5) Does a model need to fit all the evidence? 6) Can a model that does not fit all the evidence be right? 7) What if there is evidence that contradicts the model?* The results from these questions will be explored in the results section under research question one.

In the second part of the interview task, students were asked questions to probe their understanding of the tension between scientific models that fit the evidence and are complex versus scientific models that are understandable but do not fit the evidence: *1) Which is more important for a good model, that it is understandable or that it fits the evidence? 2) Suppose scientists wanted to build a model to explain why mosquito bites itch. Suppose that one scientist comes up with a clear, easy to understand model, but it doesn't fit the evidence and another scientist comes up with a model that is complex and harder to understand, but it fits all the evidence. Which model would be better?* The results will be explored in the results section under research question two.

The interviews were videotaped, and audio recorded, and later transcribed. The transcripts were then reviewed in two rounds of analysis. First, the transcript of each dyad was analyzed to build an understanding of individual students' concepts relating to model evidence fit across the interview task. Second, the transcripts were analyzed by comparing the responses of the dyads in a cross-comparison method (Glaser, 1965) to build an understanding of students' evidentiary concepts across students. The rounds of analysis helped us see patterns within students, such as whether students saw evidential fit as conferring accuracy, and across students, such as why students thought that models did (or did not) need to fit all available evidence and how students saw contradictory evidence as impacting models (Duncan et al., 2018). Any issues that arose were resolved by presenting the data to the larger research team, reviewing the data, and discussing interpretations until we reached

consensus. The data is presented in terms of numbers of students who gave responses (instead of number of dyads) because every student did not respond to every question (sometimes one student in the dyad spoke but not the other) and sometimes students in a dyad disagreed. Therefore, the totals do not always add up to eighteen students for every question. The findings from the data analysis are presented in the next section.

Results

Research question 1: How do students conceptualize the relationship between evidence fit and accuracy?

These analyses examined students' responses to the seven questions in the first part of the interview (see above). The responses to the question, "*What does it mean for a model to be accurate?"* provide us with insights regarding what students meant by "accuracy." Seven students responded that a model is accurate if it has "true information," "true evidence," or "matches real life." Students did not explain what they meant by true information and true evidence, but we assumed they are different ways of saying the same thing: a model is accurate if the evidence or information that informs the model is also accurate. We think this because, throughout the unit, teachers and students often referred to evidence as "true information". These seven students therefore held a definition of accuracy that approximates scientists' definition of accuracy. The following excerpt from Rochelle and Iona show their reasoning that models are accurate if they match real life:

> Rochelle: What it means to be accurate is like if say it's a simulation or something like we did in class… if we do like the exact same things that we did in the simulations in real life it will turn out the same and that's like accurate.
> Iona: And then the simulation would be accurate because it's similar to real life.

Eight students said that a model is accurate if it has true information or true evidence, but they also added in at least one other criteria: makes sense, on topic, has all the criteria (on the class criteria list), is in order, neat, and complete. These students therefore saw a wider range of criteria as conferring evidence. Three students explained that a model is accurate if it is on topic, makes sense, and is relevant, without any reference to evidence or true information.

We also found that students were able to reason about how evidential fit impacts model accuracy. In response to the question, "*What is more important, accuracy or fitting the evidence?"* Thirteen students stated that accuracy was more important because if the evidence is wrong then the model will be wrong. The following quote from Maggie illustrates this understanding:

> Maggie: I think that it's more important to be accurate because the evidence could be not true so it (the model) will fit it (the evidence) and still be not true.

Two students responded that fit with evidence was better because it means the model will be accurate; further, if the evidence is true, then the model will provide a better understanding. Therefore, all fifteen students that prioritized either accuracy or evidential fit did so based on the same understanding: fit with evidence confers accuracy. Finally, two students explicitly stated that both accuracy and fit with evidence was needed because accurate evidence makes the model accurate and incorrect evidence makes the model incorrect, showing that fifteen students understood that incorrect evidence would impact model accuracy.

When asked "*Can a model be accurate but not fit the evidence?"* nine students responded that a model cannot be accurate without fitting the evidence because the evidence must be accurate for the model to be accurate; again, showing that students see incorrect evidence impacting model accuracy. However, another common response (from nine students) was that a model can be accurate without fitting the evidence if the evidence is off topic, therefore showing that they have considered how irrelevant evidence (an aspect of evidence interpretation of GoE) could impact model accuracy (Duncan et al., 2018). We saw the same kind of evidentiary reasoning to the question "*Can a model fit the evidence but not be accurate?"* Twelve students responded that a model could fit the evidence but not be accurate because the evidence is inaccurate. Three students asserted that it is not possible for a model to fit the evidence but not be accurate because if the model was accurate then it will fit the evidence, therefore showing understanding that evidence fit confers accuracy. Two students responded that a model could fit the evidence but not be accurate because the evidence is irrelevant to the model. Thus, ten students used the idea of evidence-model relevance to account for instances when models can fit the evidence and not be accurate, as well as instances in which models can be accurate without fitting the evidence (Duncan et al., 2018).

When asked "*Does a model need to fit all the evidence?"* students considered how much evidence was sufficient for a good model-evidence fit. Six students said that a model should fit most of the evidence, five students said that a model should fit some but not all the evidence, and one student said a model should fit all the evidence. The justifications students provided for why models do not need to support all evidence showed that they thought about how much evidence was sufficient for scientific models in terms of relevance and comprehensiveness, which are ideals in the GoE framework (Duncan et al., 2018). Two students explained that a model does not need to fit all the evidence but that including the most relevant evidence was better. Another student claimed that it was sufficient to explain part of the model, therefore going against the ideal of comprehensiveness in the GoE framework (Duncan et al., 2018).

In response to whether models needed to fit all the evidence, two students (from the same dyad) questioned whether fit with all evidence was even attainable. First, the dyad thought about the evidence they had encountered in the unit. A few studies showed the chemical makeup of fertilizer and how fertilizer increased plant growth in ecosystems. The dyad reflected on this study and stated that the scientist might not know enough about the exact chemicals in the fertilizer that caused eutrophication, therefore the scientist might not have enough domain knowledge to know if the evidence adequately fits. Second, the dyad also reflected on when they built their own model in the unit and how they used the most relevant evidence to support the model. Some studies were ruled out as the unit progressed, so students did not link every piece of evidence to their final model. Due to these reasons, the dyad wondered whether fit with *all* evidence was even attainable.

Students were able to reason about whether all the evidence needs to be right that supports a model. In response to the question, "*Can a model that does not fit all the evidence be right?"* Nine students responded that it was possible for a model to be right and not fit all the evidence. Eight of these students responded by thinking about either the evidence or the model in parts. Four students responded that a model that does not fit all the evidence can be right because part of the model will not be supported but the other parts will be supported, therefore going against the comprehensiveness ideal in the GoE framework (Duncan et al., 2018); whereas four students responded that a model can still be right because part of the evidence does not fit, either because it is irrelevant (one student), inaccurate (one student), or does not make sense (two students). Two students reasoned about evidence relevance by considering how a model can fit only the relevant evidence and still be right; a model does not need to fit irrelevant evidence. Three students responded that the model would not be right because it would not be accurate. Thus, students' responses showed that they specified conditions under which models might be accurate even though they did not fit all the evidence (cf. Duncan et al., 2018).

Table 1

Reasons for Why Contradictory Evidence Makes a Model Stronger or Weaker

Reasons Why Contradictory Evidence Makes Models Stronger (frequency count)	Reasons Why Contradictory Evidence Makes Models Weaker (frequency count)
- Provide a counterclaim to show a weakness in the model so the scientist can revise the model and make it stronger **5** - Can make the model stronger because you can acknowledge both sides **2** - Contradictory evidence that is weak is still good because it will show that this side is better **1** - Just because there is evidence that goes against it, doesn't mean the evidence is accurate or correct **1**	- It wouldn't be good if evidence went against the model because it might prove the model wrong **2** - A model can't be good if there is evidence that goes against it (no justification given) **1** - A model that has contradictory evidence would prove it's not on that side **1**

Students were also able to reason about how contradictory evidence would impact models (see Table 1). Nine students responded that contradictory evidence would make the model stronger. This is somewhat surprising and counterintuitive. However, students provided reasons for this assertion. The most common reason (five students) was that if there was contradictory evidence, it would provide a counterclaim, which would show a weakness in the model. The scientist can then revise the model and thus make the model stronger. Another reason (two students) was that it is best for a model to represent both sides. It was curious to us why students thought a model should represent both sides and we were unsure that they meant. However, we know that students were also using the CER framework (McNeill & Krajcik, 2011) in science and English Language instruction and thus were likely used to teacher requesting them to provide counterclaims as a means to strengthen an argument and that better arguments address both sides (rather than ignoring counter claims or contradictory evidence). It is possible that students transferred these norms to their understanding of models, which would explain their reasoning here. In contrast to those arguing that contradictory evidence would make the model better, some

students (four) reasoned that contradictory evidence would make the model weaker. The most common response for why contradictory evidence makes the model weaker (two students) was that contradictory evidence would prove the model wrong—thus indicating that poor evidential fit reduces model accuracy. One student said a model would not be good if there was counterevidence because the model would prove it is not on that side and one student did not provide a justification.

Research question 2: How do students navigate the tension between potentially competing criteria? (e.g., when more understandable models are simpler but don't fit the evidence)?

In this section we will explore students' concepts about the relationship between models that fit the evidence but are complex and hard to understand, and models that do not fit the evidence but are simple and understandable. We chose this contrast because in class discussions, some students expressed a preference for simpler models that were easier to understand. But which model should be preferred when simpler and easier-to-understand models do not account for the evidence? How do students think about the trade-offs between these criteria?

In this section of the interview, we found that students' responses shifted from the first to the second question. The questions were: *1) Which is more important for a good model, that it is understandable or fits the evidence? 2) Suppose scientists wanted to build a model to explain why mosquito bites itch. Suppose that one scientist comes up with a clear, easy to understand model, but it doesn't fit the evidence and another scientist comes up with a model that is complex and harder to understand, but it fits all the evidence. Which model would be better?* In response to the first, general question about which was better- understandability or evidential fit, more than half of students (ten out of eighteen) prioritized understandability because then they know they have the right evidence. These ten students therefore conflated understandability with evidence fit. The following transcript excerpt shows how Iris conflated understandability and evidence fit:

> Iris: Ummm, understandable. Because if you understand (the model) most likely it will have the right evidence.
> Int: Okay
> Iris: Because you can't understand a model if the evidence is not correct… but if the model's accurate then the evidence will make sense.

In response to the second question, nine students thought that it was important for models to be both understandable and fit the evidence. This time, students did not conflate understandability with evidential fit. Instead, students saw the criteria as separate and viewed them both as important. Four students explicitly stated that the more complex model was better because it meant the model was accurate; however, they emphasized that a model should both fit the evidence and be understandable. All nine students explained how a complex model could be understandable: the scientist can explain the model to the audience, the audience can look up the words in the dictionary, the scientist can show where the model starts, the scientist can make an easy one that is understandable, and complex models are also understandable. The following excerpt from Axel highlights that both understandability and complexity were needed because complex models can still be understandable:

> Axel: Well, I pick the one that you can understand, but it's hard (to choose) because if it's just simple, easy, and it doesn't fit the evidence (the simple model) then you don't actually figure out the answer... And even if it's hard (the complex model) and not easy to understand, you can still understand some of it and figure out how they… and make an easy one, and one that has good, that has good evidence. You can combine the two.

A smaller number of students, five, responded that the complex model that fit the evidence was more important than the model that was simple and easy to understand. These students prioritized the complex, hard to understand model *over* the simple, easy to understand model, because it fit the evidence and would be accurate.

Discussion

Overall, the findings showed that most fifth-grade students in the intervention understood evidence as conferring accuracy and that incorrect evidence would make the model incorrect. Students' understanding of fit with evidence therefore somewhat parallels scientists' understanding of the importance of the criterion evidential fit for scientific models. Students also showed nuance in their evidentiary reasoning by thinking about how irrelevant

evidence would not impact model accuracy and how much evidence was sufficient by thinking about whether evidence could fit parts of the model or whether part of the evidence was enough.

Students reasoned about the interplay of competing criteria by considering whether a more complex model that fit the evidence but was not understandable was preferable to a simple and clear model that was understandable but did not fit the evidence. Initially, more than half of students conflated understandability and fit with evidence (they stated that understandable models will fit the evidence and vice versa); however, in response to a second, more concrete scenario, students shifted their explanation to view understandability and evidence fit as separate and important criteria for scientific models. The way students were able to reason about competing criteria of scientific models again mirrors the tradeoffs scientists make between criteria in pursuit of an aim. Scientists hold empirical consistency as a key criterion of scientific models (Longino, 1996); however, they recognize that this criterion cannot always be stringently applied (Hogan and Maglienti, 2001).

The findings contribute to research by showing how students reasoned about evidence in relation to scientific models, that students understood evidence as conferring accuracy, and that students can prioritize seemingly competing criteria. The results support previous research that showed students understand the importance of fit with evidence as a criterion (Av-Shalom et al., 2018; Murphy et al., 2021); however, they also extend prior research by showing that students in this study did not think models need to fit all available evidence and by reasoning about how counter evidence can make a model stronger (not weaker) by providing a counterclaim against which the scientist can strengthen the model. The findings also extend previous research by Ryu and Sandoval (2010) by showing that students have the capabilities to understand that evidential criteria for scientific products, such as models, are important for conferring accuracy, and the research by Sandoval and Millwood (2005) by determining not only that evidential fit is important but why, and how much evidence is sufficient to support models. Overall, students showed more nuanced and complex reasoning about evidential fit as a criterion for scientific models than previously shown by exhibiting reasoning at the metacognitive level about standards for model accuracy and what they deem to be sufficient standards of evidence for model accuracy.

Implications

The results of the intervention show that engaging students in collective negotiations about how evidence supports a model, adapting a model to evidence, and discussing criteria utility and value, supports students' metaepistemic scientific reasoning about the nuances in the relation between evidential fit and scientific models. The findings therefore point to suggestions for science education. Students can be engaged in fruitful discussions, specifically about how relevant, and irrelevant evidence impacts model accuracy, how much evidence is sufficient for a model to be accurate, and how contradictory evidence impacts model accuracy. It will be helpful for students to understand which criteria confer accuracy (evidence, true information, reasons etc.) and which criteria are important but do not impact accuracy, such as understandability.

Students can also be engaged in discussions that weigh criteria against each other in pursuit of an aim. For example, whether models should fit all available evidence and thus be complex and harder to understand or whether models should be simpler and easier to understand but fit less evidence. When students are discussing tradeoffs, teachers can point out that they are talking about the relevance of two or more criteria on their class criteria lists and this is what scientists do, thus developing students lay understanding of experts' reasoning about scientific models. The recommendations will assist students in developing a grasp of evidence (Duncan et al., 2018) and a grasp of practice (Ford, 2008) as students deepen both scientific practice and metacognitive understanding of the criterion evidential fit in relation to models.

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Exploring Socially Shared Regulation with an AI Deep Learning Approach Using Multimodal Data

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Abstract: Socially shared regulation of learning (SSRL) is essential for the success of collaborative learning, yet learners often neglect needed regulation while facing challenges. In order to provide targeted support when needed, it is critical to identify the precise events that trigger regulation. Multimodal collaborative learning data may offer opportunities for this. This study aims to lay such a foundation by exploring the potential for using machine-learned models trained on multimodal data, including electrodermal activities (EDA), speech, and video, to detect the presence of SSRL-relevant process-level indicators in successful and less successful groups. The study involves thirty groups of secondary students (N=94) working collaboratively in five physics lessons. Considering the demonstrated positive results of machine-learned models, the advantages and limitations of the technical approach are discussed, and further development directions are suggested.

Introduction

Self-regulated learning theory describes the phases and processes through which learners navigate towards achieving learning goals in the face of challenges posed across situations. Collaborative learning has advanced self-regulated learning theory contextualized within collaborative contexts under the distinct headings of co-regulation and socially shared regulation (Hadwin et al., 2018). While self-regulated learning is important for individual academic achievements, previous studies have shown that processes identified as socially shared regulation of learning (SSRL) enhance group performance and produce better learning outcomes during collaborative learning (Isohätälä et al., 2017; Järvelä, Järvenoja, et al., 2019). Nevertheless, self-regulated learning is often difficult and not always conducted by the learners while confronting learning challenges. Regulation of learning is even more difficult in collaborative learning when the individual processes must be coordinated and communicated between learners within a group. Accordingly, it is suggested that collaborative learning interventions should aim to promote SSRL.

However, it is difficult to provide just-in-time support for SSRL since the cognitive and affective processes at its core are unobservable by learners and, thus, they are not always aware enough in order to regulate them (Azevedo & Gašević, 2019; Järvenoja et al., 2018). Research in self-regulated learning has highlighted the methodological challenges in capturing the dynamic and cyclical nature of regulation. Although extensive research has been published examining self-regulated learning and its influence on learning success, a systematic understanding of how SSRL evolves in collaborative learning is nascent. While self-regulation of learning is difficult to capture at the individual level, it is even more difficult to detect and support SSRL in the face of the dynamic interactions and influences among learners in collaborative learning settings. If there would be an efficient and effective approach to capturing regulation in collaborative learning, it could significantly progress research on SSRL.

Recently, initial methodological progress towards establishing a means to make SSRL observable has been published (Hadwin, 2021; Järvelä, Järvenoja, et al., 2019). In particular, Dindar et al. (2020) has utilized electrodermal activity (EDA) data to investigate the interplay of temporal changes in self-regulated learning processes connected with behavior, cognition, motivation, and emotion in computer-supported collaborative learning. The relative importance of multimodal data analysis on SSRL research has also been subject to considerable discussion. However, despite the potential to advance domain knowledge and offer innovative learning support, recent studies have recognized issues and challenges that still need to be addressed using multimodal and multichannel data regarding self-regulated learning (Azevedo & Gašević, 2019). One of the most frequently stated problems relates to integrating the plethora of theoretical models and frameworks from multiple disciplines including educational and computational sciences. Consensus built from consideration of recent studies calls for design and application of theoretically based and empirically derived approaches for collecting, measuring, and modeling multimodal and multichannel data to elucidate the complexity and temporality of underlying processes to address learners' self-regulatory needs (Azevedo & Gašević, 2019; Hadwin, 2021). Considering recent methodological progress and related data for SSRL, advanced technologies under the headings

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of Artificial Intelligence (AI) and machine learning could be further harnessed in order to push forward the nascent science to this end.

In this paper, we present an interdisciplinary study attempting to address these methodological challenges and issues in utilizing advanced technologies on multimodal and multichannel data to study self-regulated learning. This study aims to explore different types of interactions for learning regulation between successful and less successful groups in collaborative learning. We focus more specifically on designing a machine learning model with multimodal data to automatically detect these regulatory interactions. Our study addresses the following research questions:

1) How do interactions for learning regulation differ between successful and less successful groups in collaborative learning?
2) How can machine learning architectures and multimodal data representations be designed for the successful detection of regulatory interactions for both successful and less successful groups in collaborative learning?

This study offers some important insights into the application of advanced technologies in examining regulation in collaborative learning. The experimental work presented here provides one of the first investigations into how multimodal AI deep learning could be used to exploit SSRL with the fusion of features gathered from multiple data modalities and channels. Although the study does not yet examine the direct effects of SSRL on learning performance or specifically offer a prediction of the level of success for collaborative groups, it does present a compelling novel approach and meaningful evaluation of challenges and limitations to inform future work in this area within this research community. Furthermore, this study will contribute towards methodological progress to build a foundation for future theoretical investigation of SSRL and for the development of SSRL interventions.

Theoretical Approach – Regulation of Learning in Collaborative Learning

Our theoretical approach to the study is grounded in self-regulated learning (SRL) and socially shared regulated learning theory suggesting that regulation of learning is not solely a learning process at the individual level but also involves social and contextual processes (Hadwin et al., 2018).

Self-regulation of cognition, emotion, and behavior has been a critical aspect of learning and successful academic performance (Winne, 2019). Self-regulation refers to the process in which a learner goes through goal-setting, self-monitoring, self-instruction, and self-reflecting to understand and manage their own learning (Zimmerman & Schunk, 2011). Research on self-regulation has progressed over decades with several theoretical perspectives and models proposed to describe and provision regulation in learning (Panadero, 2017). As the field has evolved, recent attempts have been made to investigate the phenomenon of regulation in a complex and dynamic collaborative learning environment. Going beyond self-regulation of an individual learner, co-regulation and socially shared regulation presented other social forms of regulation operating in collaborative learning. While co-regulated learning (CoRL) generally explains the learners' regulation with support from team members through social interactions, socially shared regulation of learning (SSRL) addresses the complementary perspective relating to a group's deliberate, strategic, and transactive planning, task performance, and reflection in learning (Järvelä, Järvenoja, et al., 2019). Although considerable effort has been made to understand the complex process of regulation of cognition, motivation, and emotion (Winne, 2019), the mechanisms that underpin regulation in collaborative learning are not yet fully understood.

Regulation of learning in collaborative settings is a complex and cyclical process in which the learners regulate themselves and each other (Järvelä, Järvenoja, et al., 2019). In the best cases, learners conduct all three forms of regulation together while confronting learning challenges progressing towards desired learning outcomes. These three forms of regulation in collaborative learning often occur alongside interactions aimed towards regulation (Isohätälä et al., 2017). Group interaction processes play a critical role in regulation promoting group success in collaborative learning. This study focuses on different types of interactions for regulation in collaborative learning. Previous studies have recognized a variety of specific challenges in capturing regulation in collaborative learning due to the complexity, "unobservability, temporality, multifaceted and situated nature of learning regulation" (Azevedo & Gašević, 2019; Hadwin, 2021; Järvelä, Järvenoja, et al., 2019). The methodological progress we report herein capturing regulation could offer a solid foundation for extending understanding regulation of learning, developing relevant theories, and designing support for promoting regulation of learning hence improving learning.

Methodological Approach – Multimodal Data and Machine Learning for Understanding Regulation of Learning

Recent progress in learning regulation research has increased the demands for innovative and robust methods in examining social aspects of learning regulation (Järvelä, Järvenoja, et al., 2019; Winne, 2019). Recently, research on learning analytics and educational data mining has exploited cutting-edge data collection and analytic technologies to reveal new insights into learning and learning processes with the goal of advancing learning sciences theories (Nguyen et al., 2020, 2017; Noroozi et al., 2019). Developments in sensor technologies have provided accessibility to different data channels such as physiological data. Collecting and analyzing data from multiple modalities and channels has provided exposure to signals thought to be related to regulatory processes treated previously as unobservable when the primary method for studying these processes was through self-report instruments such as questionnaires or interviews (Azevedo & Gašević, 2019; Järvelä & Bannert, 2019; Noroozi et al., 2019).

Previous studies have utilized multimodal data to provide and triangulate evidence of temporal and adaptive processes of learning regulation (Järvelä, Järvenoja, et al., 2019). Although the recent pioneers in using multimodal data for examining learning regulation have contributed to better understanding the complex nature of (S)SRL (See Järvelä & Bannert, 2019; Noroozi et al., 2019), they have encountered several issues related to synchronizing data from different sources (Azevedo & Gašević, 2019; Hadwin, 2021). Nevertheless, prior studies analyzing and triangulating multimodal data have provided valuable insights and progressed regulation concepts that provide the foundation for this work. The current study builds on and extends this foundation through the development of technological advances that enable effective integration of the synergistic features from multimodal data for better understanding and supporting learning regulation.

Advanced Artificial Intelligence (AI) technologies, specifically what is currently known as deep learning, have offered the capabilities to not only automatically detect cognitive and emotional activities in real-time but also objectively measure and classify relevant learning behaviors. For instance, the application of deep learning across different media has been applied to the problem of detecting human emotions including micro-expressions (Tzirakis et al., 2017; Zhao et al., 2011). Furthermore, AI deep learning methods potentially allow the fusion of features obtained from multiple data modalities to enhance the accuracy of recognizing and classifying human cognitive and emotional activities (Tzirakis et al., 2017). As cognitive and emotional activities are at the core of learning and learning regulation, the use of multimodal AI deep learning methods offers the potential for gaining novel understandings of the phenomenon and providing effective support to promote SSRL. Despite the potential of advanced technologies such as AI deep learning in examining SSRL, there are only a few studies that have empirically investigated the phenomenon. Indeed, apart from the study proposed by Nguyen et al. (2021), our search of the literature failed to find any prior studies utilizing multimodal AI deep learning to examine interactions for regulation in collaborative learning. We thus argue that the contribution of the current study is in affording the potential to establish methodological foundations to push (S)SRL research forward.

Research Methods

Participants and Procedures

The participants of this study included secondary school students (N = 94) working collaboratively in groups of three or four during five physics lessons. They were divided into 30 groups and the group assignment was based on the grades they earned in previous science courses. Students and their processes of learning and collaboration were monitored and documented with video recordings and through individual-level physiological measures.

Data collected from different modalities and channels may allow for uncovering the complex interactions of both the visible actions and the invisible mental and metacognitive processes in collaborative learning (Azevedo & Gašević, 2019). Following this line of research, our study attempted to collect the multimodal data from several channels to reveal the interactions for regulation in groups. Particularly, we capture students' physiological activities through the measurement of Electrodermal Activity (EDA) by using Shimmer3 GSR + devices. These data reflect the physiological reactions that occurred during a learning situation, such as students' physiological activation related to emotion and cognition. In addition, we used Insta360 Pro video cameras and microphones to capture the visual and acoustic data reflecting engagement in learning activities in the classrooms' natural setting.

Qualitative Coding and Quantitative Data analysis

Qualitative coding through a multi-step analysis schema was conducted to label types of interactions for regulation. First, the videos and audio were divided into thirty-second segments. Previous research suggested that the time-based segmentation of videos for observing collaborative learning would benefit the analysis by enabling time series modeling of a progression over time and providing a consistent unit of analysis (Sinha et al., 2015). The types of interactions for regulation were classified using four separate labels: 1) metacognitive interaction, 2) socio-emotional interaction, 3) task execution and 4) other interactions. The identification of these types of social

interactions would lead to the recognition of SSRL when it emerged as SSRL is socially situated and achieved through social interactions (Isohätälä et al., 2017). By examining the four types of social interactions for regulations, we could better understand how SSRL could be effectively developed to enhance group performance through different social interactions. The coding scheme is shown in Table 1. To ensure the reliability of the labels, we validate the coding by conducting interrater reliability testing on the initial set of coded data. This initial set of data are coded for ten videos randomly selected from the dataset. The result shows a substantial agreement among the results with Cohen's Kappa values above 0.7.

Table 1: Qualitative Coding Schemes for Preparing Interaction Data

Type of Interactions for Regulation	Description of behavior	Examples
Socio-emotional interaction Socio-emotional interaction was coded when group members expressed clear indicators of positive/negative affect or made a positively/negatively charged comment. Emotional expressions included verbal or other clear indicators of positive or negative affect and negatively or positively charged interaction.	Verbal indicators, e.g.: - positive/negative content - positive/negative tone of voice - sarcasm - laughing, singing, groaning, whining Bodily indicators, e.g.: - smiling - dancing - sighing - facepalm Emotionally charged interaction, e.g.: - Joking, praising - Arguing, criticizing	*"This [shimmer] gets stuck everywhere. I hate these. I wish this would be over already."* *"You sound like a hamster!"* **laughter** *"How are you able to draw such straight lines without a ruler? Look! She didn't even use a ruler to draw this line!"* *"Can he be quiet? The mic doesn't like it when he does that all the time"*
Cognitive interaction Metacognitive interaction was coded when group members' discussion targeted their cognitive processes.	Discussion regarding: - Task goals - Task understanding (e.g. checking task demands) - Prior knowledge - Resources (e.g. procedures, strategies) needed to solve the problem - Progress with the task (e.g. checking/evaluating progress) - Selecting strategies (e.g. help-seeking) - Quality of task solution (e.g. evaluation of the correctness of the answer) and overall performance	*"Okay, what are our goals?"* *"Isn't this the first task? About volume?"* *"No, it is this way, we did this yesterday in math."* *"I don't think that we have time to do that. [The teacher] is already writing down the homework"* *"Jane, is this [answer] good?"*
Task execution Concrete work towards task completion. No interaction required.	- Reading or discussing task material or content - Executing task-related measurement or calculation - Otherwise physically executing task experiment - Writing down calculations or answer	*"[Exercise] 2. d) How long does it take sunlight to reach the Earth?"* *"What was the answer to exercise 3?"*
Other interaction Non-task-related interaction	Discussion regarding: - Other school-related issues - Free-time activities - Research setting	*"Maybe [the teacher] was talking about who will be in our group during home economics class"*

Before conducting machine learning modeling for automatic detection of regulatory interactions, we investigated whether the interactions for regulation differed among successful and less successful groups. We conducted a Pearson Chi-square analysis of homogeneity of proportions to examine the differences in regulatory interaction frequencies. We hypothesized that the proportion of the types of regulatory interactions is different between successful and less successful groups. This offers empirical evidence that detection of this four-way distinction will provide leverage towards our future work automatically detecting the level of success that groups are likely to achieve as they are working, and using that detection to prompt needed interventions.

AI Deep Learning Modelling and Evaluation

The multimodal deep learning modeling approach is adopted for developing the predictive model to detect interactions for regulation. Different AI deep learning frameworks will be used to extract features from each data modality and the extracted features will be then fused using a multi-layer perception. In particular, the pre-trained 18-Layer Residual Network (ResNet-18) (He et al., 2015) was applied to encode the video stream into a sequence of features, referred to as a vectorized representation. The same method is utilized to encode the audio data into a vectorized form. Besides, the electrodermal activity (EDA) processing approach follows prior work in which EDA is also used in a deep learning framework designed for emotion classification (Ganapathy et al., 2020). EDA data were decomposed into the tonic component or skin conductive level (SCL) and the phasic component or skin conductance response (SCR). EDA features were encoded and vectorized using a convolutional neural network (CNN). A dense layer using a multi-layer perceptron with a binary cross-entropy loss function was applied to perform deep learning to identify patterns within the transformed feature encoding related to the prediction labels. We train three AI deep learning models using multimodal data from: 1) successful groups; 2) less successful groups, and 3) all groups. Figure 1 demonstrated our prototype design for AI deep learning for (S)SRL.

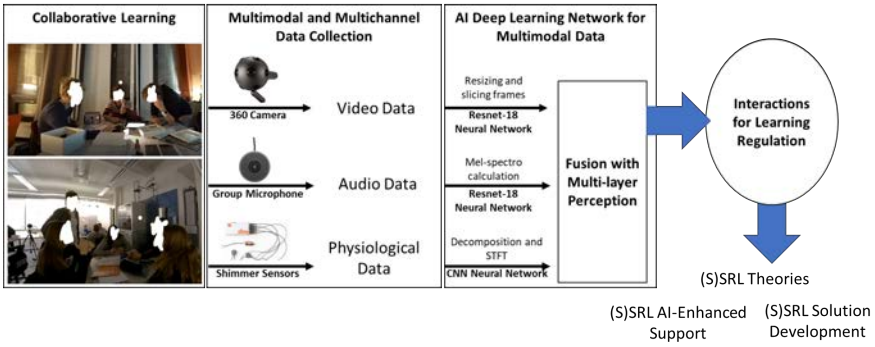

Figure 1: AI Multimodal Deep Learning for (S)SRL

For each AI deep learning model, we followed the typical machine learning experimental methodology to conduct training, validation, and evaluation. In particular, each multimodal dataset was randomly split into three subsets consisting of a training set, a validation, and a test set with a ratio of 8:1:1. The model is trained on the training set, where parameters are tuned to maximize performance on the validation set. The tuned model is then tested on the test set for evaluation. The common values of F1-score, mean Average Precision (mAP), and Accuracy score were obtained for the evaluation on the validation test and test set. The Area Under the Curve of Receiver Operating Characteristics (AUC-ROC or AUROC) is also computed for the evaluation of each model.

Results

We first address the question of the value of the four-way distinction used to code data segments to separate successful and unsuccessful groups, under the expectation that observations related to engagement in SSRL processes are included among the factors that separate these groups. The results of the Pearson Chi-Square test showed significance in the relationship between the observed distribution of types of interactions for regulation and group performance ($\chi_2 = 56.76$, $df = 3$, $p < 0.01$). In other words, the distribution of counts of different types of regulatory-relevant interactions is not independent of the success of the group. Next, we address the capability of the technical approach to automatically assign the four-way distinction to data segments. Table 2 demonstrated the results for AI deep learning evaluation for models on successful groups, less successful groups, and all groups.

Table 2: Evaluation Results for the AI Deep Learning Evaluation

	Successful Groups	Less Successful Groups	All Groups
Evaluation on the validation set			
F1-score	0.63	0.67	0.73
mAP	0.67	0.72	0.79
Accuracy	0.69	0.81	0.79
Evaluation on the test set			
F1-score	0.65	0.61	0.63
mAP	0.67	0.74	0.70
Accuracy	0.68	0.72	0.73

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Overall, our results illustrate that using AI deep learning on multimodal data has the potential to automatically detect interactions for regulation in collaborative learning. In the evaluation on the validation set, we found that the predictive accuracy on detecting the regulatory interactions for successful groups (F1-score = 0.63, mAP = 0.67, and Accuracy = 0.69) is lower than for less successful groups (F1-score = 0.65, mAP = 0.67, and Accuracy = 0.68). The evaluation on the test set also confirmed that the deep learning model for successful groups (F1-score = 0.65, mAP = 0.67, and Accuracy = 0.68) is not as accurate as for less successful groups (F1-score = 0.61, mAP = 0.74, and Accuracy = 0.72). Nevertheless, the evaluation on both the validation set (F1-score = 0.73, mAP = 0.79, and Accuracy = 0.79) and evaluation set (F1-score = 0.63, mAP = 0.70, and Accuracy = 0.73) for the inclusive AI deep learning model using multimodal data from all groups has the capability to predict interactions for regulation at a reasonable level. Thus, we believe we have a proof of concept to drive forward research, but note that in future research particular attention should be paid to performance specifically on

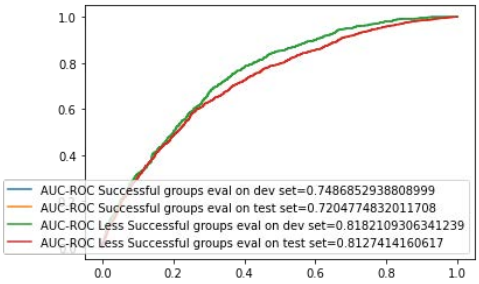

Figure 2: The Area Under the Curve of Receiver Operating Characteristics (AUC-ROC or unsuccessful groups.

Figure 2 showed the results for the Area Under the Curve of Receiver Operating Characteristics (AUC-ROC or AUROC) for both models on the successful and less successful groups. The results show that both models could reasonably predict the interactions for regulation in collaborative learning (AUC-ROC > 0.72). The lower predictive power in the successful groups (AUC-ROC=0.74 and 0.72 for evaluation on the validation and dataset) could be explained by a higher complexity in interactions for regulations than the less successful groups (AUC-ROC=0.82 and 0.81 respectively). Future work could be conducted to examine this difference further. Nevertheless, the results have validated the feasibility of our model to recognize interactions for learning regulation in both conditions.

Discussion and Implications

The development of sensor-based technologies and machine learning techniques together presents a unique opportunity to leverage data collected from different modalities in the context of collaborative learning. Prior work has reported that multimodal data have shown promise for advancing our understanding of learning regulation (Noroozi et al., 2019), yet so far very little attention has been paid to how machine learning techniques could be implemented to examine the multiple facets and processes of learning regulation. This study explored the use of the AI deep learning approach on multimodal data to detect regulatory interactions for successful and less successful groups in collaborative learning.

First, we investigated whether the types of interactions for regulation are related to group performance. The results support our hypothesis that the proportion of types of regulatory interactions differs between successful and less successful groups. Previous research demonstrated that SSRL emerged from different types of interactions and contributed to the success of collaborative learning (Isohätälä et al., 2017). Therefore, the capabilities to capture regulatory interactions could establish a solid foundation for identifying triggers for regulation and providing support to promote SSRL, hence enhancing learning performance (Nguyen et al., 2021). This study extends the understanding of learning regulation by providing evidence for the difference in the proportion of types of regulatory interactions between the successful and less successful groups in collaborative learning. Accordingly, our results showed a significance for the difference in regulatory interactions and provisioned the importance of capturing different types interactions for regulation in collaborative learning.

The development and evaluation of AI deep learning models using multimodal data in this study demonstrated the feasibility of this approach to capture the regulation of learning in collaborative settings. Previous research has already recognized the potential of utilizing multimodal data for SSRL (Engelmann & Bannert, 2021; Järvelä, Malmberg, et al., 2019), but the field has struggled with an analysis of multimodal and multichannel data, even recognizing that the data allows for examining the interplay of different facets and processes of learning regulation (Hadwin, 2021). For instance, while Engelmann and Bannert (2021) analyses the

screen recordings and verbal protocols to assess cognition and metacognition processes of regulation, Järvelä, Malmberg, et al. (2019) showed the use of facial expression extracted from video interactions and physiological data including heart rate and electrodermal activity (EDA) data to examine the SSRL facet of emotions. These studies provided evidence for the use of the multimodal approach for understanding the situated nature and temporality of regulation. Nevertheless, the synchronization of multiple data modalities across multiple data channels is complex and faces several challenges (Azevedo & Gašević, 2019; Järvelä & Bannert, 2019). Triangulating data from multiple channels could examine the interplay of multiple facets and processes of learning regulation and comprehend findings from each of the data sources (Järvelä, Malmberg, et al., 2019). While multimodal and multichannel data triangulation has provided valuable insights to extend our understanding of learning regulation, the cohesive multimodal analysis with potential synergistic effects for research on learning regulation has received scant attention in the literature. Since different data modalities from different channels reflected different facets and processes of learning regulation, utilizing synergistic features from multimodal and multichannel data could further address the temporality of regulation. However, the complexity and dynamics of synergizing features from multiple data modalities raised several methodological challenges. Therefore, this study demonstrated the opportunities offered by advanced technologies, specifically AI deep learning, for analyzing multimodal data in research on learning regulation.

This study has some limitations. First, the approach for qualitative coding and segmentation into thirty-second blocks is theory-grounded and supported by several published studies in the domain (e.g. Järvenoja et al., 2018; Sinha et al., 2015), yet other approaches should be examined and compared for improving performance. Second, while immersive video data hold valuable features for studying learners' behavior and learning, we noted that the current machine learning methods for video and image processing for this type of video data are still limited. Furthermore, the pre-trained models for analyzing video data are mostly trained with open databases in which the data are often retrieved from video scenes. The complexity and dynamics of authentic learning environments could influence the predicting performance of the pre-trained models. Thus, this study presented a unique contribution to the field with the model trained from a large dataset captured from real-life situations. And it could lead to a fruitful area for further work on SSRL theoretical investigation and multimodal methodological development.

Conclusion and Future Directions

In recent years, advanced technologies have brought opportunities for transformation across societal sectors, including education. Among these advanced technologies, Artificial Intelligence (AI) has been one of the most influential technologies and has been widely utilized in online education. However, there has been much less attention paid to the application of AI in face-to-face classroom settings. Although face-to-face learning has not been responsible for the bulk of available data from educational settings, the advancement of sensor technology and multimodal data collection methods has enabled the possibility of applying AI in the face-to-face classroom context. Despite the significant potential of AI in education, there remains a paucity of evidence on how AI could be applied to extend our understanding of learning in the classroom. This study demonstrated the implementation of an AI deep learning approach to address the methodological and theoretical challenges in the domain of self-regulated learning and collaborative learning. In particular, we designed and validated how the AI deep learning approach could reveal the previously "unobservable" processes of regulation by using multimodal data to automatically detect interactions for regulation. Future research could attempt to examine different AI approaches to offer novel methods to collecting and analyzing educational data, hence extending the methodological and theoretical boundaries in learning sciences. The results of this study also shed a light on the development of real-time support for regulation in collaborative learning. We look forward to future work building on and extending these findings in the design and creation of AI-enhanced solutions for promoting the regulation of learning.

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A Tale of Two Teacher Trajectories: Analysing Change in Teachers' Beliefs on Technology Integration during the COVID-19 Pandemic

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Abstract: Existing research on teachers' beliefs remains majorly focused on cognitive aspects, while lesser attention has been paid to affect and context. In the present study, we use the lens of the cognitive-affective model of conceptual change, to understand how teachers' beliefs about technology integration changed when they were compelled to move to online teaching as a result of the COVID-19 pandemic. We present findings from a multiple-case study of two secondary school teachers in Kerala, India. Contrary to expectations, the teacher who had low training and low self-efficacy showed stronger belief change towards effective integration of technology, compared to a teacher who was skilled in using technology for physical classroom activities. Motivation, context and situational resources played a crucial role in understanding the difference. The findings have implications for learning sciences researchers working on effective integration of technology-focused solutions in the classroom and in designing TPD programs.

Introduction

Aligned to global trends, India is striving to transform the nation into a digitally empowered society and knowledge economy. It is envisioned that technology will play an important role in achieving this goal by improving educational processes and outcomes (NEP, 2020). However, even when policies favour the integration of technology in education, its effectiveness depends on teachers' beliefs about teaching, learning and technology, and how they include it in their actual practice (Ertmer, 2005). Even if first-order barriers to technology integration such as access, training, and support were removed, teachers would not automatically use technology effectively unless their beliefs aligned with a constructivist pedagogy (Ertmer, 1999), thus the consequences of belief congruence or incongruence become important. When teachers are required to implement practices that are different from the beliefs they hold about teaching and learning, it may adversely affect their satisfaction and well-being and they may implement the practices in an ineffective manner (Buehl & Beck, 2015).

Research on how and when teachers change their beliefs is vast and diverse (Pajares, 1992; Ertmer, 2005; Park & Ertmer, 2007; Taimalu & Luik, 2019). While research has largely focused on the cognitive aspects of teacher belief change, (Fives & Buehl, 2012), recent studies have recognised the role that affective (Watt & Richardson, 2014; Gill & Hardin, 2014) and contextual factors (Tschannen-Moran et al., 2014) play in teachers' beliefs. The affective factors include motivation, emotion, goal orientation etc. and contextual factors include social, cultural, political, historical and school contexts teachers experience during their careers and have been reported to be inseparable from the teachers' beliefs and actions (Levin, 2015). One contextual factor that may play an important role in influencing a change in teachers' beliefs is an emergency situation such as the COVID-19 pandemic.

In the Indian context, there are a few studies that give evidence for the relationship between affective and contextual factors on teachers' beliefs about technology integration (Bandyopadhyay, 2013; Chand, et al., 2020; Sharma & Srivastava, 2020; Kundu, et al., 2020). However in-depth studies exploring the role of affective and contextual factors in the process of change in teachers' beliefs about technology integration are lacking. The present study aims to address this research gap and contribute to further expanding the belief change model. We chose the educational context of the state of Kerala in India to understand how teachers' beliefs about technology integration changed when they were compelled to move to online teaching as a result of the COVID-19 pandemic, and the role played by affective and contextual factors. Our research question for this study is "How do teachers' beliefs about technology integration change and what role do affective and contextual factors play?"

Theoretical framework

Teachers' beliefs about technology integration

According to Park & Ertmer (2007), teachers' beliefs about technology integration comprise three components: pedagogical beliefs about teaching and learning, self-efficacy beliefs for using technology, and beliefs about the

value of the use of technology. These three components were found to be the main predictors of teachers' use of technology for pedagogical purposes (Taimalu & Luik, 2019).

Ertmer (2005) considered pedagogical beliefs as the teachers' educational beliefs about teaching and learning. Teachers with more traditional beliefs tend to implement more teacher-centred uses of technology and do not see technology as important and useful for teaching and learning, whereas teachers with more constructivist beliefs tend to implement more student-centred uses of technology and are seen as innovators (Taimalu & Luik, 2019; Ertmer et al., 2015). Bandura (1997) defined perceived self-efficacy as "beliefs about one's capabilities to organise and execute the courses of action required to produce given attainments". Self-efficacy is formed based on four major sources of information: enactive mastery experiences, vicarious experiences of observing others succeed through their efforts, verbal persuasion and physiological and affective states (Bandura, 1997). Teachers' perception of the value of using technology for teaching and learning is an important predictor of their future use of technology in their class. Researchers found that teachers will use technology only when they see value in using technology for specific educational purposes (Ertmer, 2005).

Cognitive-affective model of conceptual change (CAMCC)

Although conceptual change models are developed primarily to explain knowledge acquisition, they could be effective in studying changes in beliefs as well (Gill et al., 2004; Posner et al., 1982). Consequently, we adopted the Cognitive-Affective Model of Conceptual Change (CAMCC) as a potentially appropriate model for our analysis, which integrates cognitive frameworks of belief change with motivational and affective factors (Gill, 2003). The CAMCC model proposes two routes of belief change resulting in either assimilation or accommodation and identifies systematic processing as the mediator of conceptual change. The belief change process begins with the presentation of *a reform message* to the teacher. If the message causes dissonance to the existing beliefs of teachers (*Implicate self? Yes*), they appraise the situation as stressful (*Stress appraisal*). It is important to note here that teachers' appraisal of the reform message happens automatically before characteristics of the message (*intelligibility, plausibility, fruitfulness*) are seriously considered.

Even though dissonance is a prerequisite, belief change is unlikely to occur unless the teachers perceive sufficient motivation and ability. Kubanyiova (2012) in their integrated model of Language Teacher Conceptual Change (LTCC), which is a modified version of CAMCC, proposed to combine motivation and ability components into a single component called '*Reality check appraisal*'. During the reality check appraisal, if a teacher feels that his or her internal and/or external resources are sufficient, may appraise the situation as challenging (*Challenge appraisal*) and adopt an immediate goal to approach the reform message (*Approach intention*), which eventually leads to its '*systematic processing*'. The CAMCC proposes that only this systematic route can lead to a teacher's belief change. However, systematic processing does not guarantee a change unless the teacher yields to the message (*Yielding?*).

On the other hand, if a teacher does not see him or herself implicated by the reform message *(Implicate self? No*), will therefore not experience stress, discomfort or dissatisfaction. This may be either because he or she believes that they are already using technology in their classroom effectively (*Positive appraisal*) or because he or she sees the reform message as neutral and therefore dismisses the reform input as irrelevant (*Benign appraisal*). The CAMCC proposes that those who make such appraisals will lead to a '*heuristic processing'* rather than systematic processing. Heuristic processing further leads to a decision choice (Yielding?). If the teachers yielded or accepted the message, he or she will lead to a state of *Assimilation or Superficial belief change.* Similarly, even if the teacher may have entered the systematic route of belief change (*Implicates self? Yes*; and experienced dissonance emotions), there is a chance that he or she may revert to a '*heuristic processing*'. During the '*Reality check appraisal*', if the teacher feels his or her internal and/or external resources are insufficient, the teacher will perceive the message as a threat (*Threat appraisal*) and adopt an immediate goal of avoiding the threat (*Avoidance intention*). From this point, the teacher follows the same path discussed in the heuristic processing.

Educational context

The present study is conducted in the state of Kerala in southwest India, which is known for its high literacy rate. Kerala has implemented various innovative programmes to support teaching and learning through technology such as VICTERS (Versatile ICT Enabled Resource for Students) and Samagra eResource Portal. VICTERS allows students and teachers to access quality education from experts through its TV and YouTube channels. Samagra eResource Portal is a repository of digital resources on various subjects from grades 1 to 12. These initiatives have strong support from the government but are driven primarily by teachers, who contribute learning resources such as videos, animations, audios, stimulations and interactive content which can be accessed by students. Teachers also contribute unit plans for various topics in addition to micro-planning that can be accessed

by any other teacher for preparing their instruction. The Samagra portal has active discussion forums, in which teachers can communicate with each other and clarify their doubts.

After the closure of schools due to the pandemic in March 2020, the Kerala government decided to continue school education through online media. The General Education Department initiated an interim arrangement for regular classes for students of grades 1-12, called 'First Bell'. The classes under the First Bell programme were streamed live through VICTERS educational channel. The unaided private schools mainly utilised tools like Google Meet for delivering classes. All schools extensively used the WhatsApp tool for communicating with students and teachers, sharing materials and providing feedback.

Methods

Participants and data collection

Our broader study has been designed for 15 teacher participants from different types of schools (government, government aided-private, and unaided-private) in Kerala. This study began in mid-2020, a few months after the pandemic and lockdown in India. The Institutional Review Board (IRB) approval was obtained from our institution. Teachers from schools near the home district of the first author of this study were contacted. Data collection includes interviews, observations of online teaching and teacher reflections. The study is ongoing and so far we have interviewed 6 teachers.

The present study used a multiple-case design and followed a theoretical replication logic (Yin, 2018). As per the 'maximum heterogeneity sampling' strategy (Patton, 2015), we purposefully selected two teachers, who showed clear evidence of the role of affective and contextual factors in the process of belief change.

The researcher conducted semi-structured interviews with the participants. The interview protocol was designed in such a way to elicit the changes in teacher beliefs about technology integration (i.e. pedagogical beliefs, self-efficacy beliefs for using technology, and beliefs about the value of the use of technology) and the cognitive, affective and contextual factors influencing this change. We also tried to understand teachers' perceptions about the use of instructional technology in future. Interviews were conducted over the mobile phone in the native language Malayalam and took approximately 1 hour. Follow up clarifications were sought via text and audio messages. All interviews were audiotaped for further analysis purposes. Personally identifiable data were anonymized immediately after data collection. Sample interview questions included:

- On a typical day, how do you utilize technology in your classroom? Briefly describe any two such instances from your classroom one year before and the present day.
- How competent do you perceive yourself to select and use various technologies to support teaching and learning?
- What might be your response if I had asked you the same question one year before? Provide some instances for supporting your statement. What might be the reason for this change?

Data analysis

The recorded interviews were transcribed into Malayalam text. The transcribed text is translated into English for further analysis. The CAMCC framework is used as a 'coding frame' for structuring transcribed data (Schreier, 2012). We have used a concept-driven way (deductively) and tried to find evidence from the data that corresponds to the related aspects of the framework.

Additionally, some of the constructs were operationalized as follows. 'Reality check appraisal' encompasses self-efficacy beliefs as well as other aspects, such as actual cognitive ability, subject-matter knowledge, educational context, supportive colleagues, students' expectations, resources and time. 'Yielding' to the reform message is influenced by a variety of factors, such as whether the processing was biased, teachers' existing conceptions, and characteristics of how the message is perceived (Gill, 2003).

Findings

Case 1: Teacher Ms. D

Ms. D is a higher secondary (Grades 11-12) school teacher in an unaided private school. She teaches Accountancy and Business. She is on a contract and her job is not permanent. Her school is situated in rural areas of the Thrissur district of Kerala. At the beginning of the lockdown, she had two years of teaching experience at the school level and four years of teaching experience at the college level prior to that. She has MPhil and BEd and is qualified State Eligibility Test (SET). She has not received any training on ICT and her exposure to educational technology before the COVID-19 pandemic was limited to WhatsApp for social networking.

Ms. D and her colleagues were not prepared for the sudden change to online teaching due to the lockdown. Ms. D and her colleagues started using the Google Meet platform to conduct online classes. It was the first time Ms. D and most of the other teachers in her school were using this platform. Teachers sat together in the school and learned the features of the platform from each other using trial and error methods. They conducted mock classes among themself to understand the possible challenges and errors that may arise during the live classes. They also used WhatsApp groups to share new ideas and information about the technology, and practices for online classes. In addition, teachers used Google classroom for sharing materials and worksheets for formative assessment. The ICT teacher in the school helped Ms. D to install the Google classroom app on her mobile phone and taught her basic features of the platform. Ms. D also took help from her husband and children to understand how to write content and upload it on the platform.

Ms. D used WhatsApp groups for communication, sharing educational materials, off-the-class discussion space for students to clarify their doubts, conducting formative assessments using quizzes and thought-provoking questions, and conducting summative assessments in which question papers and answer sheets are communicated. WhatsApp is also used as a way to encourage students by putting students' artefacts as WhatsApp status. In addition, Ms. D used WhatsApp to communicate with her students' families also.

Analysing Ms. D's change in beliefs about technology integration

The compelling situation when Ms. D's school instructed all the teachers to seek various digital alternatives for their classes can be considered as the reform message, i.e. 'rearranging the teaching-learning process by utilising available digital resources to help students to continue their education during the difficult time of COVID-19 pandemic' (see Figure 1). The message of this reform is strong because of multiple reasons. Ms. D's ability to implement this message had consequences for her continuing to keep her job. Also, she was aware of the need for students to continue their education even during the lockdown.

> *"When the school was closed……. students were anxious about their future career. Because the secondary level is the stage they need to make a career choice. As teachers we are also concerned about our students and their better career. I think these online classes can reduce these anxieties."*

However, implementing this reform message was a difficult process for Ms. D because she had no exposure to teaching online and the message challenges her conventional instructional practices. Ms. D considered this message as a dissonance to her existing beliefs about the teaching-learning process and her self is at stake (*implicates self*).

> *"We can understand things by looking at the faces of children in a normal class..further explanation is required or not. But there are limits to such things in online classes."*
>
> *"Studious children will learn in all mediums. Normal classroom learning is a must if you want to bring children who are backward in education to a forefront of the class."*

Hence she is likely to appraise the situation as stressful, (*Stress Appraisal)* and feel corresponding anxiety at first. Those who make such a stress appraisal will show the necessary motivation to process the reform message systematically. Here *motivation* will be decided by the characteristics of the person such as *Knowledge* and *Self-efficacy beliefs for using technology*. Despite Ms. D's six years of teaching experience and strong command of subject knowledge, her self-efficacy beliefs for using technology were low initially. She had not received any training in integrating technology into the teaching process. She expressed this unfamiliarity and lack of opportunity multiple times.

> *"I am not fully confident. I have not studied computers yet. I use my family's help to manage technology. I am still at an LKG [lower kindergarten] level in technology."*

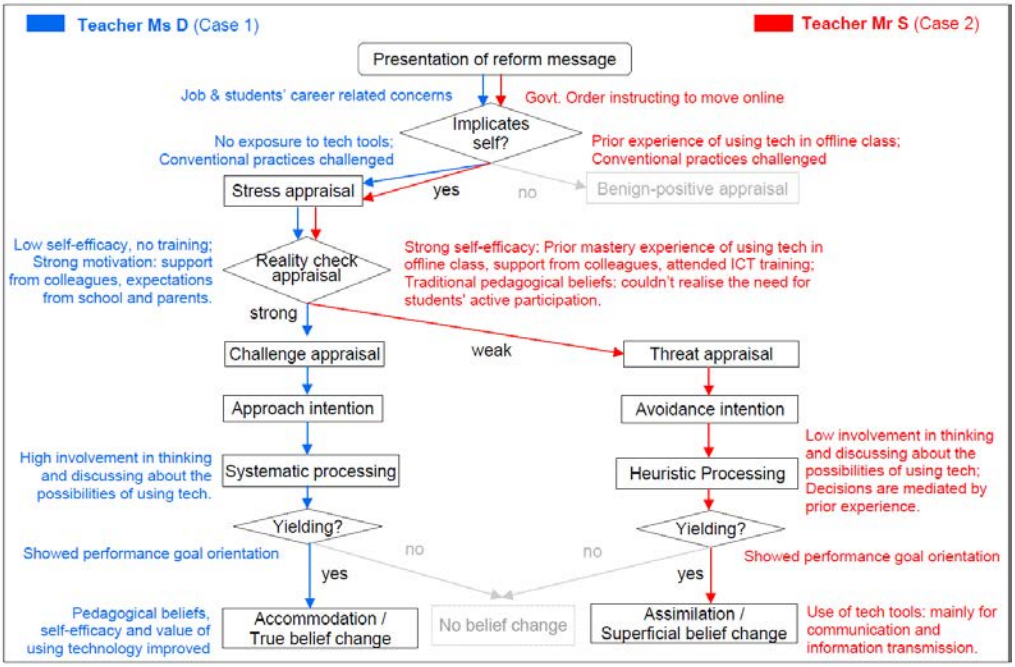
In Ms. D's case, contextual factors played an important role to affect her motivation. She shared that her colleagues and friends helped her a lot in preparing to shift to an online medium and learn new technologies to facilitate the online teaching process. There was also a high expectation from the side of school administrators, parents and students to continue schooling using digital technologies. Thus, Ms. D was motivated to approach the reform message, despite her weak self-efficacy and ability. This strong *Motivation* made her perceive the reform message as a challenge (*Challenge Appraisal*) and *processes the message systematically*. She had spent a considerable amount of time discussing with colleagues, friends and family members the possibility of moving into an online teaching-learning process. She took their help in learning the affordances of new tools required for conducting online classes and preparing materials. She made efforts to prepare students for online learning. In the case of Ms. D, since her school was a private unaided school and her posting is on a contractual basis, she had to prove that she is capable of teaching in an online medium. Otherwise, it may affect her job also. All these compelling situations created a performance goal orientation in her. Since she has strong beliefs about the value of the use of technology and goal orientation that supports the reform message, she *Yields to*, or accepts, the reform message.

Before the lockdown, Ms. D had no experience teaching with technology, and hence no specific pedagogical beliefs about technology integration. A year after teaching online, Ms. D recognised the affordances of technology, used it to foster deeper learning, and reflected upon the impact it made on her students (*true conceptual change)*.

> *'Usually, we utilize the imagination while teaching a concept. It is very difficult to pass on the imagination in our minds to children. We do not know what each child's thinking. But when we visualize with technology, we can bring everyone's thinking together to the same point."*

Figure 1

Visual model of two teachers' belief change as per the CAMCC model



Case 2: Teacher Mr. S

Mr. S is a high school Physical Science teacher. His school is a government-aided private institution located in the rural areas in the Malappuram district of Kerala. Malayalam is the medium of instruction in this school. Mr. S has eight years of teaching experience and has a BSc degree in Physics and a BEd degree in Physical Science. He has also qualified for the Kerala Teacher Eligibility Test (KTET), a state-wide teacher certification program. He has attended an induction programme for training teachers to integrate educational technology in their classrooms. In this programme, he was introduced to the pedagogical use of educational technology. He has learned to use various digital content and resources, such as those from Samagra eResource Portal and PhET simulations and completed various activities using these platforms to get a firsthand experience. Before lockdown, he had utilised Samagra eResource portal for showing educational videos to his students in a face-to-face classroom. He was also familiar with WhatsApp and used it mainly for social networking.

During the lockdown, classes were streamed through VICTERS TV and YouTube channels which are of lecture or demonstration type with thought-provoking questions to students. At the end of each class, resource teachers in the VICTERS classes gave common activities and assignments to the entire students of a particular grade in the state and asked the students to submit their answers to their concerned class teacher. Mr. S utilised WhatsApp groups for coordinating this process of collecting students' responses and giving feedback to them. Mr. S and students mainly used the texting and audio messaging features of WhatsApp for their communication. He also conducted online meetings using Google meet app weekly to clarify students' doubts and provide extra information and materials related to the topic. Mr. S used the lecture method for teaching and a blackboard for drawing diagrams and demonstrating problem-solving activities during the online class. Worksheets were created by a group of high school Physical Science teachers in the Tirur Education District. The same worksheet was given to the students in that entire educational district. The team members change every week. Every day, after the class on the VICTERS channel, the team used to meet online and prepared the worksheet. Teachers used

WhatsApp and Google Meet to coordinate this process. Students' responses to these worksheets were evaluated together in a term and these grades were considered for students to pass to the next class.

Analysing Mr. S's change in beliefs about technology integration

The reform message reached Mr. S as a government order (Department G. E., 2020) to 'rearrange the teaching-learning process by utilising VICTERS channel and available digital resources to help students to continue their education during the difficult time of COVID-19 pandemic' (see Figure 1). The order also mandated Mr. S to communicate with students before and after each class on the VICTERS channel by using social media or mobile or any other medium or face-to-face, for motivating students to actively participate in the classes and to take remedial measures to clear doubts raised by students. Even though Mr. S has some experience in using educational technology in his face-to-face class, moving completely to an online medium challenged Mr. S's conventional instructional beliefs. For example, he mentioned that:

> *"We never get satisfaction in Online mode like we get in a face-to-face classroom." "We can not get students' responses directly in online mediums and this lack of immediate feedback makes it difficult for us to improve our instructional practices."*

Mr. S acknowledged that the reform message requires something different from what he was doing in his classroom (*Implicates self? Yes*). Thus he appraised the situation as stressful and considered the message as a stake to himself (*Stress appraisal*). This is the first step on the path that eventually can lead to belief change. Mr. S has some prior mastery experiences of using educational technology in his face-to-face classes and observed that it helped students to learn the concepts much more easily. He had received practical training to integrate educational technology into the teaching and learning process. These experiences acted as a source of his strong *self-efficacy beliefs for using technology*. The *ability* (time, knowledge, resources) to implement the reform message is also an important factor. In this case, time, supportive colleagues and subject matter knowledge will determine whether Mr. S will approach or avoid the reform message. In Mr. S's case, the school was closed in the month of March 2020 and decided to start online learning in June 2020. So the decision to completely move to online learning was quick and he didn't get much time to prepare. However, he had received training to integrate technology in the teaching-learning process before the lockdown and that exposure probably gave him confidence. Similarly, colleagues, friends and family supported him to learn and use the online learning platforms.

Mr. S had reported constructivist pedagogical beliefs about teaching in face-to-face environments before the lockdown. For example, he shared an instance from his previous face-to-face class where he conducted a group activity on the topic of light dispersion, the process of converting sunlight into seven colours using a prism.

> *"We can either use sunlight or white light from a torch. The light from the torch will spread further as it passes through the prism. So we preferred sunlight for the experiment. The classroom was on the second floor of the school building. My period was after the interval. During the interval time the children fixed a mirror on the handle of a bike that was parked outside the classroom. The mirror arrangement was such that the sunlight reflected from it would fall on the prism placed in the class. The children were very excited when the rainbow was created like this."*

During this activity, he facilitated students to conduct the activity by fixing and adjusting the angle of the mirror properly to reflect the sunlight into the prism. He also stated his views about promoting the active participation of students.

> *"Discipline is not affected when children are part of the activity. I give instructions to the children before the activity begins. I explained to them about what they will to do in the class. For example, after doing this experiment, you should write down what you observed in your notebook, find out what is the reason. Then children do the activity and each group representative reads their findings in front of the class."*

However, Mr. S held more traditional pedagogical beliefs while integrating technology into his teaching. Even though he used videos and animations, his intention was mainly for information transmission and making students aware of science concepts. He could not realise the need for students' active participation in the learning process. Mr. S has failed to understand the pedagogical affordances of the simulation software and the role it could play as a facilitator of knowledge construction for students. Even though he had experience in using Samagra videos, he was reluctant to utilise those videos for online learning. He argued that students' active participation in online learning was not practical and teachers could not conduct any group activities in online classes. Because of these pedagogical beliefs, Mr. S experienced the reform message as a threat (*Threat appraisal*), despite strong self-efficacy and sufficient ability. This approach took him to *heuristic processing* of reform messages and led to a decision choice, *Yielding?* A variety of factors, such as the quality of existing beliefs about pedagogy and value of technology, and characteristics of how the message is perceived, decide whether the person will make any conceptual change finally.

When analysing Mr. S's beliefs about the value of the use of technology, we can see that he has shown utility value for the reform message.

> *"Showing the 3D versions of the atom model through digital technology can be very helpful. Children can understand and easily visualise the size of an atom and see how the heat is generated."*

At the same time, he has shown a cost value (the effort the task may take to implement online learning).

> *"There are a lot of difficulties in the online classes. There will be delays in seeing and getting feedback… more time is required for teaching a topic in online class than in face to face classes."*
>
> *"There are physical discomforts when you have to use technology for four or five hours straight."*

Mr. S has shown a performance goal orientation. His reason for considering the reform message is that he compared himself with other teachers who were going to implement this message. All high school teachers in the state were going to use technology and hence he has to consider this reform message. Similarly, Mr. S considered the reform message initially as plausible because he thought that using technology was the only way to continue education in this lockdown situation. When considering the influence of all these variables we can conclude that Mr. S has yielded to the message and ended up in *assimilation or superficial belief change*.

Discussion

The study conducted among secondary school teachers in the state of Kerala, India has shown a different range of changes in teacher beliefs about technology integration. We have found that teachers have undergone different path of beliefs changes in accordance with CAMCC. These changes can be attributed to a number of contextual and motivational factors of teachers.

In the case of Ms. D, the self-efficacy beliefs for using technology and ability were found to be very low. In spite of the weak and insufficient characteristics of the teacher, Ms. D processed the reform message systematically. The situational resource (supportive others) is found to be a crucial factor in the process. Ms. D and colleagues formed WhatsApp groups to discuss their concerns and problems faced during technology integration, share their experience of successfully using technology tools, and deepen their knowledge and expertise in both content and technology use. The idea behind this communication through WhatsApp was with a hope that everyone will benefit from their issues and expertise. Since the teachers used WhatsApp groups as their primary mode of interaction, they can also be considered virtual communities of practice (Wenger, 2008; Dubé et al., 2005). One more factor is Ms. D's empathy toward her students. She was very concerned about students' lack of digital resources. She was available to students even during weekends, through WhatApp and mobile calls for solving doubts and sharing their concerns. She was aware of the role online learning played during the pandemic in shaping students' education and their future careers. For Ms. D, technology was more than a transactional medium. She used it in a broader way by involving other stakeholders in her students' learning process and building community.

Mr. S had strong self-efficacy beliefs for using technology and sufficient ability. In some contexts, his beliefs as well as his practices were aligned and strongly supported student-centred learning. For example, he was successful in implementing active learning in face to face classes. However, his pedagogical beliefs on technology integration were found to be traditional, so he used technology mostly for communication and operational tasks. He did not show any instance of using technology for learner participation. Nor did he make the effort to exploit the affordances of the new technology medium. While he had good training and experience using technology and support from the school in terms of access to digital resources, he was unable to integrate student-centric learning practices into the new medium. In fact, despite repeated probing, he showed an inability and unwillingness to conceptualize student-centred practices in the online medium.

This case study highlights the importance of factors influencing effective technology integration, going beyond training on how to use technology. We found that factors such as support from colleagues and concern for students' future and a sense of community played a major role. At the same time, our findings may seem counterintuitive, where the trained teacher did not change his beliefs as much as the teacher who had low training for technology use due to the presence of the affective and contextual factors. However, the training prior to the pandemic did not provide for the unique situation we are in now. Hence, the training may have made Teacher 2 more rigid in their use of technology. The findings from this study contribute to expanding the understanding about the belief change process. Specifically, this study illustrates the importance of favourable contextual factors in the effective integration of technology. The findings have implications to learning sciences researchers working on effective integration of technology-focused solutions in the classroom and in designing TPD programs.

Even though we have valuable findings from the study, one limitation is that we do not have measurements of teachers' beliefs prior to the pandemic, except via retrospective reflections of teachers. We have not yet measured teachers' actual practice in the digital medium and it will be a part of future work.

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International Society of the Learning Sciences

Extending "othered" bodies into learning environments: Queer reorientations, virtual reality, and learning about gender and sexuality

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Abstract: In this paper, I illustrate how interacting with an immersive, virtual reality (VR) experience designed with queer phenomenological approaches can deepen understandings of gender and sexuality. I show how extending the queer phenomenological concept of *reorientations* (Ahmed, 2006) with complementary theories of ideological stance-taking (Philip et al., 2017) and emotional configurations (Vea, 2020) can highlight moments of emotional-ideological sense-making practices where learners become *reoriented* by reflexively negotiating between themselves and "othered" objects and people. I present an interactive, branching narrative told in immersive VR, in which the player uncovers the narrator's memories of gender and sexuality-based marginalizations in STEM learning environments. I then present illustrative cases from an ongoing design study. Analysis of the VR interactions reveals how participants used the narrative and virtual objects to recognize normative orientations to STEM and *reorient* toward counter-hegemonic actions and marginalized people.

Introduction

In this paper, I illustrate how interacting with an immersive, virtual reality experience designed with queer phenomenological approaches can deepen understanding of gender and sexuality and intersecting identities as complex experiences with individual and systemic dimensions. As reviewed by Paré et al. (2019), empirical research has shown that embodied interactions in virtual worlds can support learners to take on perspectives that would otherwise be difficult for them to adopt, across topics ranging from physics and chemistry to animal rights, racism, and ageism. I show how extending the queer phenomenological concept of reorientations (Ahmed, 2006) with complementary theories of ideological stance-taking (Philip et al., 2017) and emotional configurations (Vea, 2020) can highlight moments of emotional-ideological sense-making practices where learners reflexively negotiate between 1) their stances, 2) the "othered" people and objects they interact with, and 3) the socio-political contexts that coordinate individual and systemic conditions for marginalized people. This extended analysis of reorientations further supports identifying solidarity as an interactional phenomenon of reorienting one's emotional and ideological sense-making toward actions in solidarity with marginalized people.

Learning Sciences scholars have repeatedly called for the field to reorient itself in solidarity with marginalized people so that our research remains relevant (The Politics of Writing Collective, 2017; Curnow & Jurow, 2021), attends to issues of equity and justice (Bang & Voussoughi, 2016; Philip et al., 2018; Philip & Gupta, 2020; Philip & Sengupta, 2021), and better understands the political in learning (McKinney de Royston & Sengupta-Irving, 2019). However, despite recognition by many of the authors of these calls to include LGBTQ+ people and queer contexts in the Learning Sciences, this scholarship remains at the margins of the field (Curnow & Jurow, 2021). Nevertheless, Learning Sciences scholars have offered novel approaches to applying queer theory to illustrate how learners resist normativity (Lizárraga & Cortez, 2019; Paré et al., 2019; 2020; Takeuchi & Dadkhahfard, 2019; Takeuchi & Aquino Ishihara, 2021). In addition, Learning Sciences scholars working with LGBTQ+ identified learners have argued for greater attention to the emotional and political dimensions of learning in queer(ed) learning environments across digital and physical spaces (McWilliams, 2016; McWilliams & Penuel, 2017; Schrodes, 2021; Uttamchandani, 2021).

To this end, I present Mementorium, an interactive, branching narrative told in immersive, virtual reality, in which the player uncovers the narrator's memories of gender and sexuality-based marginalizations in STEM learning environments, moving from childhood to early adulthood, by interacting with meaningful objects in the narrator's bedroom. Analysis of the VR interactions and interviews reveals that participants drew upon the narrative and virtual objects of the VR game to recognize normative orientations in STEM learning environments. Furthermore, they *reoriented* toward counter-hegemonic and nonnormative actions and people in their narrative choices and reflection upon their lives.

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Theoretical background: Queer reorientations

My theoretical framework expands Ahmed's (2006) queer phenomenological concept of *reorientations* by bringing it into conversation with complementary theories of ideological stance-taking (Philip et al., 2017) and emotional configurations (Vea, 2020).

Scholarship on ideological sense-making as an interactional practice of stance-taking (Philip et al., 2017) offers a way to highlight the moment-to-moment processes of ideological reasoning in interaction with objects and others. Drawing upon Du Bois's (2007) dialogic framework of stance, Philip et al. (2017) showed in their analysis of classroom interactions how stance "is a matter of simultaneously evaluating an object and positioning oneself in relation to others" such that "every stance exists in a triangular relationship among the stance taker, the object that is being evaluated, and other subjects" (p. 196). The theory of ideological stance-taking aligns well with Ahmed's queer phenomenological approach that frames compulsory heterosexuality as an embodied experience of being oriented to normative ways of life in interaction with others and objects. Ahmed (2016) shows how "compulsory heterosexuality diminishes the very capacity of bodies to reach what is off the straight line" (Ahmed, 2006, p. 67) and, further, how, for BIPOC (Black, Indigenous, People of Colour), "that are not extended by the skin of the social, bodily movement is not so easy. Such bodies are stopped, where the stopping is an action that creates its own impressions. Who are you? Why are you here? What are you doing?" (p. 115). How we are oriented by others and objects affects how certain bodies can or cannot extend into learning environments. These moments of being stopped (Ahmed, 2006) and confronted with "the skin of the social" and "compulsory heterosexuality" become moments of embodied, ideological learning for marginalized QTBIPOC people (Queer, Trans, Black, Indigenous, People of Colour). This ideological learning occurs for those who are stopped, whose bodily movement is constrained by societal marginalization. A marginalized identity becomes the reason one is stopped, thus making these identities salient, while privileged identities are treated as already belonging, allowing them to go unnoticed by the privileged person. This scenario is not a simple binary in practice as people hold multiple identities, privileged and marginalized, that create unique intersecting oppressions (Crenshaw, 1990).

The reorientation of learners toward marginalized "others" and "objects" can be further understood through the lens of emotional configurations, where the emotions that emerge within social interactions shape ideological sense-making (Vea, 2020). Bringing together emotional configurations and ideological-political analyses is further supported by Curnow and Vea's (2020) work demonstrating how emotion is a key factor in understanding sense-making when learning about politics, power, and privilege. For example, Vea's (2020) analysis of animal rights activists showed that social movement learning in these spaces centered on the emotional configurations that organized social relations of "feeling, sense-making, and practice" in relation to other activists and nonhuman animals (Vea, 2020, p. 328). Specifically, Vea (2020) showed how animal rights activists intentionally organized emotional experiences, making emotion a target for learning that would then shape activist-participants' ideological sense-making by challenging human-animal relationships with nonhuman animals ("the other") and meat ("the other-as-object"). Thus, through a process of emotional configuration in collective action, animals were reconceptualized from being objects without needs or desires to being recognized as "othered" beings worthy of empathy and equitable consideration (Vea, 2020). Similarly, a queer phenomenological *reorientation* to the design of learning environments can create an intentional emotional configuration of learners from a normative alignment with the cisheterosexual "straight line" toward a counter-hegemonic reconceptualization of marginalized queer and trans people.

I propose a queer phenomenology of *reorientation* as a lens to support the design and analysis of learning environments that attend to learners' experiences of recognizing and resisting normative enforcements of docility and that reorient learners toward counter-hegemonic and nonnormative actions and people. Attending to reorienting acts highlights how learners make sense of inequities experienced by marginalized people and offers a lens to deepen our understanding of how to reorient learning and learners toward more equitable, counter-hegemonic ways of being and knowing. Extending queer phenomenological theories of *reorientation* through complimentary Learning Sciences theories of ideological and emotional learning offers an analytic lens to investigate queer(ed) learning environments that support reasoning about gender and sexuality and intersecting identities as embodied, complex experiences with individual and systemic dimensions. Further, my conceptualization of *reorientations* highlights moments of emotional-ideological sense-making practices where learners reflexively negotiate between their stances, the people and objects they interact with, and the socio-political contexts that coordinate individual and systemic conditions for marginalized people. *Reorientations* further supports identifying solidarity as an interactional phenomenon of reorienting one's emotional and ideological sense-making toward "othered" people and objects. This takes solidarity beyond an individual and internal state of being and into the realm of action, where we can leverage moments of counter-hegemonic affinity and design for reorienting learners toward solidarity-in-action.

Research questions

In this study, I ask the following two research questions:
RQ1: How can interacting with an immersive, virtual reality experience designed with a queer phenomenological lens deepen understandings of gender and sexuality and intersecting identities as complex experiences with individual and systemic dimensions?
RQ2: How do learners use emotional-ideological sense-making practices to reflexively negotiate between their stances in relation to virtual "othered" people and objects and the socio-political contexts that coordinate individual and systemic conditions for marginalized people.

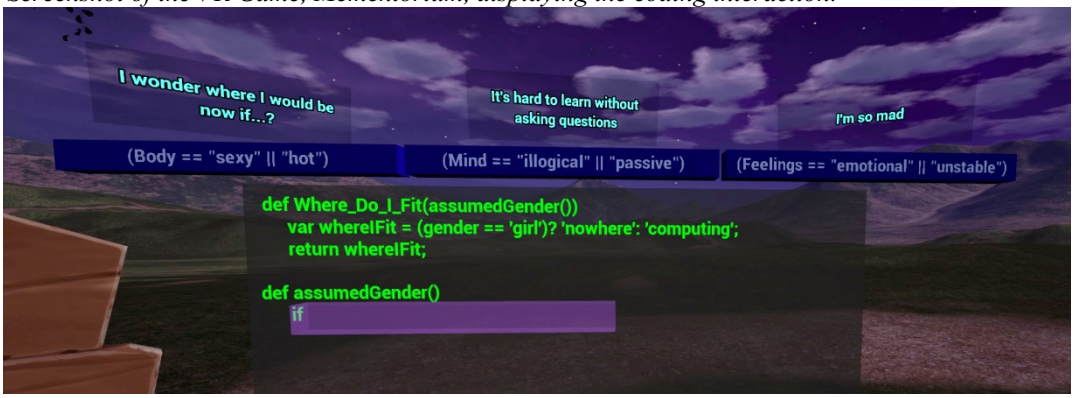
The research objectives are two-fold: 1) to deepen connections between the Learning Sciences scholarship on ideological and emotional sense-making in learning with phenomenological scholarship on gender and sexuality, and b) to extend the Learning Sciences literature on the design and analysis of queer(ed) learning environments and immersive technologies that attend to learners' experiences of recognizing and resisting normative enforcements of docility and that reorient learners toward counter-hegemonic and nonnormative actions and people.

The virtual reality game: Mementorium

To this end, I present Mementorium, an interactive, branching narrative told in immersive VR, designed by the author and collaborators. VR is experienced using a head-mounted display that players wear to enter the virtual world, hear sounds spatialized to match the source of the sound within the virtual environment, move within the virtual environment using VR controllers, and interact with virtual objects by, for example, picking up and touching objects.

To play the game, the player uncovers the narrator's memories of gender and sexuality-based marginalizations in STEM learning environments by interacting with meaningful objects in the narrator's childhood bedroom. Each of the memories that the player uncovers has three branching points in the narrative. First, the player uncovers the memory, revealing the harm caused by marginalization. Next, the player chooses their reaction to the situation that reorient the player to the narrator's experiences. Paré et al.'s (2020) work on queering simulation design found that designing interactions to encourage people to reorient their attention and emotions toward marginalized experiences supports deep reflection and learning. Finally, the player chooses a future-oriented response to direct the narrator's actions, offering choices for individual or group-oriented action or action on a larger scale of social change. The interaction design uncovers story branches that reorient players toward queer and trans imaginaries by queering science and technology objects and environments otherwise seen as politically neutral (Paré, 2021). For instance, in one interaction, the player is introduced to the narrator's experiences of a high school coding classroom. Next, the player is presented with a block-based coding interaction where the blocks they choose to complete the code also reflect their branching story choices. As the code is entered, the player is constructing Python-based code poetry that reflects experiences of gender, sexuality, and belonging in coding learning environments (see Figure 1).

Figure 1
Screenshot of the VR Game, Mementorium, displaying the coding interaction.



Each interaction with a story object transports the player to an outdoor, prairie-like environment where their bedroom furniture still exists as it did in the bedroom but is situated among flowers and trees. In the outdoor environment, each interactive object from the bedroom has been "transformed" into a fantastical or metaphorical version of itself that could not exist in reality. The game is structured around five branching narratives, occurring

at various times in the narrator's life (elementary, middle/junior high, high school, entering postsecondary, and early adulthood). Gameplay typically takes approximately 30 minutes to complete when not extended by conversations with the researcher.

Methods

As part of an ongoing design study, I have interviewed seven participants thus far as they interacted with the VR game. Interviewing people who already use VR was necessary for the study because people who are new to the technology can become distracted by the novelty of VR. The study setting is over Zoom videoconferencing, in which participants were provided access to the VR application and played the game while screen sharing their gameplay screen over Zoom. Participants included people of various genders and sexualities, ranging from their early 20s to mid-50s, and geographic locations including Canada, the United States, Australia, and Switzerland. Each participant was connected to virtual reality through interest or career -- some were interested in VR for research, others for design and application development, many were also hobbyists and players, and some were teachers interested in bringing VR into K-12 schooling. The study involved a single session, approximately 2 hours, including a pre-interview, the interaction with the VR game, and a post-interview. The pre-interview was conducted to learn about each participant's prior virtual reality experiences, knowledge of and learning experiences related to gender and sexuality, and experiences of gender and sexuality in the context of technology. During participant interactions with the VR game, I asked participants questions to understand how participants were making sense of their interactions and how they related or did not relate to the game.

Analysis and data collection were intertwined throughout the time that interviews were being conducted. Videos were transcribed, and codes were developed iteratively as data gathering continued. Videos, alongside their transcriptions, were coded line-by-line to inductively find emerging themes for focal analysis (Emerson, Fretz, & Shaw, 2011). Emergent themes were refined through my theoretical focus on identifying occurrences — i.e., turns of conversations between a participant and the game narrator or game object, or between a participant and the facilitator — that involved reasoning about gender and sexuality through stance-taking and emotional configurations. In each of these occurrences, I was specifically interested in how the participant was reasoning in relation to the game's narrative and objects — i.e., sharing personal stories related to the narration or explaining their reasoning for choosing a narrative branch or game object.

My presentation here includes Nate (he/him) — a self-identified cisgender man, primarily heterosexual, early-30s, high school computer science teacher in Alberta, Canada — and Meeran, who self-identified as a masculine-aligned homosexual assigned male at birth and still identifies as male. Meeran is in his early twenties, lives in the Southeastern United States, and is college-educated. Neither participant self-described their race. Nate appeared to be white. Meeran interviewed from within VR and presented in an anthropomorphized animal avatar. I chose to focus the analysis of this paper on these participants because their experiences of gender and sexuality differed from the VR game's narrator, thus offering distinct insights into reasoning about the "other."

Findings

Case 1: Nate reasoning about bringing gender and sexuality into his high school computer science classroom

In the pre-interview, Nate explained that he is progressively minded and relatively knowledgeable about different genders and sexualities. Nate has had discussions with his learning leader about encouraging more girls to be involved in STEAM courses. His school department decided to ask students for their preferred names and pronouns. Nate also includes some representation of gender and sexual diversity in his computer science classes through a brief history of computer science, including Ada Lovelace, Alan Turing, and Judith Love Cohen. He is also aware of industry problems such as the general male-dominated environment of computer science and issues with sexual harassment, specifically in the case of the gaming company Activision Blizzard. However, in his pre-interview, Nate explained that he finds few opportunities to include gender and sexual diversity as topics for learning in a computer science classroom.

> **Turn 1** Nate: it's just like it's it's it's hard to include gender and identity in there when it's we're literally just talking about, you know, multiplying numbers. ... it's not like there's an LGBTQ+ line of software development that we could study either.

As the VR game progresses to the fourth of five story branches, Nate begins to anticipate the narrator's experiences of exclusion before they are revealed.

> **Turn 1** The narrator tells story about being at a postsecondary open house and expressing interest in a computer science program.
>
> **Turn 2** Nate: [talking alongside the narrator and anticipating the outcome] Let me guess. He's going to ignore you. [expressed in an annoyed tone].
>
> **Turn 3** The narrator is given a cold response by the male representative that, "You have to be good at Math," and then being ignored.
>
> **Turn 4** Nate: Of course, he did [expressed in an annoyed tone].
>
> **Turn 5** Nate: [explaining to researcher] so what I was thinking about through all that was that I should definitely do a lesson on gatekeeping in computer science because computer science classes, they're not just about the coding, right? They're about the whole kit and caboodle of it. So. So maybe just even as a reminder or something that if you had any resources on that specifically, like any good ways to set up a lesson, feel free to email me those after this. And because at this point, I'm like hopping mad. I want to like on Monday, I almost want to walk in there and, you know, first 15 minutes of class, just do a lesson on that. And so like, the way I'm thinking about it is is. I mean, you know, the direct way would just be like, look around the room, what can you tell me about the people sitting here? And I'm sure someone would say it like I can think of like one or two students who probably are observant enough or it would get that of what I'm talking about to bring it up. But of course, like going about it in a more roundabout way, I'm sure, as you know, is probably more effective. So again, if you got any resources on that, you think I might be able to use for that, then feel free to send them to me.

In turns 2 and 4, Nate's anticipation of the narrator's experience and expression of annoyance demonstrate his emotional configuration toward the marginalized narrator. Then, in Turn 5, Nate's deepening emotional configuration, being "hopping mad," provokes an ideological stance that reorients his earlier stance toward computer science. Nate turns from a normative orientation to computer science during the pre-interview - seeing it as just "multiplying numbers" - to later challenging this idea, stating, "computer science classes, they're not just about the coding, right? They're about the whole kit and caboodle of it." He then quickly imagines a possible lesson design to address the problem in his next class and asks the researcher for resources to integrate more content about the political issues (gatekeeping) prevalent in computer sciences. Imagining lesson designs and asking for resources demonstrates a reorienting toward counter-hegemonic and nonnormative action in solidarity with marginalized people. Next, after the fourth story branch concludes, the researcher and Nate return to discussing industry issues as an example of gatekeeping.

> **Turn 1** Researcher: And so like I wonder like how do you? How do you bring up the relevance of these industries and their problems as students are learning computer science and thinking about their future paths? Do you see those kinds of conversations as relevant because you're obviously very aware of some of the problems, especially in terms of like some of the gaming companies?
>
> **Turn 2** Nate: I'm thinking now about like, OK, how can I do lessons on that as well? And it's. Like from the computer science curriculum, it doesn't really talk specifically about like that, the culture within the industries, which, you know, of course, now I'm going to be writing my MLA [provincial government representative]. Not that, you know, that UCP guy [Conservative party representative] will listen to me or anything. But just saying that, you know, that is something that should be included in the curriculum.

From this interaction, we can see that Nate is committed to addressing the issues raised in the narrative. He has decided that he needs to incorporate more lesson plans to address the matter and suggests contacting his government representative to argue for curriculum change. Although Nate was already knowledgeable and believed in supporting equity issues, implementing these into a computer science classroom was not a clear path given the overwhelmingly cisheteronormative orientation of the computer sciences discipline and curriculum (Paré, 2021). Lastly, Nate explains how the VR game solidified his commitments to equity and supported him in thinking through how to incorporate issues he was aware of but was not sure how to include into a lesson.

> **Turn 3** Nate: like around, like the culture within, within the companies, for example, you know, it's like, it's always been there in my brain, but. But, you know, it gave me the idea, oh, well, I should, I should address this. Like, that is relevant to my classes.

When prompted by the narrative, Nate recognized and resisted the normative orientations to computer science. Additionally, he reoriented toward counter-hegemonic and nonnormative actions by thinking about how he could teach his students to identify inequities in the classroom and challenge gatekeeping in computer science.

Case 2: Meeran reasoning about gender-neutral pronouns.

This case focuses on the interaction between Meeran and the fifth and final branch of the game narrative. Meeran demonstrates shifting stance-taking as he reasons about pronouns and gendered language.

> **Turn 1** The narrator tells a story about struggling to fit into a women's coding group that misgenders them, saying "hey, ladies" and assuming the narrator's pronouns.
>
> **Turn 2** Meeran: [heavy sigh outward] And unfortunately, I still say, hey, guys, a lot. Or you guys. I just, I don't feel like there's a standardized, gender-neutral system within the English lexicon. So, I hear from a lot of people who are transgender or gender-neutral. Usually, "you guys" or "hey, guys" like saying guys in general is OK, but I still wish there would be like an inclusive, like gender-neutral terminology. I, before I even knew, I just, I was thinking to myself, What's the gender-neutral term for sir or ma'am? There isn't really one. But I shouldn't assume.

Meeran's sigh after hearing the narrator's story expresses his emotional alignment with the narrator. Then, this sigh is followed by his sense-making of how his everyday practices perpetuate the same exclusions. As is a common initial ideological stance when people are reasoning about gender-neutral language, Meeran identifies the source of the problem as the English language. This move locates the problem in a structure ("the Lexicon") and suggests a linear system where the language structures dictate individual practices, where "you guys" exists because of the lack of "gender-neutral terminology." Next, Meeran begins reflecting on the choice for the following narrative branch about what the narrator should do about being misgendered.

> **Turn 1** Three narrative choices appear in order from left to right, floating as boxes above three chairs. The player must seat the bear in the chair of the choice: "Just ignore it," "Teach people how to include you," and "Set boundaries to be respected."
>
> **Turn 2** Meeran: You can't just ignore it. [referring to story choice 1 of 3] You have to be who you are. "Teach people how to include you" [reading story choice 2 of 3]. And I personally, I'm a masculine man. I. I look the part as well. Um. I've actually never been misgendered in my life at all. I'm.. I actually don't, unfortunately, have the experience of it, but I respect everybody's spaces. I call them whatever pronouns that they set themselves as. So, it doesn't hurt me. It doesn't hurt them. It doesn't hurt anybody. So. [looks at story choice 3 of 3: "Teach people how to include you"] I'm glad whenever people tell me their pronouns, but because I look and sound the part in how I express myself online. Plus, also just how I look in real life, I don't, I don't usually tell people my pronouns because people always assume it's masculine. And I'm OK with it. But I had a couple of people ask me what my pronouns were in VR, so I didn't think anything of it, and I just said "he/him". But people should get into the habit of asking for pronouns a little bit more often. So, "Set boundaries to be respected" [this story choice becomes Meeran's first choice] and also "Teach people how to include you." I want to choose both of these. This would be like one [pointing to story choice 2], two [pointing to story choice 3], three [pointing to story choice 1], but again, you can't just ignore it [referring to story choice 1]. [Meeran chooses, "Set boundaries to be respected."

Meeran states his ideological stance that the narrator cannot ignore misgendering because "you have to be who you are," showing an ideological orientation toward individual freedom of expression. He then relates to his own experiences with being correctly gendered by others' assumptions and identifies his lack of marginalized experience as a deficit to fully understanding the narrator's perspective. His emotional configuration toward the narrator supports extending his perspective beyond his own. By recognizing the limits of his perspective, Meeran reorients to the narrator as an expert of their life. During this reorientation, he reasons with the story object, "Teach people to include you," and notes that he appreciates when people tell him their pronouns. However, he recognizes

that his privilege means that he does not have to tell others his pronouns. His reasoning with the story object elicits the ideological stance that he likes when people tell him their pronouns, but his earlier emotional configuration supports him to recognize that his perspective is limited. He concludes that people should ask for others' pronouns more often. Meeran reorients his stance from his initial perspective toward a perspective more aligned with "the other." He chooses the story object "Set boundaries to be respected," reasoning that this is most aligned with the marginalized narrator's perspective. Merran then listens to the narrator explain similar reasoning that the burden of asking and providing pronouns should not always fall to marginalized people.

> **Turn 1** The narrator explains that the burden should not be on marginalized people to pre-empt others' assumptions of them by offering pronouns first when they are already at a disadvantage as a marginalized person.
>
> **Turn 2** Meeran: But I feel like saying hi, everybody or addressing everybody as well, everybody would work. It's just not used that often because again, everybody just likes saying, Hey gals or Hey guys.

In Turn 2, Meeran counters his initial stance that the English language does not offer gender-neutral options for addressing people and, instead, reasons that "hi, everybody" is a possible solution to the gendered language problem. He further identifies that the barriers to using gender-neutral language have less to do with the formal English language structure and more to do with the gendered social conventions that people reproduce as they tread familiar paths that orient them to the "straight line."

Summary and Discussion

Overall, my work offers insights into designing VR experiences and learning environments in general that extend "othered" bodies and their ways of knowing and being into the learning environments. The design, development, and investigation of Mementorium supports developing understandings of how to use new technologies (VR) and pedagogies (immersive, interactive narratives) to create learning environments that can address inequities in education (LGBTQ+ learners' marginalization).

Pedagogically, this work advances understanding of designing activities that encourage reasoning about socio-political issues of gender and sexual identity that encourage learners to reorient their perspectives toward marginalized people. This shifts the design of learning interventions that address LGBTQ+ inclusion away from conceptual approaches based on definitional work ("what is a trans person?") toward a more meaningful, phenomenological approach grounded in more profound forms of experience. Teaching gender and sexuality-based issues is often challenging work for marginalized people because it puts them at risk for harmful interactions when learners become defensive or resistant. Defensive learners often engage in microaggressions that deny marginalized people's ways of knowing their experience, leading to epistemic injustice (Fricker, 2007; Kidd, Medina, & Pohlhaus, 2017). However, people who do not experience marginalization but aim to act in solidarity (often called allies) lack valuable lived expertise (and sometimes also formal training) to lead the work. As a result, allies can fail to reorient themselves to the marginalized perspective in the ways necessary to act in solidarity (McKinnon, 2017). The design of Mementorium begins to address these problems by removing marginalized people from direct harm without losing the expertise of lived experiences and formalized expert knowledges that are present in the form of the immersive, interactive narrative game design.

Theoretically, this work extends queer phenomenological *reorientations* as a lens to support the design and analysis of learning environments through a complimentary combination with theories of ideological stance-taking (Philip et al., 2017) and emotional configurations (Vea, 2020). Further, I show how a theory of *reorientation* can attend to learners' experiences of recognizing and resisting normative enforcements and support reorienting learners toward counter-hegemonic and nonnormative actions and people. This takes solidarity beyond a notion or expression — "I am in solidarity with such and such marginalized group" — and into the realm of solidarity-in-action, where researchers can leverage moments of counter-hegemonic affinity (reorienting to emotional configurations in alignment with marginalized people) and design for reorienting learners toward ideological stances and proposed actions in alignment with the needs of marginalized people.

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Elevating the Ways in Which Latina Mothers Perceive, Do, and Envision Early STEM learning

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Abstract: Early STEM learning opportunities aligned with families' funds of knowledge can produce meaningful learning experiences for children. We investigated Latina mothers' perceptions and values of STEM learning, STEM-related activities with their children, and the early STEM learning experiences mothers designed for community spaces. In a research-practice partnership, we conducted seven virtual co-design sessions with 32 caregivers and individual interviews with a subset of 10 mothers. A thematic analysis revealed that Latina mothers' STEM perceptions were primarily informed by school-based notions, yet they also integrated STEM in everyday, family practices such as cultural games. Mothers valued experiences promoting family unity, intergenerational learning, heritage, active citizenship, and *ganas.* Finally, Latina mothers' values and practices informed their vision and design of early STEM learning artifacts in the community. Thus, diverse parents' contributions in design efforts can serve as a mechanism through which stakeholders connect and enhance children's learning experiences across contexts.

Introduction

Education researchers and learning designers recognize the critical role of caregivers in facilitating learning outside of school with their children. One ongoing effort is to create Playful Learning Landscapes (PLL), environments that combine science, technology, engineering and math (STEM) experiences, with play and family-interactions in everyday spaces (e.g., bus stops, grocery stores; Bustamante et al., 2019). Despite efforts to include diverse perspectives on STEM learning experiences (Garibay & Teasdale, 2019), much of the research on STEM learning activities may not accurately represent the diverse practices of families who are multilingual, from a lower socioeconomic status, and from underrepresented cultural groups. To promote STEM learning outside of school, it is critical to ground the design of learning experiences to support daily parent-child practices by recognizing and leveraging the ways caregivers already encourage STEM learning with their children. In this work, we unpack the current ways Latina mothers perceive STEM learning, how they naturally engage in STEM learning with their children, and the ideas they have for future experiences for their children. Our guiding research questions are:

RQ1: What are Latina mothers' perceptions and values for their children's STEM learning?

RQ2: What are the activities at home and in their community that Latina mothers engage in with their children that support STEM learning?

RQ3: How do Latina mothers' perceptions, values, and activities relate to the kinds of STEM learning experiences they design for the community?

To examine these research questions, we analyzed a research-practice partnership (RPP) with leaders and mothers of a community organization, and a university in Southern California focused on designing PLLs in community spaces. We analyzed seven virtual participatory design sessions where we engaged 32 caregivers to design STEM learning experiences. Our data set also included interviews with a subset of 10 mothers to gain an in-depth understanding of their experiences with STEM learning at home and in the community. We used theoretical frameworks from funds of knowledge (Moll et al., 1992) and speculative futures (Lukens & DiSalvo, 2011) to guide our analysis and research questions. We offer design implications for STEM learning experiences that honor the ways Latina mothers conceptualize STEM learning, are grounded in the concrete ways they already facilitate STEM learning, and are informed by their ideas for STEM learning futures.

Theoretical Framework

Funds of knowledge

Funds of Knowledge (FoK) refers to families' strategic and cultural "bodies of knowledge and skills" accumulated over time and with their communities that are "essential for household or individual functioning and well being"

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(Moll et al., 1992, p. 133). The framework counters deficit thinking of linguistically, economically, and culturally diverse students and instead leverages the FoKs within diverse families and communities that are assets in supporting students' learning (Llopart & Esteban-Guitart, 2018). Across content domains, researchers have adopted FoK to align programs to families' values and practices and create more meaningful experiences for students (e.g., Olmedo, 1997; Riojas-Cortez & Bustos Flores, 2009). In K-12th grade STEM education, most recent studies using FoK have focused on curriculum development, improvement of teaching practices, and community-school connections (Denton & Borrego, 2021). Such approaches are crucial to address the systemic disadvantages underrepresented students undergo in the pursuit of STEM careers (Whitcomb & Sign, 2021). We aim to create community-home connections through designs that align with families' FoK and promote early STEM learning in out-of-school community spaces. We use FoK to identify the perceptions and values of Latina mothers and their family activities that support children's STEM learning.

Speculative futures

In the human-computer interaction literature, scholars describe the ways in which the act of creating design artifacts and envisioning those artifacts in an intended context is meaningful research of a speculative and desired future (Zimmerman & Forlizzi, 2014). Utilizing design as a reflective practice, the manner that a problem space is interpreted and framed by participants provides insight as to what the world can progress towards (Rittel & Webber, 1973; Schön, 1983). Lukens and Disalvo (2012) propose key characteristics of speculative design approaches which include projects that are future oriented, cross-disciplinary, and integrative. We build on a speculative future design framework to analyze the artifacts mothers created which not only focused on STEM learning principles but also the ecosystem within which these design ideas would be implemented in their neighborhoods. We intersect this lens with FoK to unveil the underlying perceptions, values, and assets that inform the design of playful learning landscapes.

Methods

Research-practice partnership

This project is part of a larger multi-year study to design playful learning landscapes with and for local community members using a research practice partnership (RPP) approach. The RPP involves partners from the university, the city, and nonprofit organizations. Our leading partner was a cross-sector community organization of caregivers, educators, and community leaders committed to enhancing early learning opportunities and outcomes for children in the local community. The local school district serves children who are predominantly Latine (80%), of low-income households (about 87%), and from families who speak Spanish at home (79%).

Participants

Participants were recruited with the help of the directors of the community organization. Participants were 32 caregivers of children enrolled in kindergarten through 12th grade and members of the organization. Latina mothers composed almost all of our participants (N= 31) and one participant was a Latino father. Our sample is primarily representative of Latina mothers' viewpoints and therefore we represent our findings as such. Participants were predominantly of immigrant backgrounds, mainly of Mexican descent, and Spanish-speaking.

Procedure

Between November 2020 and May 2021, we conducted seven monthly 2-hour codesign sessions over a video conferencing platform due to the COVID-19 pandemic. The virtual sessions consisted of whole group discussions and six breakout groups of 4-7 parents. Participants' attendance per session ranged from 72% to 97%, with most parents (81%) attending six or seven sessions. We also conducted 1-hour individual interviews with a subset of 10 mothers who volunteered. The design sessions and interviews were all facilitated in Spanish to allow for more comfortable and genuine discussions, with a translator present for non-Spanish speaking researchers. We compensated participants $50 for attendance to every 2-hour session and $25 for interviews.

Each codesign session was structured to facilitate three types of activities. The first two types were conducted in breakout groups and facilitated by Spanish speakers who were instructed on the activity goals prior to the session. The first was a reflective activity focused on eliciting prior experience and knowledge of the topic. For example, we used storytelling to learn about families' everyday experiences and practices centered on science and math learning across contexts. We asked questions such as, "*What are everyday science things you do as a family?*" and *"Tell us a story about grocery shopping with your family when you were little and now with your children."* The second type of activity was design-based where we asked mothers to use arts and crafts to create

low-fidelity mock-ups of the type of installations they would like to see in their community spaces that bridged their backgrounds and values with general learning principles (e.g., active, meaningful, joyful; Hirsh-Pasek et al., 2020) and practices and cross-cutting concepts that support STEM learning (e.g., making observations, asking questions, cause and effect; National Research Council, 2012). Finally, we concluded the sessions by sharing key themes from our small group discussions as a community.

The second codesign session focused on eliciting core values mothers wanted the installations to perpetuate for their community. First, mothers engaged in a reflective activity in breakout groups, where they shared photos of their community and gave stories of those spaces, described the characteristics of people or things in that space, the feelings evoked, and what they valued about those spaces. In those same groups, we then asked mothers to complete a mad-lib design activity that completes a statement on principles. The purpose of the task was to convert values into community design principles to serve as a foundation for future designs emerging from our partnership. The mad-lib was presented in Spanish and read:

> I would like for us to create something _ (a descriptive word)_ while upholding _ (value)__while making sure people who are __(characteristics)__ feel welcomed, and feel _(feeling)__while interacting with the playful learning landscape.

In the individual interviews, we aimed to gain a deeper understanding of families' STEM activities, and their perceptions and values on STEM learning. We asked questions on math and science such as, *"What themes or concepts do you relate to learning science,"* and *"What feelings do you associate with science and its learning?"* Furthermore, we inquired about science and math activities at home with questions like *"What type of activities do you and your family engage in at home related to science and math learning?*"

Data analysis

We video recorded, transcribed, and translated all sessions and interviews using software programs and Spanish speaking members of our team for reliability. We obtained a total of 47 recorded codesign sessions (~ 42 hours total) composed of whole group and breakout room discussions. For this study, we analyzed 24 codesign video sessions and all 10 interviews. The analyzed codesign sessions included at least two breakout videos of each of the seven sessions, with a focus on the first two sessions due to the emphasis on family practices. We analyzed the data in Spanish using two phases. First, four researchers approached the data with inductive thematic analysis (Guest et al., 2012). At this stage, four progressions of a codebook included codes of *Described Parental Roles*, *General Learning Values*, and *Doing STEM with Children*. In the second phase, three researchers reviewed the codebook in conversation with existing literature, a deductive process (Azungah, 2018) that primarily informed subcodes such as *Activity Transfer Across Settings* and *Cultural Artifacts* for the root code of *Doing STEM*.

Findings

We divide our findings into three parts. First, we describe how Latina mothers perceive STEM learning and its relation to values they want to instill in their children. Second, we illustrate the ways Latina mothers currently enact STEM learning experiences in the home. Third, we provide an overview of the imagined futures mothers wanted for STEM learning experiences for the children in their community through the designs they developed.

Latina Mothers' STEM perceptions and values

Perceptions

The mothers' perceptions of STEM learning were informed by school-based learning experiences: STEM learning experiences in their youth and their child's learning journey at school. When asked what math and science meant, mothers defined the "doing" of math and science under the academic lens of school, with math associated with skills such as recalling numbers and conducting operations while science was often associated with hands-on school experiments and projects. One mother stated, "*For example, for the kids to learn numbers. I would really like for designs to have numbers, and to have those [geometric] shapes. And for them to say on their own that 1+1 is 2.*" While mothers saw the importance of math and science as disciplines that are "*necessary for any career because in reality… in a job it is what is needed*", many admitted to a negative sentiment towards the field due to its difficulty or lack of experience in applying the disciplines beyond everyday practices. As one mother noted, "*Mathematics, it is a very important subject to which I have panicked about,*" despite describing the use of math when managing money everyday.

Yet mothers acknowledged that school-based or formal ways of learning were not the only way, nor the best, to learn these disciplines, "*I think that it would be very, very rewarding ... for children in these times to not see something repetitive in science, something boring ... They are very intelligent so if they do it in a more fun way they can obtain more... like deeper into something*." Furthermore, mothers envisioned STEM learning as a process to promote agency, intergenerational interactions, and fun in their child's learning experience; one mother mentioned, "*I would like us to create something fun… to promote learning and family bonding*."

Values

We observed five core values mothers defined and abided by when tasked to design STEM learning spaces: family unity, intergenerational learning, heritage, active citizenship, and *ganas* or a will to succeed. Family unity or a sense of togetherness through activities echoed the concept of *familismo* that represents interdependence, loyalty, and cooperation in Latine households and that places family at the core (Espinoza, 2010). Mothers extended *familismo* to a learning value of intergenerational learning, which they defined as experiences that promoted family learning regardless of age, such as between grandparents and grandchildren. Mothers wanted installations to represent their heritage, and allow for the opportunity to teach children about their culture, the history of their city, and for a majority of mothers, their homeland of Mexico.

Mothers voiced the value of active citizenship or giving back to the community under the premise of *respeto* and *bien educado*. These values consisted of cultivating positive relationships and acting "appropriately" to others (Espinoza, 2010). While this premise is often associated with the concept of "good behavior" (Valdés, 1996), the mothers oriented this concept of *respeto* and *bien educado* to active citizenship and defined ways they wanted their children to conduct positive actions for the benefit of their community and beyond their immediate family household. Additionally, most of our mothers model active citizenship to their children by being involved in grass-roots initiatives such as park reconstruction. One mother expressed:

> I am doing it for my children, I am doing it for the children, I am doing it for, wanting to leave a better future for them... At first I began to want to give my children values, even if it was to participate in church. Then at school and then at the community level.

Finally as mothers described what they wanted children to take away from these playful learning landscapes, they referred to the notion of *ganas*, that evokes the motivation and the will to overcome challenges. *Ganas* is often used to instill perseverance and confidence in order to believe one can succeed and be able to take actions toward success (Barrios Gutierrez, 2010). As one mother mentioned: "*Having two girls here in [city anonymized] has given me the opportunity to get involved in many [educational] programs so that they see that I am interested in their progression ... they are in a place where 'Si se puede' and 'Echarle ganas' [Give it all]."*

Mother-Child STEM activities

As mothers reflected on family activities associated with STEM learning, many described structured activities that entailed a prescribed approach or a clear end-goal as opposed to a discovery approach. Cultural game-based activities were the most prominent way that mothers facilitated STEM learning opportunities, such as *loteria* or *pirinola* games. Mothers described how actions required to play the game can develop and reinforce math skills such as recalling numbers or math operations like summation. For example, one mother stated:

> We try to find table games… that I used to play with my mother, my sisters. Like Juego de la Oca [Game of the Goose], Lotería [Bingo], Serpientes y Escaleras [Snakes and Ladders]. I would explain how to play them.... There is a game that I love; it has always fascinated me since I was little, the Basta one… I like it because we are learning, even if we think we are not. We put in a little bit of math, counting squares, counting the dots in the dice, and adding.

The quote above emphasizes how games are a cultural socialization practice that Latina mothers transmit to their children and are valuable due to the memories, enjoyment and connection between family members, and learning they facilitate. To further support their children's learning, mothers also demonstrated high agency in looking to community video platforms like Youtube and TikTok, afterschool programs, and school activities for inspiration to expand learning in the home. Mothers noticed the benefits of these platforms, "*My daughter, the little one, has a lot of that [behavior] of going to YouTube and doing many things*" and utilized the learning affordances that technology provides in scientific practice (Yip et al., 2014). Mothers reported how these resources promoted structured STEM learning activities at home like making slime, volcanoes, or crystals.

Despite the prominence of structured activities, mothers also viewed everyday practices as opportunities for STEM learning. Mothers actively connected math and science ideas to their daily actions like running and measurement of speed, daily practices like counting money or cooking, and utilized daily surroundings such as learning about ecosystems and plants at the park. Without using the specific terminology, mothers alluded to the teaching of various science *crosscutting concepts* and *practices* (as specified in the Next Generation Science Standards; National Research Council, 2012) as they conducted activities and catered discussions with their children. Cooking is a prominent family activity that supports the learning of practices like making observations of food texture or taste, and crosscutting concepts such as quantity, proportion, and numbers. One mother said, "*On the example of cooking, if you want to make cookies, you are going to use a certain amount of sugar and if you want twenty cookies, you are going to double the amount of sugar. Like the idea of proportion, but in this concept of science.*" Cooking at home which requires experimenting with recipes represent open-ended explorations as opposed to the prescribed nature of formal learning environments.

As mothers described their learning practices at home, they simultaneously revealed their approach to facilitate these learning opportunities by taking on co-learner roles and child-centered teaching. Despite having revealed negative sentiments or fear of not knowing enough about STEM, mothers often placed themselves as co-learners with their child and expressed a willingness to learn alongside their children. As a parent mentioned, "*Well, when they have any questions related to any of these [science or math] topics, I try to help them the best I can. If I don't have the answer, I go to Google and we look for it together and I learn at the same time.*" Mothers still viewed their participation in their child's learning as essential to teach kids how to navigate learning more so than teaching content "*because we ourselves are the teachers in which we are teaching them how to participate.*" Furthermore, mothers noticed that young children were naturally curious and were filled with questions about their world. Thus, they embraced this natural curiosity to promote child-centered ways of learning where the child was encouraged to think through a problem with the scaffolding and guidance of the parent. They did so by giving responsibilities to their children that required the use of STEM skills, such as collecting the right number of food items when cooking at home or shopping at a grocery store.

Imagined STEM learning experiences

Overall, in our design sessions caregivers came up with ideas that echo their values, existing practices, and perceptions of learning. In this section, we provide two illustrative examples that highlight key themes caregivers emphasized throughout our design sessions toward their imagined futures ideas for playful learning landscapes that promote STEM learning: sustainability and games.

Sustainability vignette

The third co-design session had mothers design an installation for their community with three constraints. Mothers were randomly assigned an object or place, a value, and a science practice (e.g. making observations, making predictions) or crosscutting concepts (e.g. patterns, cause and effect) to guide ideation. Mothers were provided with crafting materials, paper, and markers to create a visual representation of their idea at home.

One group was assigned the design constraints of a street as the place, intergenerational learning as their value, and scale/proportions as their science focus. Their design idea was centered around a community trash awareness activity that helped people learn about scale, proportion, and quantity. When sharing their idea, the mothers noted that the inspiration for their design was their observation of community members constantly throwing their trash on the streets and the desire for more civic responsibility among them, especially their children. The mothers explained that if the community were more conscious about the impact of waste habits, trash would be disposed of and placed in the appropriate waste bins. One caregiver noted, *"like a community we could come together or as families…we could come together as one to maintain our streets clean and we can teach our kids how to properly dispose of their trash."*

Despite the focus on the intergenerational value where they designed an opportunity to teach their children about wasteful habits, this idea also echoes the value of active citizenship where mothers want their children to be positive members of their community. The group resorted to varied math measurement systems to measure waste in a way that would encourage comparing trash weights across streets, including a height or measurement feature across the bins. Thus we note that they viewed mathematics as a mediator for community action and promotion of active citizenship. Mothers explained that the design would motivate children to separate the trash into recyclable, non-recyclable, organic, and inorganic trash to teach children how to differentiate between the trash contents. Related to the community value of intergenerational learning, this design idea shows how it would be meaningful to the community to improve the neighborhood as a collective activity that includes people from all ages, and through an active manner that involves collecting, separating based on observations of the characteristics of items, and measuring.

Gaming Vignette

Just as game-based activities were a primary mechanism to learn STEM in the household, mothers designed a plethora of ideas for games that could promote STEM learning with their children in their community. In another case, we saw how mothers' prior experiences in STEM learning and perceptions of what counts as STEM played a key role in the majority of brainstormed activities. These games included competitive and active versions of card games, puzzles, memory games, and physical challenges that would test or familiarize children to fundamental skills or content. Among these game-based ideas, Hopscotch was prominent throughout the codesign sessions as mothers shared that they played Hopscotch to actively learn colors, shapes, and numbers.

> Juego de avión [Hopscotch] is what we call it in Mexico and I think the children are playing it here [United States]. They are having fun and they are also learning mathematics because they are jumping … to number ten and … you can also ask what number you stayed at.

Mothers redesigned Hopscotch to include prompts or questions that would reinforce children's math and science skills, including jumping to a shape of a certain color or size or integrating math questions. While these ideas were grounded in mothers' experiences, they used their values as a guide to modify those experiences towards a specific learning goal. In this example, intergenerational learning informed the manner in which parents modified Hopscotch in order to share a piece of their past with their children. Family unity was also a prominent value as mothers proposed to infuse hopscotch into everyday, family spaces such as integrating this activity into the sidewalks that families use to walk children to school.

Discussion

Our findings reveal how mothers approach and conduct early STEM learning as informed by cultural values and evolving perceptions of what counts as STEM. The FoK lens unveiled existing practices and knowledge that mothers contributed to early STEM learning. Mothers largely refer to school-based content for the "what" of STEM such as math operations, and utilize child-centered approaches for impactful learning. We saw mothers encourage the transfer of activities from school or online platforms into the home to support their child's natural curiosities and take on co-learner approaches despite their lack of confidence in the topic. Additionally, mothers leveraged everyday practices such as cooking or grocery shopping to incorporate STEM concepts relevant to a child's daily life. This is essential for youth to become full participants in the field (Yip et al., 2012) and mothers are a clear resource to promote relevance. As such, their cultural values represent the deeper lessons and morals they want to instill in their children, thus viewing STEM learning as an opportunity to promote family unity, intergenerational learning, heritage, active citizenship, and *ganas*. Instilling these values in the design of future STEM learning experiences symbolizes the desired or speculative future mothers wish for their children.

Implications

Our analysis of mother's perceptions shed light on research studies of Latine parent perceptions in early STEM. Most research on Latine parents' perceptions and involvement have focused on general education (Valdes, 1996; Tinkler, 2002) and those focused on STEM subjects have yet to explore current family practices for young age groups (Deleon, 2018; Hernandez et al., 2016). We build on this past work through an FoK and speculative futures lens to show how mothers immediately resorted to school-based notions of what counts as science and math, however, through further prompting and designing for speculative futures in community, they revealed the need for and practice of informal, everyday approaches that instill values in their children. This aligns with Latine families' notion of education, where academic goals and morality are seen as interconnected and not mutually exclusive learning experiences (Halgunseth et al., 2006).

FoK is a lens that reveals opportunities for designers to actively design for inclusion that is built on families' values and the ways that diverse parents support children's learning. Understanding the cultural knowledge of underrepresented families when designing for spaces that are not historically inclusive of diverse practices is an important step towards validating and leveraging their forms of learning (Aschbacher et al., 2010). For example, *familismo* is critical in the development of STEM identities of Latine students, as they often rely on friends and family as a source of aspirational capital (Matos, 2021). Yet such value contradicts values upheld by academic institutions which embrace the US culture of independence and self sufficiency (Espinoza, 2010; Rodriguez, 2021). In the context of designing playful learning landscapes, the focus on FoK and cultural assets allowed us to reimagine ways that STEM learning can embrace community values explicitly using math and science learning opportunities. Through the lens of speculative futures, this awareness resulted in design ideas

such as an activity that focuses on environmental sustainability through the measurement of community waste. The idea was meant to take advantage of moments of family unity and togetherness, such as walking around the community or waiting for a bus stop, to encourage active citizenship through math.

Involving caregivers in the design of STEM learning installations in their community ensures that ideas are grounded in the lived experience of families who will use them. Designing from an approach that builds on families' experiences and incorporates parents in the design process can result in greater usability of artifacts, more rich learning experiences for children facilitated by family members, and families feeling greater ownership of the artifacts resulting in their long-term sustainability. In this paper, we have shown that Latine mothers' values and practices are reflected in their design ideas, and as such the contributions of diverse parents in design efforts can serve as a mechanism through which researchers and practitioners connect and enhance children's learning experiences across home, school, and other community spaces. This contributes to ongoing research on the development of meaningful STEM experiences that is inclusive of different cultural communities through community-based informal learning (Clegg et al., 2014; Santo et al., 2019). We extend this body of research with the perspective of Latina mothers' practices for early STEM education through play.

Limitations and Further Research

One limitation to our research are the missing perspectives of Latino fathers in the design of STEM learning artifacts. Prior research suggests that mothers and fathers in Latine families do not always socialize their children in the same ways and that children's responses to a specific practice sometimes vary depending on which parent it involves (e.g., Kuhns & Cabrera, 2020). Thus, future research in STEM learning should include fathers and potentially extended family members (e.g., grandparents, aunts or uncles, godparents) that might have an additional contribution to the learning experiences of underrepresented young children. Another limitation in our study is that our team is currently working on the final designs of playful learning landscapes and as such we have not yet examined the extent to which families' cultural knowledge is maintained and incorporated in the final artifacts resulting from the elaboration process between community members and the research team in RPP work. Our next steps are to evaluate the alignment between families' cultural assets and learning principles in the final artifacts and whether installing those artifacts in community spaces result in greater opportunities for families to engage in STEM learning interactions.

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The sensitive nature of feedback as a sequential phenomenon

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Abstract: Social actions such as advice and feedback are sensitive actions, often triggering emotional and defensive reactions. Moreover, just how to understand and describe such actions – for instance, as "constructive advice", "complaints", or even "insults" – is a potential point of contention and dispute for participants in interaction. Based on a corpus of video data from higher education, our research aims to develop a conceptual and empirically grounded understanding of the social organization of feedback. This study investigates how students and teachers orient towards the sensitive nature of feedback in critique sessions in architectural education. With a few examples from the data set, the study focuses on three issues: a) the sequential organization of feedback; b) the grounds for two (conflicting) orientations to the feedback; and c) the ongoing instructional work to make the students hear the feedback in the "right" way.

Introduction

Numerous studies and meta-studies show the massive presence, relevance, and diversity of feedback in higher education – from formative assessments of completed course work to responsive instructions produced during the performance of tasks (e.g., Evans, 2013; Hattie & Timperley, 2007). Feedback is used to point out mistakes or misconceptions, provide advice on how an assignment could be further improved or differently approached, and strengthen the students' ability to monitor their own performance. While the central role of feedback is agreed upon, not all feedback is equally effective in terms of learning. In a review of research on feedback, Hattie and Timperley (2007) maintain that praise is ineffective "because it contains such little learning related information" (p 86). They further argue that feedback seems to be "more effective when there are perceived low rather than high levels of threat to self-esteem, presumably because low-threat conditions allow attention to be paid to the feedback" (ibid.).

Although claims by Hattie and Timperley could be problematized on both empirical and conceptual grounds, they highlight a persistent challenge for university teachers: how to point out mistakes and deliver advice that is beneficial to student learning in ways that pose little 'threat' to students. Students and teachers tend to report different perspectives on what feedback is or should consist of (see Carless, 2006; Henderson et al., 2019). It is often possible to understand feedback, advice, or critical remarks in different ways. What the teachers perceive to be constructive feedback, the students might hear simply as complaints. This tension is not limited to higher education: feedback, advice, and similar social actions are delicate matters in mundane and institutional settings (Sutton et al., 2012).

When locating feedback as a critical activity within many educational settings, we see a need to enrich the view on what this notion might encompass. This study, therefore, takes an interest in the delicate, ambiguous, and potentially contentious nature of critical feedback and how this delicacy is constituted and handled in interaction. We have examined a larger corpus of recordings of critique sessions in architecture education with an analytical starting point in ethnomethodology and conversation analysis (Garfinkel & Sacks, 1970). To develop our line of argument, we will address a) the sensitive nature of feedback as a *sequential* phenomenon; b) the grounds for two potentially conflicting *orientations* to feedback; and c) the ongoing *instructional work* designed to make students hear and understand feedback in the "proper" way.

Background

Before turning to the empirical part of the study, we outline some prior research tied to the interactional phenomena and context of the study. The first section summarizes some findings on the social organization of feedback, advice, and critique, and more specifically, studies that investigate the sensitive and potentially problematic aspects of this type of interaction. The second section concerns the context of the study, and briefly discusses prior research on 'critique sessions' in architecture education. As the term critique session implies, and the existing literature demonstrates, such educational arrangements are useful settings for investigating *critical* feedback and how teachers and students orient to its sensitive nature.

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The interactional organization of feedback and advice

The problematic and ambiguous character of critical feedback is reflected in the English language (as well as other languages). As a verb, 'critique' could mean to "evaluate (a theory or practice) in a detailed and analytical way", but also to "indicate the faults of (someone or something) in a disapproving way" (Oxford Dictionary of English). Delivering 'constructive criticism' might have positive connotations, but 'being criticised' seldom does; and although 'complaining' is regularly understood to be essentially different from 'giving advice,' it is often hard to determine whether an utterance removed from its natural context is advising, critiquing, complaining, or something else. Whether an utterance is understood to be offering advice or making a complaint is tied to particular occasions, and its sense might be perceived differently by speakers and recipients (Heritage & Sefi, 1992).

Actions are also reflexively tied to activities and membership categories (Sacks, 1992). A remark on the speed of a driver that is uncontroversial during a driving lesson, has the potential of becoming provocative when it is said by a fellow passenger. During a driving lesson, the remarks, directives, and advice from the traffic instructor are relevantly understood in terms of teaching and learning. When fellow passengers comment on the speed or proximity to the roadside, this might be heard as a negative remark on the driving. As noted by Heinemann and Traverso (2008), speakers seldom characterize what they are doing as complaining, but instead use "less negatively valenced labels such as 'criticizing,' 'troubles-telling' or even 'factually reporting'" (p. 2381). Nevertheless, the insurance that the passenger is 'just telling' does not necessarily lead the driver to hear anything but a 'complaint' from a 'back-seat driver.' As Edwards (2005) surmises, "'complaining' [and we might add, 'critique' and 'feedback'] is a defeasible vernacular category with normative oriented-to properties and consequences" (p. 7)

In educational settings, where feedback and critical advice from teachers are expected features of educational exchanges, one might think that the sensitive aspect of feedback would be absent. As observed in previous research on feedback in higher education (Vevhiläinen, 2009), however, the educational context per se does not remove the sensitive nature of feedback. When a teacher suggests that something could be done in a different way – for instance, that the introduction of a manuscript could be differently organized – it could potentially be heard by the student as saying that the introduction is not good enough, or that the student has failed to live up to the relevant standards. It is therefore common that teachers orient towards feedback that potentially involves negative assessment as socially problematic (Skovholt, 2018). As testified by the literature on architectural critiques, moreover, students sometimes experience that feedback is more closely tied to power and authority than to learning and development.

Critique sessions in architecture education

All over the world, students of architecture traditionally spend much of their time working with models, sketches, and plans in different kind of design-projects – sometimes alone, at other times collaborating in small groups (Schön, 1983). At the end of a course, students and their projects are regularly assessed and evaluated. Reflecting the project-based structure of the education, as well as the complexity and multifaceted nature of the domain, assessments such as written tests are commonly put back in flavor of what is variously called *design reviews*, *juries, dialogues, critiques*, or *crits*. Design reviews typically begin with students presenting their projects to an audience of staff members, professional architects, and peers (e.g., Lymer, Ivarsson & Lindwall, 2009; Lymer, Lindwall & Ivarsson, 2011; Webster, 2005, 2007). After the presentation, staff members and invited professionals criticize, comment on, and discuss the students' work, elaborating on the strengths as well as the weaknesses of the presented projects.

When asked, students and staff members often highlight that design reviews provide students opportunities to display their work and to articulate their ideas, to receive formative feedback from teachers and peers, and to critically reflect central issues, and to improve and progress in their work (Smith 2021). Even if the strengths of design reviews are brought forward, however, students as well as staff frequently display mixed feelings about these events. As noted by Webster (2007), for instance, it is not uncommon for "students to describe the purpose of design juries as an occasion for both individual learning and the collective celebration of student achievements while at the same time recalling their own experiences of design juries as profoundly de-motivating and competitive." (p. 287). Other students express more reproving attitudes towards the design reviews, describing them "as an ordeal devised by tutors to leave them feeling as though they have been 'undressed in public'" (Doidge, Sara & Pamell, 2000, s. vii).

With titles such as "Design juries on trial" (Anthony, 1991), "Judging juries" (Anthony, 1989), "Reviewing the review" (Wilkin, 2000), and "Critiquing 'Critiques'" (Dannels & Norris Martin, 2008) several studies of design reviews critically assess and evaluate the educational format. Reporting on a one-year ethnographic study at a British school of education, for instance, Webster maintains that the design reviews mainly

are events where "staff uses their power to coerce students into reproducing staff-centered constructions of architectural habitus" (2005, p. 265). She further argues that the practice of critique itself is replete with structural features working against student learning. In light of this argument, "the continuing use of the architectural review is questioned" (ibid.). In a later study based on the same material, Webster (2007) draws on Foucault to discuss "the analytics of power" and the "startling schism between the official, or declared, intentions of the critics and their actions" (p. 24). From this analysis, Webster concludes that the design review should be "replaced by a new set of pedagogic events that are carefully constructed to support student learning" (p. 21). Other researchers, while acknowledging the problems with the design reviews, take a less radical approach and point to the need of "feedback literacy" among students and teachers (Smith, 2021).

Theory and methods

In this study, and in contrast to some of the research outlined in the previous section, we are less interested in evaluating or critiquing the educational format, as in explicating the local and situated organizations that occasions the sensitive or contentious features of feedback. Prior studies that have investigated these features have drawn on existing models and theories from sociology and social psychology, and conceptualizing the sensitive nature of feedback in terms of face-work (Goffman, 1955), politeness (Brown & Levinson, 1987), and motivation (Swann, 1990). With an analytical starting point in ethnomethodology and conversation analysis (Garfinkel & Sacks, 1970), our interest is instead directed to the endogenous organization of social actions, and how members continually display their understanding of and orientation to prior actions as a constitutive part of this organization.

As repeatedly demonstrated in conversation analytic studies, social actions have a sequential organization; this means that each turn-at-talk displays an 'analysis' of the previous, which may then be either ratified or 'repaired' in subsequent contributions. This, in turn, provides us as researchers the material for our 'second-order' analysis – if the members sequentially display their understanding to each other, they do so for us as professional analysts as well (Lindwall, Lymer, & Greiffenhangen, 2015; Sacks, Schegloff and Jefferson; 1974). This sequentially based interactional conception of participant orientations provides a powerful analytic tool to ground claims that participants in a particular activity can be described as, for instance, orienting towards aspects of feedback as 'delicate' or 'sensitive'. Likewise, an analysis of resistance and/or dispute in relation to feedback interactions can be grounded in the sequential, turn-by-turn achievement of shared, contested or negotiated understandings.

In conversation analysis, the notion of "sequence organization" refers to the organization of meaningful courses of action enacted through turns-at-talk and embodied practices such as head nods, gestures, and shifts in posture (Schegloff, 2007). In order to follow and to be part of a meaningful interactional exchange, members need to monitor and analyze talk and embodied practices so as to understand what other members are doing and in order to respond in appropriate and coherent ways. The most basic sequential organization is the adjacency pair, which is a unit consisting of two actions produced by different speakers, and where one of the actions initiate the exchange, whereas the next action responds to the first. Typical examples of adjacency pairs include greetings ("Hello", "Hi") and question-answers ("what time is it?", "five a clock?"). In feedback interactions, more complex sequences emerge. Just as with adjacency pairs, however, analytic attention is devoted to examining actions and their responses, along with the ensuing sequences.

The study is part of a larger project where we investigate the sensitive nature of feedback across different settings, including text supervision in social science and 'debriefings' in martime and medical education. The examples presented in this study is drawn from a corpus of 70 hours of video material of critique sessions in architecture education. The recordings were made during a period of four months at a Swedish school of architecture. In total, 159 critique sessions have been video recorded, ranging in length from 10 minutes up to one hour. In the present paper, a highly selective approach is taken, presenting two extracts of interaction as illustrative examples of the issues under discussion. The episodes have been transcribed following the conventions developed in conversation analysis (e.g., Jefferson, 1984). In the transcripts, pauses are represented as numbers of seconds within brackets, with (.) indicating micro pauses. Co-occurring talk is horizontally aligned, with square brackets marking the onset of overlap. Extended vowel sounds are marked with colons, as in e:::h; >talk< indicates that it was delivered more rapidly than the surrounding talk, and <talk> that it was delivered more slowly. The original material is in Swedish, but given the limited space, only the English translations are offered here. For the same reason, actions such as gestures, head nods, and posture are excluded from the transcripts.

Results

Feedback and sequence organization

By examining the video recorded material, and returning to the notion of sequence organization, it is clear that feedback is not constituted by one specific type of initiating action with its corresponding next; feedback sequences do not constitute a particular form of adjacency pairs. The feedback provided by instructors and professional architects in the critique sessions take many forms and shapes; among the common variants, we find assessments ("this is a beautiful solution"), suggestions ("perhaps you could have used marble as the base"), questions ("what was the main concept with this floor plan?"), and directives ("do not read the presentation, but speak freely instead").

A first issue for students is whether they should explicitly respond to the feedback or not. This issue turns on the shifting and ambiguous addressivity of critic's talk – and its 'split audience design'. On the one hand, the critique is addressed to the group of students responsible for the design. Also present, however, are the students' peers from the same class. In an important sense then, the feedback is at the same time produced to be heard by a larger audience of students. During the course of a session, the relative emphasis put on addressing the particular group, or addressing the audience as a whole tends to vary. The critic might move from asking the responsible students a series of questions about the design, to elaborating on more general concerns. Even when doing the latter, however, the particular design proposal is often explicitly used as an example. This generates an interactionally difficult situation for students, in terms of the relevance of responding to feedback.

If a first issue for students is when to respond, a second issue is how responses should be designed. Since conversational exchanges are produced sequentially through a 'paired' structure, which includes expansions to the 'base-pair', the students need to produce a next action that fits the first for the interaction to be coherent. A request can both be met with acceptance and rejection, but if someone responds with a greeting it could potentially signal some trouble of hearing or understanding. In the design reviews, students typically respond to initiating actions with "type-conforming" (Raymond, 2003) nexts; i.e., questions are responded to by answers or accounts, suggestions with acceptance or rejection, and assessments with acknowledgement or perhaps second assessments.

Going back to the introduction, however, feedback in its various forms have the potential to be understood in different ways. Regardless of the form of the criticism – whether it is produced as questions, reminders, or assessments – it could be heard as doing 'complaining' rather than 'constructive advice'. Given that interaction is sequentially ordered, moreover, these understandings are displayed in and through the students' responses. When advice is is met by "I am sorry I made these mistakes", moreover, the response is not only doing an excuse, it also shows that the student heard a complaint in the previous utterance. In our data, such ascriptions are treated as problematic by instructors and invited professionals, and they typically engage in attempts to 'repair' the students displayed understanding of feedback as complaints.

'Counter complaints' is another next action produced by students which turns the interaction away from issues of learning and constructive advice towards issues of guilt and blame for having done something wrong. Excerpt 1 is a case in point. Before the episode, the students had presented a design proposal which include a hotel and a restaurant. One of the things that the instructor raises in relation to this proposal is the size of the ventilation shaft. When the episode in Excerpt 1 begins, the critic has already told the students that the ventilation shaft needs to be much larger, and he concludes by summarizing this point in the first three lines of the transcript.

Excerpt 1

```
01 KENT: what one has to show when making hotel and restaurant in this way (.) you have to
02       think like something goes up and something also goes down (.) we recycle air (.) and
03       things like that=
04 Per:  =it had been good if you had told these things us when we asked you
05       [during the process]
06 KENT: [yea but you have  ] to arrive at that point in the drawings (.) we can't
07       tell you everything from day one you know cause then (.) you'll (.)
08       collapse in-=
09 Dan:  =but [we   ] have had            [just] that discussion with you actually
10 KENT:      [yeah ]                     [yeah]
11 Dan:  =if one should be strict (.) and we didn't get any measurements,
12 KENT: yeah
13 Dan:  it's very hard when you say (.) that yea it demands very much  [space]
14 KENT:                                                                [yeah ]
15       but [then I say that now         ]
16 Dan:      [yea and then it's like that ] aha then we asked like this y'know
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In the beginning of the episode, the critic turns from looking at the plans to the audience of peer students when saying that "one has to show" (line 01 and Figure 1). The gaze and the posture, together with the use of a generic one (sv. *man*), marks the utterance as addressed to all the students rather than just those responsible for the project. When shifting from "one" to "you" (sv. *ni*) in "so you have to think like" (403), the critic is still looking at the audience, and the utterance can therefore be relevantly heard as still addressing a generic recipient rather than pointing out those who had produced the design proposal. Understood in this way, the comment is not just about this specific project, but something that all aspiring architects have to think about. This kind of hearing would also constitute a case of 'formative' assessment, where the comments grounded in the current example occasions larger issues and contexts not yet encountered. It is something to be heeded by all participants, not just the group under scrutiny.

The discussion that ensues, however, makes evident that the presenting students hear the critic differently. The comment about missing air ducts is treated as a 'summative' assessment of the presented design and not just a relevant consideration for anyone designing a hotel or restaurant. The missing feature is thereby understood as a flaw in the design. While hearing the critics remark in this way, the students are unwilling to take the full blame. By topicalizing a prior discussion about ventilation when the critic was acting as teacher, Per and Dan jointly formulate a counter-complaint targeting the lack of prior advice. The organization of this interchange is more complex than the examples of adjacency pairs initially offered in this section. For the purposes here, however, the most relevant thing is that the students, through their response, treat the feedback as a complaint about the design and by implication their performance. Heard as such, the critic's comments are relevantly countered based on what happened during the process.

In his response to the students' counter complaint, the critic addresses both the grounds of the counter-complaint and dismissing the relevancy of it in the current situation: he talks about the conditions of giving feedback – that it is impossible to provide all the relevant information at once – and that he frames the feedback as advice that is offered "now" (line 15), thereby accentuating the forward-looking aspect of the design reviews. The comments are thereby framed as lessons to be learned from the design review rather than evaluations of previous performance.

Two orientations

Design reviews have both *summative* and *formative* functions. On the one hand, the activities provide evaluations and gradings on students and their projects. On the other hand, they are instructional activities, aimed at furnishing and scaffolding the learning and development of disciplinary skills – for the students responsible for the project, but also for the peers acting as an audience to the critique. In Excerpt 1, like in many other episodes in our material, there is a tension between how the students and the critics approach the design review. In this example, the students orient towards the summative rather than the formative aspects of the critics' comments – it is about *their* design and what *they* should have done. The manifest orientation of the critic is different: he uses the students' design proposal to make general and instructive comments to the audience of students in the room, not just the ones that presented their project. The core issue is what the design proposal in front of him can teach all students present in the room.

From the latter orientation, the students 'misunderstand' the remarks by responding to them as primarily having a summative and retrospective character. Although he initially addresses the issue of the 'missing advice', and the rationale for why he did not do what the students wanted him to do, he then turns to the ways in which the comments should be heard – that it is the lesson that is important, not when this lesson is learned. For students and critics alike, however, the situation is inherently unstable. The students are sometimes expected to provide accounts and explain their choices, whereas at other times, such explanations are treated as interferences. This means that from one situation to a next, the activity could turn from an assessment of a particular project to a 'lecture' where the work of the students is merely used as an example of some more general issue.

The two orientations can partly be understood with reference to the members' different relation to the design proposal. The students have spent several weeks, working hard to produce a strong design proposal that is now to be assessed and discussed by a professional architect. They are there to present and to some extent defend their proposal, and it might therefore be hard to switch to a hearing where the proposal is just being used as an example. For the critic, in contrast, the proposal is just one of several proposals that are being discussed that day, and the point is not just to give feedback to the students who produced the proposal but also to use the occasion to lecture about general issues central to architectural practice.

In other design reviews, the issue of 'fairness' is raised by students: 'how come that the critic raised a problem with our design proposal and not with the subsequent proposal which had the same manifest problem?' From the point of giving advice to the whole group of attending students, however, the very fact that they have already dealt with the issue is a reason for not dealing with it again. There are countless issues that could

potentially be raised during the design review and time is limited so there might be plenty of reasons to not bring the same issue up again. Still, the design review is also an occasion for assessment, and as such, it is understandable that the students orient to quality – the strengths and weaknesses of design proposals – in relative terms.

Continuous interactional work

A central point in Mehan's (1979) classic study "learning lessons" is that pupils in the lower grades are not just learning the content of the lessons – they are learning 'lessons' in the sense of learning the endogenous organization of the lesson, how to appropriately take the turn, respond to a question, hear and understand what an appropriate question sounds like et cetera (see also Macbeth, 2003). In a parallel way, the students (and in a different way, the critics) taking part of the design review are learning how to hear and understand the critique. Although there are separate occasions where the format of the design reviews is discussed, including how one gives and receives critique, the instruction on how the critique should be heard is ongoing throughout the actual critique sessions. As already pointed out, the situation is in a sense inherently unstable where the students sometimes are expected to give accounts for their decisions and at other times they are just supposed to listen.

In Excerpt 1, this could be seen in how the critic attempts to end the issue of 'who's to blame', and the associated retrospective orientation, by pointing out that the main thing is what is said here and now. During this sequence, moreover, the critic breaks in with (10, 14, 16) minimal responses in overlap, thereby signaling a move towards a closing of the sequence. This orientation towards the ways in which the comments are heard and responded to is also displayed through bodily means. The critic might for instance give a thumbs up, showing a positive stance towards the effort that the students have put in their work, at the same time as he looks down (Figure 1, left) or turn towards their design proposal, thereby signaling a readiness to move on to the next thing; or use a gesture to the effect that an account is not necessary (Figure 1, right).

Figure 1. To the left, the critic gives a thumbs up while looking away and then turning to the poster. To the right, the critic makes a gesture to the effect that further explanations are not necessary.

On some occasions the purpose of the critique, and how the critique should be heard and understood are formulated explicitly. Excerpt 2 takes place approximately a minute after Excerpt 1, and during this time, the issue has centered on what was done in the design studio, and what teachers could or could not be expected to do – especially whether and to what extent the teachers should or could provide answers to the students' detailed questions about their projects. At this point, the critic breaks in by formulating the activity of critique, which is heard and treated as closing this particular issue, and a move to the next.

```
Excerpt 2
01 KENT:  but take don't take it like the correct answer don't take critique in that way.
02        like we have taken apartments but but (.) bring with you the knowledge y'know
03        instead tha- better (.) uhm it's only that you can do this (.) you can think like
04        that when you redesign the house.
```

In Excerpt 2, the critic is explicitly correcting the students' responses to the critique and previous comments and proposes how they should understand the critique instead. According to this proposal, it is not so much about the mistakes made – that the students "have taken apartments" – but that they should bring with them "a knowledge." This formulation of the activity provides a clarification of how critique should be understood: that they should listen to critique as suggestions on what they "can do" and "can think," rather than about the things that actually have or have not been done.

Discussion

A central aim of the project is to use the empirical results to discuss, problematize, and expand the theoretical literature on feedback. Schegloff (1996, p. 164) has argued that the disciplined study of particular actions is missing in much of the social scientific discourse. He adds that sometimes "they appear to be virtually epiphenomenal expressions of 'underlying' factors, processes, and variables – norms, rationality, conformity, power, system functions, and the like, but important largely as the public face, the accessible display and indicator, of those underlying forces." This characterization is also applicable to theories that set out to investigate the sensitive nature of feedback. Although theories of facework, politeness, and self-enhancement have some explanatory value, our video recorded material suggest that such matters are secondary to more manifest and pedagogically relevant concerns. The point of the infamous 'sandwhich model of feedback', where constructive or critical feedback are embedded in positive comments delivered before and after the critique, might not be to act or come across as nice or polite, as often is claimed; but to make the student hear, understand, and respond to the comments as educationally relevant feedback and not compliants. We therefore believe that a reconceptualization of feedback, grounded in the in vivo orientations of the participants and sequential organization of the interaction, would be a significant conceptual expansion of and a potential alternative to current theories and models.

A prominent strand in educational research on feedback is a 'remedial' agenda, embodied both in the efforts to develop optimal ways of delivering feedback, and in the fostering of student and teacher competencies to relevantly understand the significance of instructional feedback. Although there are many mertis to such appcoaches, it is also important to understand how the ambiguous nature of critique is not limited to educational situations and that the very *possibility* of hearing an advice in a negative way might be without remedy. At the same time, it is important to understand that that an emotional and defensive reaction to critique cannot be discarded simply as a 'misunderstanding'. The possibility of emotional and defensive responses are to no small degree provided by the interactional nature of feedback activities; "hearing it the wrong way" is one in a range of accountably rational ways in which any instantiation of feedback can be heard. There are of course strong reasons why we should aim for a better 'climate' in educational setting and there are clearly benefits of fostering different forms of 'feedback literacies'. Nevertheless there are also reasons to closely investigate the 'endogenous pedagogies' of settings where critical feedback is a constituve part, and to connect our understanding of feedback with our understanding of how critique is produced and received in other mundane and institutional settings.

It might be possible to read Hattie and Timperley's (2007) conclusions regarding "low levels of threat" through an interactional lens, as saying that feedback should ideally be produced and heard as e.g., 'constructive criticism', rather than 'complaints'. As Edwards (2005) notes, however, these lables are defeasible vernacular categories "with normative, oriented-to properties and consequences" (p. 7). The defeasibility of categorizations point to the fact that "the same stretch of talk might […] be glossed as criticism or accusation, troubles-telling, or merely story-telling or factual reportage, which are potentially relevant alternatives for speakers when characterizing their activities" (ibid). This means that what levels of perceived threat might be ascribed to a particular instance of feedback cannot be located solely in the production features of the feedback turns. As our analyses illustrate,moreover, orientations to 'threat' is a sequential phenomenon, developed incrementally through student responses as much as the design of the feedback itself. In some cases, something akin to 'perceived threat to self-esteem' is even explicitly addressed in critics' remarks regarding 'how to take critique'. Excerpt 2 can be read as an exhortation to pay attention to the feedback, instead of responding to its summative elements. The important thing is, again, that these are sequential phenomena with an inherent openness to them.

Although the problem of how critique is heard or understood is inherently interactional, it is also connected to whatever resources one has to make sense of the critique. In this respect we could observe that students became accustomed to feedback as something prospective and formative as they progressed through their education. This form of hearing is thus itself a lesson to be learned where one adjusts to the professional expectations at work. Nevertheless, there is still room for instructions in the communication. Whenever there are shifts between retrospective assessments and prospective lecturing these shifts can be more or less clearly communicated. The mitigation of what is perceived as threatening to students could reasonably be managed by critics overtly describing what they aim to accomplish with specific comments. We certainly see that this is happening in our materials (and it is partly present in the example as well). For the future however, this topic is worth further treatment.

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Exploring the Diagnostic Process of Pre-service Teachers Using a Simulation – A Latent Profile Approach

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Abstract: Assessing individual students' learning progress is a key task in teachers' everyday life, which allows them to infer students' zone of proximal development and offer adaptive support. Because of the complexity of the diagnosing in classroom settings, training pre-service teachers using standardized settings with adaptive support seems desirable. However, to design effective learning environments and offer adaptive support, a deep understanding of the diagnostic process is necessary. Thus, the present study investigates the diagnostic process of pre-service teachers in a video-based simulation by examining the occurrence of diagnostic activities and their relation to relevant learner prerequisites and learners' diagnostic outcome. Findings suggest that describing and evaluating simulated students' learning process is sufficient for an accurate diagnosis. However, only students with higher professional knowledge made further-reaching pedagogical decisions. Moreover, we identified three profiles representing pre-service teachers' distinct engagement in diagnostic activities and suggest the implantation of different types of scaffolding.

Introduction

Assessing individual students' learning progress is a key task in teachers' everyday life. For instance, teachers gather information about students' current understanding of a concept or method, about students' learning prerequisites in general, or about their current learning processes. This information enables teachers to infer students' learning status and their zone of proximal development (Vygotsky, 1980), which in turn allows them to make adaptive pedagogical decisions, for instance, by adapting the conduct of a lesson, by scaffolding individual students' learning processes (Reiser & Tabak, 2014; Wood et al., 1976), or by giving individual recommendations for further training (e.g., Südkamp et al., 2012; Urhahne & Wijnia, 2021). Thus, teachers' ability to accurately diagnose students' learning progress is vital for teaching quality and has been shown to positively impact student learning (e.g., Brunner et al., 2013; van de Pol et al., 2013). Yet, prior research has also shown that teachers in general and novice teachers in particular, often struggle when diagnosing (e.g., Urhahne & Wijnia, 2021).

Based on novice teachers' struggles and their so-called practice shock, there has been a call for a 'practice turn' in teacher education. Consequently, researchers as well as practitioners have emphasized the need to implement authentic learning opportunities, often called approximations of practice (Grossman et al., 2009), for pre-service teachers in higher education. Simulations have been proposed as one such means, as they allow to offer a balance between cognitive demand and authenticity (Codreanu et al., 2020). The general idea of simulations is that learners can engage in authentic situations that represent real world demands and by that develop complex skills, which are based on and at the same time exceed their prior knowledge acquired during their studies. Moreover, such simulations allow to adapt the complexity and course of the simulation based on learners' individual learner prerequisites and processes. Thus, simulations allow for individualizing learning processes and for implementing adaptive learner support, which allows increased learning effects (Chernikova, Heitzmann, Stadler, et al., 2020; Radkowitsch et al., 2021). Although adaptivity as a core feature of learning environments is not a new concept (see Plass & Pawar, 2020) and contingency as a key aspect of scaffolding is based on adaptivity, implementing adaptive support in scalable learning environments such as simulations requires a deep understanding of i) participants' learner prerequisites (e.g., Kramer et al., 2021) and ii) participants' cognitive processes within such learning environments (Stadler et al., 2019). With respect to diagnosing, most research has focused on outcomes of a diagnostic process (mostly diagnostic accuracy) (Urhahne & Wijnia, 2021) and the influence of various covariates such as content knowledge (CK) or pedagogical content knowledge (PCK) (e.g., Brunner et al., 2013; Kramer et al., 2021). However, participants' diagnostic process in such simulations, differences between their individual diagnostic process as well as the relation to various prerequisites are not yet well understood.

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To address this gap in prior research, this paper examines a video-based simulation for diagnostic skills for mathematics teacher education and investigates i) how pre-service teachers' diagnostic activities within the simulation are interrelated and how they relate to their ability to diagnose accurately as well as to learner prerequisites, ii) if there are systematic differences between pre-service teachers' diagnostic activities that can be interpreted as different profiles, and iii) if these profiles differ systematically regarding their learner prerequisites and the diagnostic accuracy. Results not only give novel insights into pre-service teachers' diagnostic process within simulations, but also provide essential information for adapting such simulations to learners' needs, for example by implementing contingent scaffolding (see further Plass & Pawar, 2020).

Diagnostic skills and diagnostic process

Educational assessment is a core task for teachers and is seen as an essential prerequisite for individual support and adaptive teaching (Reuker et al., 2021). Although different terms are used to describe educational assessment and corresponding skills (e.g., diagnostic competence (Heitzmann et al., 2019; Herppich et al., 2018), assessment literacy (Xu & Brown, 2016)), conceptions agree that diagnosing involves gathering and integrating information in a goal-directed way in order to reduce uncertainty with respect to a professional decision (Heitzmann et al., 2019). The central indicator for teachers' diagnostic skills has long been the accuracy of the diagnosis, operationalized as the extent to which a teacher's judgement matches a (more or less) objective measure (e.g., by using standardized tests or expert ratings) of a student's true performance (Südkamp et al., 2012).

Lately, research has shifted the focus on the diagnostic process (e.g., Herppich et al., 2018) as its understanding generally is an important requirement for the implementation of instructional support (Engelmann & Bannert, 2021). There are different frameworks describing the diagnostic process and different activities therein. For example, the diagnostic process was described based on frameworks for teachers' professional vision (Goodwin, 1994; Seidel & Stürmer, 2014), in which important cues of a specific diagnostic situation are first noticed and then processed internally to arrive at a diagnosis and an educational decision (Loibl et al., 2020). The professional vision paradigm assumes that for the deep processing of the noticed cues, teachers need to describe the specific information, explain the described information by linking it to professional concepts and finally predict students' learning by drawing conclusions (Seidel & Stürmer, 2014). Similar activities were described by Blömeke et al. (2015) for the conceptualization of their so-called situation-specific skills and for the conceptualization of scientific reasoning by Fischer et al. (2014). In an attempt to unite these frameworks in the context of diagnosing, Codreanu et al. (2021) proposed four observable diagnostic activities: *describing* (verbalize noticed cues or information), *evaluating* (inferring a general pattern of behavior of the student), *explaining* (linking the respective information to professional concepts), and *decision-making* (drawing conclusions about educational actions). Despite these numerous, mostly overlapping conceptualizations of the diagnostic process, little is known about teachers' engagement in different activities during diagnosing, about individual or situation-specific factors determining the engagement in specific activities, or about the relation between these diagnostic activities as process measures and outcome measures such as diagnostic accuracy.

Learning with simulations

Simulations are representations of real-world situations that allow learners to engage in relevant activities for the specific situation (Gegenfurtner et al., 2014). Thus, simulations allow learners to apply knowledge to realistic cases in standardized settings and by that to acquire practice-oriented knowledge (Kolodner, 1992). Additionally, simulations allow learners to focus on specific professional skills and to learn in a risk-free environment. A crucial point is that simulations reduce complexity of a specific task for training, but at the same time approximate practice (Codreanu et al., 2020; Grossman et al., 2009).

There is a vast amount of research showing the general effectiveness of simulations for learning but also a large amount of unexplained variance (e.g., Chernikova, Heitzmann, Stadler, et al., 2020; Gegenfurtner et al., 2014). For example, Chernikova, Heitzmann, Stadler, et al. (2020) found positive effects of simulations on learning of complex skills such as diagnostic skills in their meta-analysis. Effects of simulations were higher if learners received additional instructional support during learning, yet the type of instructional support interacted with learners' prior knowledge. Thus, adapting instructional support to learners' prerequisites and/or learning process seems beneficial (Plass & Pawar, 2020; Radkowitsch et al., 2021). This, however, requires a deep understanding of the cognitive processes and of learner prerequisites that might influence the cognitive process.

Beside their general positive effect on learning, simulations (and especially digital simulations) additionally allow to document cognitive processes in detail, for instance, based on logfiles or notes. The documentation of learning processes allows researchers to infer on and analyze cognitive processes that are involved during solving the task (Greiff et al., 2015), which is important for gaining a better understanding of the concept under research, e.g., diagnostic skills. Moreover, simulations allow to standardize the simulated situation

in a way that reduces the possible influence of confounding variables (Herborn et al., 2018). This seems particularly important in situations in which interaction between persons is simulated (e.g., interaction between a teacher and a student) and which are as "messy" as teaching situations in regular classrooms. For instance, the motivational or affective state of an unstandardized student could affect a teacher's judgement of the students' learning processes. Keeping constant the motivational or affective state of students during a training session in a simulation might thus help pre-service teachers with little experience to focus on the relevant aspects of the diagnosis.

Influence of relevant learner prerequisites

Learner prerequisites are likely to influence diagnostic processes as well as outcomes within a simulation (e.g., Heitzmann et al., 2019; Kramer et al., 2021). Therefore, investigating how learner prerequisites affect the diagnostic process as well as and outcomes seems important when investigating diagnostic skills. So far, research on teacher education has largely focused on the role of professional knowledge. Particularly, CK, that is subject knowledge about facts, concepts, and methods, and PCK, that is knowledge about how to teach a specific content, taking into account subject-specific (mis-)conceptions and instructional strategies (Shulman, 1986) seems to be predictive of teaching quality and learning of students (Baumert & Kunter, 2013). Less evidence exists for the role of professional knowledge for diagnosing (see Förtsch et al., 2018). Kramer et al. (2021) investigated the influence of professional knowledge on the diagnostic process and the diagnostic outcome in a simulation and found that PCK enhances both, diagnostic process and the diagnostic outcome, but CK does not.

Besides professional knowledge, Heitzmann et al. (2019) suggest a number of other factors possibly influencing the diagnostic process and outcome such as interest (e.g., Rotgans & Schmidt, 2014), self-efficacy (e.g., Klug et al., 2016), or motivation (e.g., Wigfield & Eccles, 2000), which may be especially important in simulations as learning environments. As evidence of the impact of these learner prerequisites on the diagnostic process and outcomes is sparse and relevant learner prerequisites might be target of specific interventions, identifying prerequisites that affect how pre-service teachers engage in diagnostic activities seems relevant.

Research questions

Based on the prior research presented above, the present study investigates diagnostic skills of pre-service teachers in a video-based simulation by examining the occurrence of diagnostic activities and their relation to relevant learner prerequisites and diagnostic outcome. More precisely, the following research questions are addressed: (1) To what extent are pre-service teachers' diagnostic activities interrelated and related to their diagnostic outcome as well as their learner prerequisites? (2) Do pre-service teachers systematically differ in the extent to which they engage in different diagnostic activities? (3) To what extent do pre-service teachers with distinct profiles differ with respect to their diagnostic outcome and learner prerequisites?

Method

Sample and procedure

We used data from two studies (N_{Study1} = 60, N_{Study2} = 84) that investigated pre-service mathematics teachers' diagnosing. Data of 26 participants was excluded since the data coding process of Study 2 was not yet finalized. The included sample consisted of 118 pre-service mathematics teachers (N_{female} = 76) from five German universities. Their age ranged from 18 to 43 years (M_{age} = 23.32, SD_{age} = 3.59). In both studies, all participants first completed a questionnaire and test assessing their cognitive and motivational-affective learner prerequisites. Afterwards, participants diagnosed two simulated students' mathematical argumentation and proof skills using the video-based simulation.

Video-based simulation

In the simulation, participants acted as intern who was asked to diagnose two students with respect to their mathematical argumentation skills in the context of a geometry proof. For that, pre-service teachers watched short, staged video clips about one-on-one teacher-student interactions in which the teacher prompted the student to share their thoughts about the task. Meanwhile, participants were asked to take notes relevant for the given diagnostic task. All notes were used to examine participants' diagnostic activities. After each clip, participants could decide on whether they wanted to further observe the respective student by watching another video clip. Participants could watch up to 10 videos. Once participants had decided to stop observing the teacher-student interaction, they were asked to rate students' mathematical content knowledge, methodological knowledge, and problem-solving strategies. For more information about the simulation, see Codreanu et al. (2021).

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Instruments

In both studies, we assessed participants' diagnostic activities and diagnostic accuracy based on notes and ratings generated during the interaction with the simulation. Moreover, we used a self-generated test to assess CK and PCK as well as a questionnaire to assess interest for diagnosing, for geometry, and for mathematics education, their self-efficacy as well as their motivation focusing on the perceived task value and their expectancy to succeed.

The *diagnostic activities* were assessed based on the notes taken by the participants during watching the videos. Notes were segmented content wise into sense units. We coded whether each segment contained one or more of the diagnostic activities describing, evaluating, explaining, and decision-making based on Codreanu et al. (2021). *Describing* was coded when participants described observations of actions (e.g., "She used the characteristics of angles in parallel lines without being able to name them explicitly"). *Evaluating* was coded when participants inferred levels of knowledge or patterns of behavior (e.g., "He has very big problems with mathematical terms and concepts"). *Explaining* was coded when participants named reasons for the students' actions or their level of knowledge (e.g., "Her methodological knowledge is already quite good since she tries to use the angles to establish a proof."). *Decision-making* was coded when participants made recommendations for further pedagogical actions (e.g., "In order to improve the understanding, the basic characteristics of the congruence theorems and quadrangles must be deepened."). For each simulated student, counts for each activity were summed up for all notes taken during the simulation. We calculated the mean across both simulated students.

We used the final ratings of the simulated students' mathematical content knowledge, methodological knowledge, and problem-solving strategies as indicator for participants' *diagnostic accuracy*. For each content dimension, participants rated two to three items on a 4-point Likert scale with a total of 8 items per simulated student. Ratings were compared to an expert solution. If participants matched the expert rating, they received 1 point. Participants' diagnostic accuracy ranged from 0 to 16 points. Scores were rescaled to lie between 0 and 1.

CK and *PCK* were each assessed using 8 items that were developed to fit the content of the video-based simulation. Participants' *interest* was measured using 9 items (3 for each aspect) adapted from Rotgans and Schmidt (2014), which were rated on a 5-point Likert scale. *Self-efficacy* was measured using six items adapted from Kunter et al. (2002), which were rated on a 5-point Likert scale. We assessed *task value* with four items that were rated on a 5-point Likert scale from Wigfield (1994). *Expectancy to succeed* was assessed with four items on a seven-point Likert scale adapted from Rheinberg et al. (2001). Cronbach's alpha for all scales and tests reported above were acceptable (between .55 and .90). For all scales, scores were rescaled to lie between 0 and 1.

Data Analysis

We used R version 4.1.2 for all analyses. To answer the first research question, we computed Pearson correlations between all diagnostic activities as well as the diagnostic accuracy, and learner prerequisites using the *Hmisc* R package. To answer the second and third research questions, we conducted a latent profile analysis (LPA) with the diagnostic activities as indicators. All indicators were *z*-standardized to increase the probability of convergence. We then estimated model fit for models with one to six profiles using the *tidyLPA* R package. The best fitting model was chosen based on relevant fit indices (AIC, corrected AIC, BIC, Entropy, and BLRT *p*-values) as well as content related interpretability. For AIC, corrected AIC, and BIC, smaller values indicate better model fit. Entropy values should be close to 1. Next, we assigned participants to the most likely profile. Finally, we compared profiles with respect to relevant learner prerequisites and diagnostic accuracy.

Results

For the descriptive results, means and standard deviations for all diagnostic activities as well as for pre-service teachers' diagnostic accuracy and their individual prerequisites are displayed in Table 1. For example, pre-service teachers on average wrote down 1.82 descriptions per simulated student throughout all videos watched from that student. For all variables except for the diagnostic activities, possible values range between 0 and 1.

Concerning RQ 1, we identified a sign. moderate correlation between the diagnostic activities evaluating and describing (see Table 1). Evaluating and describing also correlated significantly with diagnostic accuracy. No other diagnostic activity was sign. related with diagnostic accuracy. CK and PCK were both sign. related to the diagnostic activity decision-making. However, only PCK was related sign. to diagnostic accuracy.

For the RQ 2, we conducted LPA with 1 to 6 profiles. Statistical fit indices for all models are listed in Table 2. Based on the fit indices (particularly cAIC, BIC) the three- and five-profile models seemed best fitting. Upon inspection, the five-profile model merely reflected the four distinct diagnostic activities included into the analyses and a fifth group that has low values for all activities. Thus, due to theoretical considerations and to address the need for parsimony, the three-profile model was considered as the best fitting model. The profiles and their specification regarding the four diagnostic activities are depicted in Figure 1.

Table 1
Pearson Correlations Between Diagnostic Activities, Diagnostic Accuracy, and Learner Prerequisites.

	M	*SD*	1	2	3	4	5	6	7	8	9
1 Describing	1.82	1.65	-								
2 Evaluating	2.84	1.61	0.33**	-							
3 Explaining	0.33	0.49	0.06	0.15	-						
4 D-M	0.38	0.58	0.11	0.02	0.16	-					
5 Accuracy	0.47	0.21	0.26**	0.23*	0.02	-0.03	-				
6 CK	0.64	0.17	0.00	0.06	0.03	0.19*	0.11	-			
7 PCK	0.67	0.10	0.07	0.12	0.09	0.20*	0.18*	0.41**	-		
8 Interest	0.74	0.16	0.26**	0.19*	-0.04	0.13	0.03	0.10	0.27**	-	
9 S-E	0.61	0.17	-0.02	-0.01	-0.07	0.02	0.09	0.08	0.13	0.18	-
10 Mot	0.72	0.11	0.14	0.10	-0.03	0.14	0.07	0.26**	0.15	0.16	0.29**

** $p < .01$, * $p < .05$; D-M: Decision-Making; S-E: Self-efficacy; Mot: Motivation

Pre-service teachers in the first profile engaged in all diagnostic activities on an above average level. Especially for the diagnostic activity decision-making, participants showed much higher numbers in their notes compared to the other profiles. Therefore, we named this profile *decisive profile*. On average, participants in this profile showed 2.13 descriptions, 3.13 evaluations, 0.52 explanations, and 1.37 decisions in their notes per simulated student. In total, 23 participants (19.5% of the sample) were assigned to this profile.

Pre-service teachers in the second profile engaged above average in the diagnostic activities describing, explaining, and in particular in evaluating. We named this profile *evaluating* profile, as they showed most engagement in evaluating. On average, participants in this profile showed 2.65 descriptions, 5.35 evaluations, 0.58 explanations, and 0.15 decisions in their notes per simulated student. In total, 20 participants (16.9% of the sample) were assigned to this profile.

Pre-service teachers in the third profile demonstrated below average diagnostic activities in general. Thus, we named this profile the *restrained* profile. On average, participants in this profile showed 1.51 descriptions, 2.08 evaluations, 0.21 explanations, and 0.14 decisions in their notes per simulated student. In total, 75 participants (63.6% of the sample) were assigned to this profile.

Table 2
Statistical Fit Indices for Different Profile Solutions.

Number of profiles	AIC	corrected AIC	BIC	Entropy	BLRT *p*-values
1	1329.56	1359.73	1351.73	1	-
2	1310.48	1359.50	1346.50	.77	.01
3	**1280.18**	**1348.05**	**1330.05**	**.82**	**.01**
4	1268.78	1355.51	1332.51	.88	.01
5	1248.94	1354.52	1326.52	.90	.01
6	1258.95	1383.38	1350.38	.69	1

To answer RQ 3, we analyzed whether the profiles identified for RQ 2 differed systematically with respect to relevant learner prerequisites and diagnostic outcome. We found descriptive differences (see Table 3) between most variables showing that the restrained profile was less accurate, had lower prior knowledge, and was less interested compared to both other profiles. Participants associated to the decisive profile had descriptively higher prior knowledge. The evaluating profile showed the descriptively lowest self-efficacy.

Discussion

As an overarching finding, our results demonstrate that assessing the diagnostic activities in a simulation based on pre-service teachers' notes is generally feasible and results in theoretically meaningful differentiations between activities and participants. Based on pre-service teachers' notes, we identified three distinct profiles that differ with respect to the amount to which they engage in the different diagnostic activities. These profiles allow for the implementation of specific scaffolding that addresses pre-service teachers' needs and takes their actual cognitive processes into account (Engelmann & Bannert, 2021; Plass & Pawar, 2020). Compared to a "one scaffolding fits all" strategy, this should lead to better learning outcomes (Chernikova, Heitzmann, Fink, et al., 2020).

On a more specific level, our results show that pre-service teachers mostly describe and evaluate when diagnosing a simulated student. Higher order activities such as explaining or decision-making occur only rarely and mostly in a subgroup of pre-service teachers. On a first look, this is unproblematic, as only describing and evaluating are significantly positively related to diagnostic accuracy. Explaining and decision-making do not seem necessary for making an accurate judgment about the students' learning process. Although this might be a

Figure 1
The Profiles Based on the Engagement in Diagnostic Activities

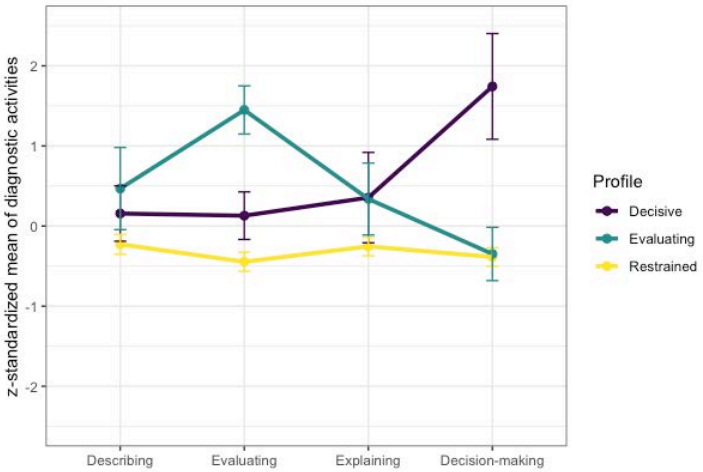

Table 3
Differences in Learner Characteristics between Profiles

Learner Prerequisites	Decisive profile		Restrained profile		Evaluating profile		Overall	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Diagnostic accuracy	0.50	0.25	0.46	0.21	0.50	0.17	0.47	0.21
CK	0.74	0.14	0.60	0.17	0.64	0.19	0.64	0.17
PCK	0.71	0.09	0.65	0.10	0.68	0.11	0.67	0.10
Interest	0.77	0.14	0.73	0.17	0.77	0.13	0.74	0.16
Self-efficacy	0.63	0.20	0.61	0.16	0.58	0.18	0.61	0.17
Motivation	0.74	0.11	0.71	0.11	0.71	0.12	0.72	0.11

statistical artefact since explaining and decision-making rarely occurred, it seems conceptually plausible that describing and evaluating a specific aspect of a students' learning progress is more important for an accurate judgement than theoretically explaining it or deciding on future pedagogical interventions. However, from a practical perspective, this is problematic because going beyond the mere diagnosis by inferring pedagogical actions from the diagnosis is *the* key challenge for adaptive teaching and individual scaffolding of students (Reuker et al., 2021). Our results allow for some conclusions about how those pre-service teachers who make decisions differ to those who do not: decision-making seems to be mainly related to pre-service teachers' professional knowledge (see Table 1), which is also reflected in the finding that pre-service teachers associated to the decisive profile seem to have more professional knowledge than participants associated to both other subgroups. Although results are only provided on a descriptive level, particularly the difference between profiles in their CK is interesting. These findings partially disagree with findings from Kramer et al. (2021) who found no relation between CK and diagnostic activities on an aggregated level. Yet, our findings suggest that CK and PCK are not equally important for all diagnostic activities, which could explain their null finding. Our findings related to CK, thus, suggest that pre-service teachers with low professional knowledge need to be scaffolded to make pedagogical decisions. For instance, knowledge prompts could be a suitable means to support pre-service teachers in their higher order diagnostic activities. Moreover, the difference between the predictivity of the diagnostic activities for judgement accuracy (describing, evaluating) vs. for adaptive teaching (explaining, decision-making) suggests that future research should not only focus on diagnostic accuracy (e.g., Südkamp et al., 2012), but understand diagnostic skills in a broader sense to include decisions based on the diagnosis and investigate how different diagnostic activities are related to this broader conception.

Interestingly, we identified only small differences between the three profiles beyond the differences in professional knowledge. Even the restrained profile, which engaged little in all diagnostic activities, was not much less accurate than both other profiles and was also not less motivated or self-effective. It is unclear, what exactly leads to the differences between participants' engagement and motivational interventions appear only little suited. Future research should examine their partially smaller values on interest. It might be that they are not as much interested in the topic of diagnosing and that an intervention addressing their interest could enhance their general engagement. However, the restrained profile captured more than half of all pre-service teachers who participated in the study and it could be that the group is rather heterogeneous. Further qualitative analyses of the restrained

group might enhance our understanding of how participants in this group could be scaffolded beyond knowledge prompts to also engage in higher order diagnostic activities.

As always, this work is not without limitations. Firstly, the diagnostic activities were captured based on notes learners generated during the diagnostic process. Hence, conclusions of our work are limited to observable diagnostic activities represented within these notes. Pre-service teachers might differ systematically in the extent to which they noted down their observations and thoughts and even might not be able to access all relevant cognitive processes themselves since reasoning processes often happen unconsciously (e.g., Loibl et al., 2020). Yet, our analyses resulted in meaningful profiles which should be extended by further qualitative analyses as mentioned above. Secondly, we group participants to the profiles based on the most probable profile membership. We did not (yet) consider that participants could have similar membership probabilities for the profiles. Future research should address this issue by comparing different methods for class membership (e.g., BGH method).

In all, our study provides valuable insights into pre-service teachers' diagnostic process and suggests more and less relevant starting points for adaptive scaffolding. Yet, more research is needed with respect to their ability to make inferences about pedagogical actions and how different diagnostic activities are related to this ability. Besides, studies implementing the suggested scaffolds and longitudinal investigations focusing on how pre-service teachers learn to diagnose in the long term are necessary. Altogether, we showed that pre-service teachers' diagnostic process in simulations differ inter-individually and that their diagnostic activities are related to professional knowledge and to the diagnostic accuracy and we emphasized the importance of taking the diagnostic process into account when facilitating pre-service teachers' learning of diagnosing.

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Constructing relations between STEM researchers and publics: A case study of empathy in action

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Abstract: How academic researchers engage with non-researchers is critical to supporting the public's understanding of complex socio-scientific and sociotechnical challenges. In this paper, we examine the learning of one scientist, Murphy, in the STEM Liaison Program (SLP), a project that trained university STEM researchers to design public engagement events. Focusing on the ways "empathy" was represented in trainings and enacted by Murphy as a kind of emotional configuration (Vea, 2020), we track accompanying shifts in how Murphy saw youth in a residential treatment facility and his own role in conducting public engagement efforts with them. We argue that tracing the co-constitution of emotional configurations with "relationship schemas" (Polletta, 2020), cognitive and cultural representations of the nature of relationships and what obligations they entail, can expand the learning sciences' understandings of relationships as a learning outcome with important societal implications.

Public understanding of scientific and social scientific phenomena is crucial for addressing massive public crises like climate change and pandemic diseases. How academic researchers engage with non-researchers is important to supporting people's learning of these complex and collective problems. People are radically dependent on the actions of each other in approaching these problems. They require cooperative behavior and ways of seeing our dependent relations that support us to take action. How we learn to be in relationship is a critical question, and survival depends on how we collectively respond.

In this paper, we present a case study of the pathway one scientist traveled with incarcerated youth towards realizing the capabilities members of the public have for engaging with complex science. The scientist was a participant in the STEM Liaison Program (SLP), a project that trained and supported university STEM researchers to design public engagement events for groups underserved by informal STEM opportunities and institutions such as those who are incarcerated, people with disabilities, or seniors in constrained living situations. The program combined training in science communication methods with practices from human-centered design. In a human-centered design approach, designers engage in empathy-focused practices such as observation and interviewing to gain understanding of the perspectives and needs of those for whom they are designing (Goldman & Zielezinski, 2021; Hasso Plattner Institute of Design, 2013). With the incorporation of these empathetic practices, the program provided a novel approach to building relationships between STEM researchers and public groups around science exposure and understanding. Through the case study, we explore how a physical anthropologist named Murphy conceived of and shifted his relationships with non-scientists as he tried to bridge the gap between science and the public. We ask:

1. How does the STEM researcher come to enact and represent "empathy" in the design of his public engagement activities?
2. What kinds of social relationships are cultivated through the design processes as he practiced them?

In the following sections, we provide background on empathy and navigating it within STEM professional contexts, describe our approach to understanding emotion and the construction of relationships using sociocultural learning theory, articulate our methods in relation to SLP, and present findings from the case study of Murphy and his learning as a scientist doing outreach. Finally, we present implications from the case for the learning sciences and public engagement efforts in STEM, and we discuss future directions for this research.

Navigating empathy in STEM

The word "empathy" has multiple meanings, but it generally indicates a complex of feeling and knowing (Verducci, 2000). It involves a form of intentionality directed at the experiences of another (Stein, 1989). Empathy has been considered to have two major roles, one epistemological and the other social and relational (de Vignemont & Singer, 2006; Song, 2015; Verducci, 2000). Epistemologically, empathy provides a basis for intersubjective understanding of the experiences and subjective point of view of another person. This understanding aligns with an interpretivist epistemology in which knowledge is constructed by people in relationship with each other. In its relational and social role, empathy can be seen as a form of sharing of another

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person's "inner experience," fostering a sense of connection with the other. Empathy in this sense facilitates effective social communication and motivates cooperative and prosocial behavior.

The study of STEM disciplines is a social system itself (Latour & Woolgar, 1986). It is governed by norms that are socially and interactionally achieved, and that develop and change through their enactment. They are also powered and determine who gets to be where in relation to science and STEM (McDermott, 2013; Medin & Bang, 2014). Part of the norms of Western science is what forms of emotion are considered appropriate (Davidson et al., 2020). In the dominant, Western white ways in which STEM is instantiated in university departments, empathy is seen as running counter to its practices and epistemologies. Hegemonic STEM epistemologies are positivist, holding that all true knowledge can be scientifically verified (empiricism) or is capable of logical proof (rationalism) (Reynante et al., 2020). A discipline's underlying epistemology or theory of knowledge has significant ramifications for how the discipline determines what counts as legitimate knowledge. We see this problematic as a central challenge both of SLP in its preparation of STEM researchers for public engagement and for the larger question of relational development between STEM researchers and publics in approaching global sociotechnical and socio-scientific challenges. Learning sciences researchers have previously examined how learners in STEM can come to navigate across multiple epistemological systems (Bang & Medin, 2010; Rosebery et al., 2010). In this paper, we aim to build on this and similar work by focusing on the relational and emotional dynamics that are central to researchers' navigation of empathy and STEM in SLP.

Conceptual resources: Empathy as relational and emotional configuration

Sociocultural theories of learning have long supported a softening of individual autonomy, figuring the individual within social relationships that support learning (Lave & Wenger, 1991; Vygotsky, 1978) and adopting units of analysis that extend beyond the individual learner (Engeström, 1999; Wertsch, 1998). An ongoing line of research examines how relations develop between actors in learning settings as a kind of learning outcome (Nasir & Hand, 2006). For example, DiGiacomo and Gutiérrez (2016) argued that relational equity, marked by more symmetric relations between teachers and learners, should be considered as "both a tool and an outcome of designed learning activities" (p. 141).

There is an opportunity to further explore the interplay of cognition and emotion in the achievement of relation as a learning outcome. In social movement studies, Polletta (2020) explored how "relationship schemas," cultural and cognitive patterns that shape our expectations and norms for interacting with one another, shape what kinds of participation are possible. She describes the formation of relationships as a process of "relationship work" (p. 11)—a matter of "craft" and "invention" (p. 9). A relationship schema is a constructed understanding of the ties between self and other that also carries with it implications for who we can be and how we can act together. In light of these bodies of work, we attend in our analyses to the ways being together and cultural materials support people's developing understandings of how they are in relation to one another.

Due to the specific focus on empathy in SLP, we also place analytical focus on the role of emotion in these developing understandings. While many models of emotion in affective science assume that emotion is an internal and individual phenomenon, a sociocultural and social constructivist view of emotion is gaining traction (Clore & Ortony, 2013; Mesquita & Boiger, 2014). In this view, emotions emerge from social interactions and relationships, which they in turn constitute, shape, and change. They are also situated—embodied, enacted, and experienced in particular situations which give them particular definition and meaning. Therefore, while "empathy" has particular meanings in psychological research, we defer specialist definitions in favor of seeking how empathy is emotionally configured (Vea, 2020) within the specific cultural settings and practices of SLP.

Just as relationship schemas point to the importance of attending to the relationship work that people do as they make sense of their commitments to one another, the notion of emotional configurations directs attention to the ways emotion becomes meaningful in the conduct of social activity. The ways humans configure emotion, such as how a concept like "empathy" becomes enacted in social practices and interactions, have implications for what is possible to achieve together. In this sense, both relation and emotion are processes and outcomes of learning. Furthermore, emotion and relation are co-constituting. How we see our relationships helps determine how we feel toward one another, and how we come to feel for one another helps determine how we relate (Dewey, 1975; Jasper, 2011). As a result, the form that scientists' designs for public engagement take emerge in part from the interplay of emotional configurations and relationship schemas that participants in social activity construct.

Methods

Research context

We conducted research in SLP, an initiative that facilitated a multi-faceted engagement model for STEM researchers working with communities and people in the public who have historically lacked access to STEM

research and STEM researchers. The goals of SLP included helping STEM researchers gain new understandings of public groups, supporting public learning in STEM, and connecting public groups with STEM fields and researchers in new ways. In other words, SLP involved refiguring the social relationships between scientists and the public. The SLP was innovating a combination of three engagement models: a model of science communication informed by learning research, an outreach mentorship structure to support researchers as they engaged in the planning and execution of public engagement, and practices and principles from human-centered design. The human-centered design components of SLP provided a structure, a set of practices, and ways of thinking that supported the construction of a different kind of social arrangement between researchers and public groups. Human-centered design's "empathy" focus encourages designers to see beyond their own expertise and understand what the situation looks like from someone else's perspective. These insights can then help the designer develop interventions (in this case, public engagement programming) that meet their needs. Human-centered design also entails taking a different emotional and relational stance compared to Western science.

Each year, the SLP invited a cohort of university STEM researchers to participate in training and subsequent supports that covered aspects of the three models. Two of the three authors of this paper, along with other members of our research team, developed and led workshops on the use of human-centered design for developing public engagement in STEM. This training included understanding the empathy basis of human-centered design and how making sense of empathy can lead to more effective design outcomes than processes that center on designer expertise alone. The training began with a focus question: "How might we design engaging and effective science outreach events for non-traditional outreach participants, about whose life experiences, interests, and concerns we know very little?" This question emphasized that public engagement in STEM is "for" the public and should serve their interests and needs. Yet it also emphasized that most STEM researchers were starting from a position of incomplete understanding about the public, and that building a better understanding was key to designing successful public engagement.

Here we explore "empathy" as a kind of emotional configuration that brought together ways of feeling about members of the public with particular ways of making sense of their needs and the goals of public engagement. This configuration also included sets of practices aimed at understanding the other, distilling what was learned, and acting on that understanding through design. "Empathy" was explained as a way to understand the situation of public engagement from the public's point of view. Enacting empathy in this context required "lingering in ambiguity," immersing oneself in the problem space of trying to understand the needs of the public *before* jumping to design solutions. The training included opportunities to practice developing and enacting empathy with people for whom the STEM researchers would be designing public engagement programs, first through a prerecorded video interview and then with in-person interviews that the STEM researchers themselves conducted. In attending to other people's perspectives through these exercises, the researchers were encouraged to "Listen carefully," "Ask questions about the person's ideas and experiences," and "Never judge the person even if you do not agree." In this way, the enactment of empathy included interactional practices and habits of thinking in regard to those for whom the STEM researchers were designing. Collecting information was only half the picture. After taking notes and accounting for what they had heard, the STEM researchers were trained in strategies for sense-making around the information they gathered. This process involved reflecting on what they learned and trying to distill synthetic statements about what the members of the public they heard from might need to accomplish through engaging with STEM. These needs might be very different from the STEM researchers' own goals for public engagement. Finally, the STEM researchers were explicitly encouraged to think beyond the lecture-and-Q&A format of public engagement and to develop ways of relating to public groups that were more equitable and multi-directional in the flow of expertise and knowledge.

Data sources

We report on research that examined the experience of the STEM researchers who participated during the SLP's first two years. This analysis takes an in-depth case study approach aimed at examining the pathways and experiences of one researcher. A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context by drawing upon multiple sources of evidence (Yin, 2013). The emphasis in performing case studies is primarily on interpreting the data (Stake, 1995). In this paper, we take a descriptive and exploratory approach, describing the data as they were generated in context and developing explanatory propositions for further inquiry (Yin, 2013). The goal was to deeply understand the experience of a STEM researcher in the program. Case studies are generalizable to theoretical propositions, but not to populations of cases (Yin, 2013). The goal of a case study is not usually generalization but rather particularization—emphasizing its uniqueness (Stake, 1995). We use the case of Murphy to help reveal the analytic contours of what is possible in shifting STEM researchers' relationships with the public, revealing theoretic propositions for further study.

In this paper, we focus on qualitative data and use an interpretive approach. In the larger study, we collected data for a subset of 16 SLP participants. Each case study subject was interviewed in a 20-40-minute interview prior to SLP training. They completed pre-program surveys, including open-ended written responses, that were administered to the entire cohorts. They were observed during the training, and observational field notes were written for each outreach event they completed. We recorded their initial meetings with program staff in which each answered a question about their commitments to public engagement. Evaluation feedback was collected from the public participants at their engagements, and the SLP researchers were asked to complete a reflection survey within 24 hours of completing an engagement event. Each SLP researcher also participated in an end-of-program personal interview and a post-program survey.

Analytical approach

All interviews were audio-recorded and transcribed verbatim. We developed a preliminary list of codes conducting an open-coding process (Emerson et al., 2011; Strauss & Corbin, 1994) and a grounded approach to data analysis and theory building. To ensure reliability, we co-coded data, checked for any discrepancies, and resolved disagreements through discussion. Of particular interest in this paper were codes and data sources that tracked the STEM researchers' developing practices and representations of empathy in the preparation for, execution of, and reflections about their public engagement activities. We paid close attention to constructions in language that documented the ongoing sense-making that STEM researchers were accomplishing about the role of empathy in developing relationships with public groups, how representations of empathy were related to the work of STEM research, and how researchers' constructions of STEM research itself shifted through the relational work of designing public engagements. In tracking how the emotional configuration of empathy was taken up, we also attend to the ways its enactment was associated with shifts in relationship schemas, the cognitive and cultural representations of the relationship between the STEM researchers and the public.

We present the case of one participant, Murphy, because it is indicative of growth in understanding and change in thinking about what people in the public know about science and how to approach engaging them. Rather than arguing that Murphy's experience in the program was representative of all SLP participants, we make the case that his experiences illustrate processes of shifting relations in ways that can be helpful for theory building and future design work.

Findings: Murphy and the public

Murphy was a graduate student in physical anthropology, studying the connection between genes and variation in the structure of brains of both humans and non-human primates. Based on prior experiences, Murphy had the idea that the general public has a very poor understanding of science, influenced by both his previous long career as a lawyer working with juries and his graduate studies in physical anthropology. During the pre-program interview, Murphy revealed a view of the general public as having poor understanding of science: "Because I came to science late in life, after another career… what I learned was—is that, um, people on juries—the level of their science knowledge is somewhat shockingly low." Also before the SLP, Murphy participated in a science outreach program at a local museum where his experiences might have reinforced that thinking. Murphy surmised that the attendees of his public talk at the museum were not very engaged because the adults did not ask many questions and they seemed to want to be entertained instead of to engage deeply with the science. When asked what he would think if the public at an engagement event had a great experience and were excited but left with inaccurate scientific understandings, Murphy shook his head back and forth: "Again, I suppose it accomplishes something, it puts a human face on scientists, but I think that there's… yeah, that's not good. Inaccurate information is not good. I think that that ought to be fundamental. Everything else ought to flow from that." In the interview, Murphy said it was important to bridge the gap in public science knowledge:

> What's happening in science today, especially in broadly speaking the field of genetics is astounding—it's changing people's lives. And will do much more so in the future, over the next ten or 15 years. But really the gap between the regular person who's not in science and what's happening is becoming broader and broader and broader.

Speaking of his previous STEM engagement experiences, Murphy said describing complex science to people who "don't know what cells are" made the talks ineffective. "People said, 'Wow, that's amazing,' which I guess is somewhat flattering, but I don't know how much it accomplished."

Murphy's enactments and representations of empathy

Murphy's thinking about the potential for the "public" to become engaged and think deeply about science shifted during his participation in the SLP. During his SLP participation, Murphy held engagements in two residential centers for youth. One was a medium security juvenile justice center that aimed to prepare youth to rejoin the wider community. The second was a residential treatment center for girls 12 to 17 years old where girls enter based on referrals from the juvenile justice system or Child and Family Services.

Murphy's most prominent enactments of empathy occurred during his first SLP engagement event, when he learned about the teenagers and their interests. He reported a change in opinion and increased empathy about what teenagers knew and how to approach science with them after the visit. Murphy started by mentioning that he was an anthropology student. Almost immediately, a girl asked, "What is anthropology?" which led to an explanation of the branches of anthropology and their differences. Murphy went on to show the youth a picture from the science lab where he worked, displaying the equipment and explaining what it does. After moving to explain how DNA sampling works, more questions started coming. Surprising Murphy, the teenagers backtracked to asking about how being a "PhD student works." They expressed interest in Murphy's previous career as a lawyer, and they wanted to know how the move from that profession to being an anthropology student happened.

Murphy then moved into asking the youth questions: "What is a gene? Do you know what an MRI is? Have you had one?" Murphy explained brain structures and asked them how brains recover from trauma. The youths' responses showed quite a bit of brain knowledge. This line of questions sparked a girl to ask about how brain changes can "make a person act differently, be more susceptible to drug or alcohol addiction." The youth also raised questions about Zika virus and microcephaly and how viruses can affect the brain and brain development. These questions and tangents had the participants involved. After Murphy answered them, he forged ahead to describe a set of topics more closely related to his personal work: different brain structures, the functions of neurons, risk and reward, different reactions of mice to stimuli, optogenetics, and algae. In each case, Murphy presented information, asked questions, and was asked questions. Finally, Murphy showed a demo of a chance and risk game that a few students got to play. All told, Murphy covered at least twelve sub-topics. The youth raised another six or seven topics. They asked a steady stream of questions that Murphy answered even when the questions were related to connections the youth were making instead of those that Murphy had planned to present. This experience was surprising for Murphy. Speaking of it in his post-SLP interview he said, "They asked questions constantly throughout the whole thing, a few of them did. If anything, it was... I would have guessed I would have been asked three or four questions. I was probably asked 30 or 40."

On the post-engagement survey regarding the first event Murphy wrote about what he learned about the youth in the facility and how he would apply his new empathic understanding in his future public engagements:

> I addressed some topics that I thought would be a big hit and I was wrong, but I'll learn from it all. These are young people that respond well when the subject matter is made directly applicable to their lives and their futures. I would be better prepared to address their career in science-related questions, and I would make more explicit the connections between different aspects of the presentation. The highlights were each of the several occasions when a significant portion of the students were amazed by the subject matter I was addressing.

In the way Murphy spoke and wrote about his experience in this event, we can see him enacting the emotional configuration of "empathy" presented in the SLP training in particular ways. Though he did not attempt to meet and learn about the teenagers before his first engagement event, he made note of his surprise at the questions they asked and how they wanted the science to be "made directly applicable to their lives and their futures." In the statements he made about what he "would be better prepared to address" in a future event, we see evidence of his sense-making about these young people and what it meant for productive public engagement.

Murphy's shifting relations with the public

Murphy treated this first SLP engagement as a prototype to learn from and to help him redesign the next engagement at the second youth facility, with 15 girls in attendance. We examine the second engagement event and Murphy's discussion of it to understand how his relations with youth in residential facilities were shifting.

In this session Murphy brought physical models of the brain and showed them to the youth, passing them around so they could feel them. Murphy started by explaining the career change from law to studying anthropology. Next, Murphy showed a slide on "what is anthropology," explaining what the word means then outlining the different branches of the discipline. Finally, when he got to biological anthropology, Murphy talked about the components of the brain, DNA, and genes. A girl asked a question about genetic traits, and Murphy talked about

eye color and height. Murphy showed an MRI image, compared it to a physical model of the brain, and passed around a cast of a homo habilis skull. During this time, Murphy fielded questions. Murphy then moved to discuss the specific gene of interest to his research and showed videos of mice activity. The students asked questions about the use of mice in research. Murphy showed them how to take a DNA swab from the cheek. The participants offered explanations and asked questions through the talk and demonstration. Murphy concluded again with a game about chance and risk.

Murphy left this second event feeling like the girls were engaged, even though not everyone understood every piece of the material. From the event itself and from Murphy's discussion of it, we analyze several ways in which the relations between himself as a science communicator and the girls in the facility were shifting. In his post-program interview, Murphy described how he had learned from the previous engagement event to plan differently for the second one:

> After the first one, I had a lot of ideas myself. Now at least I had some experience to know what worked and what didn't. The addition of these things that I passed around I think was important. I focused more on things people could relate to. Just that your brain weighs about three pounds and it's kind of a flimsy thing if you tried to hold it in your hand and it would leak through your fingers. Just things to make it more real.

In the first event, the girls had asked about brain changes that might make people more susceptible to addiction, and Murphy saw these questions as evidence that the girls were trying to understand what studying the brain could tell them about their own experiences. The model brain he brought to the second event was another thing he thought "people could relate to." Having learned that adolescents had some grounding questions at the beginning of the first engagement, Murphy also began the second one with those very questions: What is anthropology? What does it mean to be a Ph.D. student? Murphy's design for the second event further involved a different relation to the girls in the way he positioned his own goals. In the post-program interview, we asked: *Could you talk just a little bit in general about how you found a balance between your goals and your interests, what you wanted to communicate, and the needs and interests of the youth who were there?* He responded:

> I hope I abandoned my goals on the second one. I think that that's one of the wonderful things about this. I don't have a curriculum. I don't have to make sure I'm leaving no student behind or any of this or that they're going to do well on standardized testing. This is a tremendous advantage. You can go there, try to stay flexible, and be responsive to tell people what they're interested in. […] You also respond to questions and listening to the question carefully will take you a long way… I tried to be more responsive and to improvise more.

We take Murphy's words as evidence of a shift in his relationship with the public. He began to differentiate his relationship to the public in the SLP from the relationship between instructors and students. While Murphy kept key science messages in mind, he emphasized that adapting to the participants' particular questions and interests was the heart of his approach for the second and future engagements. His new relationship carried distinct expectations for his actions. His evolving relationship with the public required him to listen "carefully" to what people say and to be willing "to improvise more" rather than follow a unidirectional lesson plan. Relating to the public required that Murphy position his knowledge and practice more humbly.

Murphy also mentioned in the post-program interview that going into these events he did not much "like" teenagers. We see evidence that Murphy improved his regard for the youth at the first engagement, which then became consequential in the second engagement. On the post-engagement survey for the second engagement, Murphy wrote that he saw the girls as "engaged and attentive, mostly" and that they expressed "their appreciation at the end." At the same time, he saw how "the [girls'] participation can be encouraged by asking questions, answering questions even if off-topic and altering the presentation outline as participant areas of interest emerge." Murphy's perception of the girls as "engaged and attentive" contrasts with his earlier dislike of teenagers. His remarks also indicate a recognition that the qualities of the girls' participation were not innate to them, but rather at least partially a result of the way he related with them. Murphy sees his own role in fostering an engaged and interactive atmosphere, including altering the plan as participants' interests changed during the event. Murphy came to see the adolescents as engaged, curious, and insightful learners who thought scientifically and critically about the content at hand. Through interacting with them, Murphy learned about their knowledge, interests, and identities and seemed to have come away with a new appreciation for adolescents in terms of who they are and their capabilities. He recalled their "stunningly insightful" questions about genotype heritability, genes' effects on risky behavior, and the role of nature versus nurture. He said these questions "really illustrated a kind of

scientific thinking in my mind, and these are people who had gotten it and were trying to move a step ahead." He also saw them as "better questions, by the way, than I got when I did my four […] presentations up at the museum."

One of the goals of the SLP training was to emphasize the role that empathy could play in STEM communication (e.g., learner-centered activities, understanding the needs and interests of the public, and finding points of personal connection with non-scientists), and Murphy's experience seems to have provided an opportunity for growth in empathy. Responding to the question about the SLP's human-centered design training on empathy, Murphy said, "It helped me focus on the needs and desires of the participants, rather than on what I may think is important."

Discussion and conclusions

Murphy's case illustrates what may be possible in shifting STEM researcher's relations with the public. He came into the SLP thinking that members of the public had poor scientific understandings and that the most important thing in science communication was to deliver accurate information. In his first public engagement event in the SLP, Murphy's experience went off-course from his plans. He was surprised by the youths' interest in his personal trajectory and the overall sophistication of their questions. He worked to derive insights from his empathy experience in that first event and apply them in the design of the second event, in which he focused much more on grounding the presentation in aspects he thought the youth would relate to. He also tried to relate in ways that were more responsive to emergent interest and to be improvisational. The experience ultimately shifted how Murphy regarded the youth in the residential facilities as scientific, intelligent, and engaged.

From this case, we highlight several areas of significance for the learning sciences. First, while empathy has particular technical definitions in psychological and affective research, the case shows the importance of attending to how empathy takes shape as an emotional configuration, socially achieved through the framing enacted in the SLP training and in Murphy's uptake and enactment of empathy's practices and ways of thinking about the other in his public engagement events. We see evidence of Murphy's attunement over time to how the youth he encountered, despite being in a residential treatment facility, were engaged scientific thinkers who were interested in what biological anthropology might have to say about their life experiences and futures. We argue that the emotional configuration of empathy in the SLP provided structures for Murphy's thinking and practice that enabled him to improve his regard for these youth and for members of the public more generally. This case is also instructive as an example of how emotional configurations can be instructive outside the strongly politicized social movement context in which the theory was initially developed (Vea, 2020).

Second, building more generous interpretations of the youth and other members of the public was associated in this analysis with shifting ways for Murphy of seeing himself in relation the public. In his early interviews and surveys, he emphasized the central importance of providing correct scientific facts to uninformed publics. He saw himself as the holder of knowledge that should be transmitted to passive audiences. In contrast, by the end of the SLP, Murphy was articulating a revised relationship schema of public engagement. In his new understanding, he saw his role as connecting with what people see as meaningful to their lives—something that could not occur in a unidirectional transmission of his expertise to the public. Rather, this new relationship required Murphy to take up new ways of practicing in relation to the public. He saw the need to let go of his own agenda, be responsive to emergent interests, and improvise. If relationship schemas involve expectations and norms for how people should interact together (Polletta, 2020), the emotional configuration of empathy in the SLP helped Murphy shift his expectations for his own behavior as a STEM communicator. We see these shifts as productive for societal needs. Meeting collective sociotechnical and socio-scientific challenges will require STEM researchers to relate with public groups in new ways, and focusing public engagement work on what members of the public see as relevant to their lives and futures can help all of us work together toward collective solutions.

We see the potential for future work in the learning sciences to continue to analyze the relationship between emotional configurations and relationship schemas to understand how they co-constitute one another over the course of social interaction and unfolding activity. Interaction analytical approaches (Jordan & Henderson, 2011) may be especially useful for building on the work presented here by illuminating the moment-to-moment ways that people work together to shift their understandings of each other and their obligations to one another's wellbeing.

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Possibility, Perspectives, Personal Investment, and Process: How K–12 Teachers Support Programming Projects Through Assessment

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Abstract: Creating personally authentic projects can support student engagement and motivation in learning to program. Assessment can play a role in supporting student learning, but it can be challenging for teachers to employ assessment practices that benefit students and their programming projects. In this interview study conducted with 80 U.S. K–12 computing teachers, we explored how teachers supported students' programming projects through their assessment practices. Teachers navigated tensions between their pedagogical aspirations (e.g., supporting creative possibilities) and practical considerations (e.g., logistical constraints) as they supported students projects by (1) encouraging possibility through rubrics; (2) inviting multiple perspectives through feedback; (3) increasing personal investment through self-assessment and resubmission; and (4) surfacing process through documentation and conversation. Findings from this work support understandings of how assessments can support or constrain learning through creating programming projects.

Introduction

Learning to program through the creation of personally authentic projects can be an inclusive and equitable pathway into computing, supporting learner motivation through experiences that are "personally or culturally meaningful in the mind of the learner" (National Academies of Sciences, Engineering, and Medicine, 2021, p. 30). In elementary school teacher Oscar's classroom, students created Scratch projects about their favorite locations in their neighborhoods, and in middle school teacher Tara's classroom, students designed 3D models of objects for their family members. Assessment is a critical component of supporting student learning through creating projects (Earl, 2012), but programming projects can be challenging to assess (Brennan & Resnick, 2012; Shute et al., 2017). Without clearer understandings of how to support students' programming projects through assessment practices, teachers may be deterred from designing opportunities for students to learn through the creation of programming projects altogether (Brennan, 2015). In this study, we investigated: *How do K–12 computing teachers support students' programming projects through their assessment practices?*

Background

When students engage in creating projects, well-designed and ongoing assessment is critical for supporting student learning (Barron & Darling-Hammond, 2010). It can be difficult to design effective assessments, however, because assessing and understanding student projects can be a complex process (Brinkerhoff & Glazewski, 2004; Pedersen & Hobye, 2020). Because students' projects and project processes necessarily diverge from one another, teachers often draw on pedagogical content knowledge (Jones & Moreland, 2005) and assessment literacy (Lew & Nelson, 2016) to effectively support many students simultaneously. A lack of time—not only for students to make projects but also for teachers to assess those projects—is a common challenge (Kleinert et al., 1999; Lumadi, 2013). Moreover, assessment practices themselves run the risk of stifling student motivation and interest (Earl, 2012). As Barnes et al. (2015) write, "assessment practices hold power that can enhance learning and democratic practice or can be used to punish and control learners, teachers, and schools" (p. 298).

In the context of teaching and learning computer programming, teachers may face unique challenges when supporting students in engaging in projects. While students' programming projects are easily visible, student learning may be harder to understand and support (Brennan & Resnick, 2012). In computing education, manual checking of student code is a customary and time-consuming form of assessment (Grover, 2017), though some researchers and educators have developed automated assessment tools (Blikstein et al., 2014; Douce et al., 2005; Ihantola et al., 2010). Even with automated tools, teachers need a high degree of pedagogical content knowledge to assess student learning through programming projects, particularly when students have been encouraged to take their projects in directions that feel personally authentic to them. Students' programming projects can vary, even when they incorporate the same or similar computational concept (Capraro & Slough, 2013). Students might engage with different computational concepts, practices, and/or perspectives by attempting projects in different

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ways (Brennan & Resnick, 2012). In the U.S., although there has been increased demand for and investment in computing education for students, there has been a lack of commensurate support for teachers' professional learning (Blikstein, 2018). Limited access to professional learning can stifle computing teachers' development of pedagogical content knowledge and assessment literacy, leading to difficulties in knowing what to teach and how to assess (Bower et al., 2017; Yadav & Berges, 2019). Without the requisite assessment literacy, computing teachers sometimes forego the assessment of projects altogether, relying on separate, more "traditional" assessments (i.e., handwritten exams) as ways of understanding student learning. These exams typically focus on student acontextual conceptual knowledge, and a lack of assessment around students' projects can unintentionally minimize how much students value their own projects (Yadav et al., 2015).

Method

In this study, we investigated the assessment practices that teachers implemented in their classrooms. We explored how teachers' aspirations for supporting students' programming projects informed their assessment practices, as well as how teachers negotiated challenges in employing these assessment practices.

Teacher participants and interview design

Eighty U.S. K–12 computing teachers were recruited via social networks (e.g., Twitter) and email listservs (e.g., Computer Science Teachers Association). Half of participating teachers worked with grades 9–12 and half worked with grades K–8. 20 teachers taught at least one Advanced Placement (AP) course. While some had prior CS experience, most participants taught other subjects (e.g., math, science, or the arts) and had begun teaching computing because of personal interest or school demands. They taught in rural, suburban, and urban districts in 27 states. School contexts varied, with two-thirds of teachers working at public schools. Some K–5 teachers taught all subjects, including computing, to their own class of students, while others taught computing to all students in the school in their roles as librarians/computer lab teachers.

Individual members of the research team conducted interviews with pairs of teachers about assessing programming projects in computing classrooms. Asking teachers to share and discuss two assessments they used in the classroom enabled us to ground interviews in student work and teacher-generated assessments. The pair design offered opportunities for peer learning and richer data (Haduong & Brennan, 2020). Interviews were virtual, over video chat, and teachers were paired randomly by scheduling availability. Interviews were structured as a three-part turn-based protocol: after the research team member asked a question, each participant responded to the same question. First, we asked participants to define key terms (e.g., "assessment") and how these constructs manifested in their classrooms. Then, participants shared their assessments (e.g., rubrics and student reflective writing), describing how and why these assessments were developed. Finally, we asked participants to share advice or questions they had for other teachers. Interviews averaged 75 minutes, and they were audio-recorded and transcribed. All teachers were assigned pseudonyms, which is how they are referenced in this article. After the interview, each participant received an Amazon gift card ($100).

Data analysis and limitations

Interviews were analyzed through a collaborative and iterative process of thematic analysis (Braun & Clarke, 2012). In the initial rounds of open coding, the first author and another research team member focused on assessment practices (e.g., "feedback"), coding together to develop a preliminary codebook in NVivo, then piloting the codebook by individually coding the same interviews and meeting weekly. Once the assessment practices had been established, the team then focused on developing codes related to each practice's underlying rationale (i.e., aspiration for supporting programming projects), as well as the challenges related to each practice. After a codebook was established, they engaged in split coding, discussing discrepancies and concerns weekly with the second author to arrive at consensus (Cornish et al., 2013). Through reflective memos and regular discussions, the research team worked together to reorganize codes and understand the relationships between aspirations for students' projects, assessment practices, and practice-related challenges. In the final phase, we looked for "discrepant evidence" that was at odds with the existing codebook (Maxwell, 2010) and revised accordingly (see Table 1).

There are several limitations to our approach. In this study, we recruited teachers interested in supporting and assessing student creative programming projects; this call may have excluded teachers who were implementing programming projects in the classroom but didn't feel that their work was "creative." As an interview study conducted remotely, we were not able to observe participants in their classrooms, though we triangulated participant responses with submitted assessment examples. We sampled a broad and diverse group of teachers working in K–12 computing education across the U.S. and found that key practices spanned contexts.

Table 1
Assessment Practice Codes by Teacher (n=80)

Aspiration	Practice	Example	Teachers
Possibility	Rubrics	"I want four sprites, but I don't specifically say what the four sprites are, and that gives them creativity within my constraints."	70
Perspectives	Feedback	"Bringing another person into the conversation helps them push their thinking along because they're testing their ideas out on an actual user … it's really great to get feedback from a peer, and it's great to watch someone play your game."	65
Personal investment	Self-assessment	"Did you do more than you ever thought you could do? And do you keep wanting to do it? That's when [you] can self-assess and say, "I'm starting to get there.'"	53
	Resubmission	"They can keep resubmitting, [and] manage and design their own test loop … they can iterate very quickly."	21
Process	Documentation	"It's like they're walking around with a tape recorder … And they're showing me all of the process that was involved, and then the product ends up only being a small part of it."	29
	Talking to students	"I walk around and they run [their programs] for me, and then I may ask them some questions about, "What did you do? How did this work? Show me what you did here."	68

Findings

In learning environments where students were engaging in programming projects, teachers aspired to encourage expansive possibilities, invite multiple perspectives on student work, increase students' personal investment in their projects, and surface students' process. One way these aspirations informed how teachers designed opportunities for creating programming projects was through their assessment practices, which enabled teachers to differentiate project support based on students' varied needs, skills, and lived experiences. At the same time, teachers negotiated external accountability demands, expectations of what learning and assessment "should" look like, and the time constraints of K–12 class schedules. Participating teachers described supporting programming projects through four assessment practices: (1) encouraging possibility through rubrics; (2) inviting multiple perspectives through feedback; (3) increasing personal investment through self-assessment and resubmission; and (4) surfacing process through documentation and conversation.

Encouraging possibility through rubrics

Having a sense of what is possible facilitates the ability to create personally authentic programming projects. Teachers described how students, unused to opportunities to engage in this type of open-ended project work, struggled to make sense of what they were "supposed" to create. In response to this challenge, most participating teachers (n=70) used rubrics (or scoring guides) when facilitating programming projects, which helped students imagine expansive creative possibilities while understanding expectations for project requirements. Defining expectations helped teachers justify grades. But teachers also felt that too many expectations could limit student freedom. More than half of teachers (n=48) asked students to make projects that included specific computational concepts (e.g., loops or variables) while leaving the type of project and specific implementation up to them, striving to support a diversity of outcomes. A few teachers (n=4) designed rubrics that were purposefully minimal and open-ended (e.g., "Creativity: Student explored and expressed multiple ideas in a unique way") while others (n=12) strove to make them as specific as possible (e.g., "Creativity: Student selected a stage, sprite, and action commands that create an engaging dance performance for the viewers"). Joshua, an elementary school teacher, described how the rubric–as–checklist helped students decide how much challenge they wanted to take on in their projects, while also helping students see what else they might do in their projects.

Several high school teachers noted that they used rubrics despite their limitations, particularly around student motivation. Derek said, "Many students see the rubric as the maximum" while others "see it as the minimum," and Shannon expressed a concern that using rubrics "really lowers the level of creativity and engagement in a project." Teachers also differed in *when* they shared rubrics with students in the project process. Some teachers (n=13) gave rubrics to students at the beginning of the process to help students imagine what was possible. Kayla, a high school teacher, said, "I do give [students] that base rubric so they have a starting point. I find that if I don't, they feel very lost." Some teachers (n=14) used the rubric as a checklist throughout the project

process, though others felt strongly about sharing the rubric only at the end. Damien said, "I don't want them going into checklist mode" in the beginning, because he wanted students to be "exploring and figuring out and not limiting themselves based on the rubric yet." Even though the use of rubrics was a common practice, several teachers raised questions about how rubrics could better support opportunities for students to understand what they might explore within their programming projects.

Inviting multiple perspectives through feedback

Programming projects can benefit from students' access to multiple perspectives, which can spark new ideas and support students when they get stuck. Assessment in support of learning is most effective when delivered in a timely manner (Brookhart, 2008), but teachers noted that, particularly with large classes, assessing student programming work could be burdensome. Erin's biggest problem was "timeliness in getting them feedback … I can't be a bottleneck for anything; kids have to know where they are as soon as they can." Throughout projects, many teachers (n=65) created opportunities for timely and individualized feedback by inviting multiple perspectives on students' projects. Erin, a high school teacher, incorporated peer feedback through "round robin presentations," splitting her class in half and asking each student to present individually to another student for ten minutes before rotating, so that every student was able to share and receive feedback multiple times. Teachers also reported that students valued peer feedback more than teacher feedback; Tracy, a middle school teacher, said, "the most meaningful thing [for kids] is the feedback they get from their peers."

Practicing assessing others' work can inform students' awareness of other solutions and scaffold their ability to assess their own programming projects (Smith et al., 2012). Having other people test their projects was often helpful for students' progress, and Leslie, a K–5 teacher noted that students were "really quick about finding mistakes" in others' work. Peer feedback, however, can take *more*, instead of less, time. Anita, an elementary school teacher, reported that written peer feedback resulted in more work because "it takes a long time for me to read all [the feedback] for the students." Students may also need to learn how to give each other feedback (Beach & Friedrich, 2006). Quentin, a high school teacher, printed and displayed students' code on large sheets of paper, so students could "appreciate other people's code and look at a variety of directions that students took to solve a problem." He then gave students sticky notes and discussed how to provide feedback. To his students, he said, "If I came to your desk and told you that your code was good or bad and didn't say anything else, you'd hate me, right? I'd be a bad teacher. So, be a good peer and provide constructive but respectful feedback."

Feedback could also come from other authentic audiences. In Jill's AP CS A classroom, industry volunteers offered technical expertise that she did not have. Jill, a novice programmer, described how having less content knowledge slowed down her ability to support student work. Because she was not able to understand students' code by reading it, she often had "to test it out because we don't know all the ways the kids' minds work … they're all over the place." A few teachers (n=8) also facilitated opportunities for students to receive feedback from audiences beyond their classroom, such as asking family members, friends, or industry volunteers to play the games they had designed. For students, receiving feedback from others at multiple points during their projects helped them refine their ideas and iterate on their projects.

Increasing personal investment through self-assessment and resubmission

When students are working on personally authentic projects, they are more likely to be invested in their creations. Personal investment can support persistence in the face of challenges, possibly leading to future participation in computing. Assessments can support personal investment, but assessments are often thought of as something done *to* students, instead of *with* students (Earl, 2012). Many teachers (n=60) spoke about tensions between how they wanted assessments to support student learning and the expectations that students, parents, and/or administrators brought to assessments. Teachers wanted to prioritize formative assessments, but the formal structures in which they were operating often demanded summative assessments that felt antithetical to learning goals. Teachers (n=35) also noted uneasy relationships between assessment, motivation, and teacher feedback. In class, high school teacher Lorena tried to encourage students working on projects to "forget about the grade, forget about what I want from you, because you're not doing this for me." But students would push back, expecting "traditional assessments," such as multiple-choice quizzes. Other teachers spoke about students' tendency to focus on grades, rather than reading and incorporating feedback. Ashley, a high school teacher, said, "Most kids honestly just look at the grade, and that's all they want to see," specifying that even though she wanted to give specific feedback, students "really just want to say, 'All right. Did she give me a B? What am I getting here?'"

To more closely connect student motivation to assessment processes, teachers (n=53) described the ways in which they helped students self-assess and resubmit their programming projects until they were satisfied with their work, as well as the teacher's assessment of their work. Evan spoke about how teaching kids to self-assess helped them "monitor their own progress," and Betsy felt that self-assessment involved students as "participants

in the process." Typically, teachers were asking students to give themselves a grade and offer a justification of why they deserved that grade. A high school teacher, Jesse also scaffolded students towards self-assessing their final project by using a consistent rubric across multiple projects before giving students a blank template and asking them to define their final project's minimum requirements, saying, "What I'm looking for from them is to not only decide what they want to make, but also to decide how they want me to assess it." This process of self-assessment helped teachers gain a better sense of whether students felt that they had met their own goals, and how students' understanding of their own learning was connected to their teachers' assessments. Students were fairly accurate, or even too harsh, in their self-assessments. Natalie, a high school teacher, said, "Usually, when students grade themselves, they're either right at where I graded them, or they're within one grade. When I give them back my rubric with the feedback on it, they can see … what they would need to do to change it if they wanted to."

Some teachers (n=21) encouraged regular resubmission of work for full credit if students were dissatisfied with their grade and wanted to resubmit. However, resubmission sometimes worked against students—Justin, a high school teacher, pointed out that students could introduce new bugs, saying, "Sometimes, when they fix one thing, they break something else." Resubmission offered opportunities for students to demonstrate what they knew, rather than what they were able to do in any particular moment. Rhonda noted, "Anytime they don't do as well as they can, I give them a chance to retake … It's not a test of, 'Did they do it right the first time?'" In creating opportunities for students to be more involved with the assessment process, teachers were helping students deepen their personal investment in their programming projects.

Surfacing process through documentation and conversation

When teachers have greater understandings of students' project creation process, they are better able to support students' current and future learning. Across grade levels, teachers experienced difficulties in understanding individual students' learning solely by examining students' work product. Several teachers (n=12) noted that students could copy and paste code into their projects without understanding how the code worked. Others (n=35) raised that seeing a student use a concept in a particular project did not indicate whether they understood the concept and could transfer that knowledge elsewhere. Many teachers (n=38) designed programming projects to be collaborative, but it was difficult to understand individual contributions. Natalie, a high school teacher, described how students with greater expertise could easily dominate in group projects. When looking at students' code, teachers (n=49) had difficulties seeing what students cared about and how much effort they invested, what their "individual gains and personal bests" were (Richards, 2010, p. 193). Even with recent increased access to computing in K–12, teachers (n=36) described how some students had many years of prior computing experience, while other students were new to the subject. Brooke, a middle school teacher, described this differentiation challenge as one of equality, of "how to assess [students] equally based on their skill level, because they're all at such varying levels when they come in." In contrast, Janet, a K–12 technology integration specialist, aimed to differentiate her assessments, saying, "If I'm looking at the work of one student, and then a different student's work, I have to remember where this person started from." Without understanding learners' process, it could be challenging for teachers to celebrate students' successes and highlight areas of future learning.

Sawyer (2021) notes that "ideas do not originate from internal thoughts during solitary meditation; rather, they emerge from a visible and embodied process of engaging with the work" (p. 17). Most teachers (n=74) found ways to attend to students' process as well as product, asking students to articulate their ideas through written documentation or in-class conversations. A third of teachers (n=29) asked students to document their process as a way of making their thinking and learning visible. Documentation helped teachers gain insight into whether and how much students understand the code in their projects. Students wrote in-line comments in their code, pasted screenshots of their projects into separate reflection documents, or recorded summative video reflections. Adrienne, a middle school teacher, said, "You could copy code quite easily … which has been an issue … that's why I use the design process of creating documentation. You're able to talk about what you've been doing. You can explain how you got the information you got."

Documentation practices also helped students develop insight into what they had learned. In Evan's inclusive classroom, students did not always finish their projects. He noted, "I hate for students, especially [those] who have struggled or who have IEPs[1] that really presented challenges in their learning to think the project was a wash." Writing a final reflection helped students realize, "Hey, there are times where I hit a challenge … and I grew." However, several teachers noted that documenting process could take time away from the product, particularly when there was emphasis on written reflections for English language learners or students with disabilities. Shannon, a high school inclusion teacher, said that documentation could be "way, way too oppressive, and then they can't be creative because they're so busy writing [things] down. It's a fine line." Lindsay, a middle school teacher, said that working "with the population of learners who struggle with reading and writing, I can't say I'm surprised that they're not putting comments in between their lines of code to express their thinking."

Many teachers (n=68) described a desire to assess process by talking to students about their work, which helped to develop shared understandings of what was new or exciting. But this could be time-consuming. Damien, a high school teacher, wanted to have conversations with every student but said, "I don't ever do that.… I don't know how to make it happen." Robin, an elementary school teacher who saw every class every week, said, "I'd love to [meet with students], but I have 800 students." Stacy, a middle school teacher, shared a story about the challenges of not being able to see what students had learned through working on their projects.

> Several years ago, I had this student. This girl, who was just really fun and a very creative girl, and she turned in this game that was a cute game. I wrote, "This is a cute game. You did this well, and you did that well and it … meets expectations." I got this seething email from her father that has really stayed with me. He said, "You know what? My daughter wanted to be a computer programmer until this moment, and now she never wants to do it." I thought, *Oh, my God. What have I done?* "She spent so long on this one feature, and you did not notice this feature."

Because of this experience, Stacy changed her assessment practices to focus on deepening her understanding of her students and their process, telling them,

> Please tell me what you're really proud of in this. Please tell me what I might not notice. I want to know what you were up against, and what battle you won. And if you didn't win the battle, but you were fighting it, I want to know that too. Please just tell me what to pay attention to.

When teachers were able to learn more about their students' process, they were better able to support students in making progress on their programming projects. Teachers (n=68) relied on their direct experiences with students to determine what they had learned. Jill, a high school teacher, emphasized the importance of classroom observation: "I observe my students interacting with each other's projects acutely, because that says so much that I could never [understand] otherwise."

Discussion and conclusion

Creating programming projects can offer opportunities for students to engage in personally authentic computing experiences, which can support sustained participation in computing. Across contexts, we saw K–12 computing teachers aspire to support students' programming projects by encouraging possibilities, inviting multiple perspectives, increasing students' personal investment, and surfacing students' process. The process of learning to program by creating projects, however, is seldom predictable or linear, and students' diversity of interests often led to a diversity of learning outcomes. We saw teachers grapple with these complexities as they used various assessment practices. Their assessment practices were typically formative, helping teachers assess what students had learned thus far while supporting their future learning. Through *rubrics*, teachers were describing to students what they might try in their projects. Giving and receiving *feedback* helped students develop judgment of their own and others' work. *Self-assessments* helped students set their own goals and decide what they wanted to learn. And by *documenting and talking about their work*, students stepped back and articulated their thinking, which could advance their learning. Teachers rarely relied on a single assessment practice—different practices were used at different moments during students' project processes. When used together, assessment practices supported teachers in developing better understandings of their students as thinkers, creators, and learners.

However, teachers' desired assessment practices could be hard to implement, given the time constraints of K–12 schools. Teachers offered opportunities for students to resubmit work, but that could take time away from the next project. Some teachers said that there was insufficient time for peer assessment, and others pointed out that students needed time to learn how to give feedback. Notably, many of the elementary school teachers, who often saw more students for shorter class periods, cited time as a limiting factor. Teachers' assessment practices were also striving to address this particular moment in U.S. computing education. Because of computing education's uneven implementation across K–12, the ability to offer learning experiences that meet the needs of all students can feel daunting, and almost half of participating teachers (n=36) described challenges they faced in offering differentiated teaching and assessment. Teachers are often working in inclusive classrooms, where students may have a range of learning needs, and students are entering classrooms with a range of prior programming experience. Some students may not have access to technology at home, reducing the amount of time that students can work on their projects. Building relationships helped teachers gain a better sense of students' prior experiences with computing and how much effort students were investing in their projects, but this could be a time-intensive process.

In addition, a desire to understand student learning can have unintended consequences on the design of opportunities to create personally authentic programming projects. Because it can be challenging to surface what students have learned through examining their projects, there may be an impulse to assess what is easily visible, focusing on accuracy in usage of programming concepts and/or easily-checked solutions to programming puzzles. Sometimes, this can mean divorcing the assessment of learning from the project process, or this can mean constraining student agency in their projects, such that students undertake similar project creation activities. When we limit ourselves to what is easily assessed, we risk artificially constraining learning opportunities in ways that benefit teachers and researchers, and not the students themselves. And when we limit student agency in their projects, we risk limiting opportunities for students to engage in expansive learning when learning to program (Wilson, 2021). As computing education becomes more widespread, there is increased need to consider not only whether students have access to computing education, but also what *kinds* of computing education opportunities are accessible. What are students being asked to do as they learn to program? And how might assessment practices support, rather than constrain, student learning?

Assessment practices can unintentionally undermine student confidence and their progress. But as teachers demonstrated, assessment practices can also encourage possibility, invite additional perspectives, increase personal investment, and surface creative process. Teachers' practices pushed back against traditional forms of assessment and encouraged understandings of assessment as an integral component of the project creation process. We hope that these teachers' assessment practices inspire researchers and teachers to expand access to opportunities for students to pursue personally authentic programming projects, which can enable students to express their ideas with code and see themselves as computational creators.

Endnotes

(1) For young people to receive special education services in U.S. public schools, they are given individualized education programs, or IEPs.

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International Society of the Learning Sciences

Queer Orientations as Resources for Mathematics Learning

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Abstract: This paper investigates how queer orientations shaped mathematical meaning-making in an afterschool documentary filmmaking program. We focus on queerness as both a lived/experienced phenomenon *and* a lens for thinking about learning, following scholars who have examined mathematics learning from racialized and gendered lenses (E.g., Gholson & Martin, 2019; Rubel, 2016). To do so, this paper explores how the performance of and negotiations with queer identities are co-constructed and emerge with meaning making around mathematical concepts. Findings call for centering these stories as productive, critical aspects of learning such that youths' queer positionalities and identities in and across contexts are seen as an essential aspect to advancing equity in mathematics teaching and learning.

Purpose

It is late afternoon when four members of an after-school documentary filmmaking program we call Digital Studio (DS) – Zeena, Xane, Lucas, and Cai - huddle around a computer in a school's library. They are working on compiling research for their documentary on "The LGBTQ (1) Youth Experience in Schools in 2017." The Youth Producers (YPs) are creating a voiceover script for the documentary they will write, film, edit, and showcase within the course of one school semester. In small groups, they have spent the last few days looking for statistical information that describes the LGBTQ community. This afternoon they record informational statistics found online about the relative sizes of LGBTQ populations in different U.S. cities. As they gather the information for the voiceover, their discussions weave in and out of mathematics, such as notation, mathematical operations, and proportional relationships, and affective responses to the numbers. Amongst the note taking and calculations, ponderings emerge; how a statistic prompted one youth to reconsider a familial relationship, and another to hope for a desired future. A traditional lens on learning might isolate the explicitly mathematical parts of the conversation, finding a largely uncontested discussion of concepts and notation. Such an approach might further relegate the personal to an uninterrogated background, dismissing with it entire histories, identities, and relationships through which collective mathematical meaning emerges. In the analysis presented in this paper, we adopt a queer perspective and turn intentionally to this forgotten background to reclaim the more relational and subjective dimension of learning. Turning in this way allows us to bring into sharp relief how participant stories are implicated in the construction of a statistic for their documentary film.

In the past few decades, out of school settings have occupied a place of some prominence in mathematics education research (Carraher, et al., 1985; Ma, 2016; Nasir, 2002; Saxe, 1991). Collectively, these studies have examined the social and cultural practice of mathematics in everyday, non-school life. Yet, only a small subset of this literature has decentered school mathematics in informal settings, interrogating how mathematics learning and identity development are mutually constitutive of each other (e.g., Hull & Greeno, 2006; Nasir & Cooks, 2009; Radke, 2021). Such an approach has made it possible to understand how mathematics, as a practice, is the effect of interplay between subjects, artifact, and the environment. In particular, studies like Ma's (2017) of whole-body mathematics, Nasir's (2002) into domino and basketball activity, and Saxe's (1991) of gameplay have offered perspectives on how mathematics and mathematical activity are produced in interaction and within particular settings. We draw on this latter scholarship and extend its ideas by considering affect as another element of meaning-making in mathematics (Leander & Ehret, 2019).

This paper investigates how participants' queer orientations, discerned through a queer analytic lens, shaped mathematical meaning-making in an afterschool documentary filmmaking program. We begin by positioning ourselves as researchers from a post-colonial feminist perspective with an interest in surfacing erased stories of learning and practice in mathematics education. The Black/feminist scholar Kristie Dotson (2014) argues that stories often go untold due to our "inclination to understand oppression as we experience it and to extend our analysis of it beyond what we ourselves can see from our particular vantage point" (p. 57). She urges us to interrogate the places from which we see and conduct research to unpack the stories that might be obscured by our particular "socioepistemic orientations" (p. 45). Ahmed (2006) writes similarly about orientations:

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> Some things are relegated to the background in order to sustain a certain direction; in other words, in order to keep attention on what is faced. Perception involves such acts of relegation that are forgotten in the very preoccupation with what it is that is faced. (p. 31)

In other words, our orientation to a scene relegates some aspects of it to the background while foregrounding others. The orientation of our gaze, therefore, affects what we see and the stories we tell; the background, forgotten, holds some of the stories we may have lost along the way. The purpose of this paper is to search for these lost stories by critically attending to the forgotten background. We contend that by telling these lost stories, we are positioned to better understand learning as it takes place in the margins

An emerging field within educational and learning sciences literature engages marginalization as an intersectional phenomenon, and examines the ways in which race, class, gender, and other social subjectivities interweave to mediate experiences of learning. Gholson and Martin (2014; 2019) focus on Black girlhood as a unique social location from which Black girls experience the mathematics classroom. They point out that the social networks of Black girls at school form at the intersection of their Blackness and their girlness, so that any examination of their experiences of learning must necessarily recognize both race and gender. Similarly, by simultaneously interrogating institutions (such as schooling and STEM education) and structures (such as race, U.S. imperialism, and neoliberalism) across time and space, Sengupta-Irving (2021) and Sengupta-Irving & Vossoughi (2019) sought to give voice to the subjective experiences of Brown girls in contemporary western education. Taking a similar approach to studying embodied mathematical learning, Takeuchi & Ishihara (2021) followed the mathematical sensemaking of a collective of migrant women activists by attending to their social and political histories of migration and labor, as well as the violence their bodies had been subjected to. Taken together, these studies share a commitment to seeing social processes—and therefore learning—as at once emplaced, embodied, racialized, gendered, and classed. We share this commitment and offer (queer) orientations to surface socially, geographically, and politically entangled processes of learning.

While racialized (McGee, 2015; Leyva, 2016; Martin, 2012) and gendered (Ceci & Williams, 2011; Legewie & DiPrete, 2014) identities have been examined in mathematics education research, few scholars have centered the mathematical experiences of students with marginalized sexual identities with notable exceptions (e.g., Esmonde, 2011; Rubel, 2016). Thus, we focus on queerness as both a lens for thinking about learning and lived/experienced phenomenon. This paper is guided by the following questions: *What orientations are brought to the fore when interactions are viewed through a queer lens? And how did these orientations shape mathematical participation?* Analysis revealed that youth's reasoning followed personal trajectories into the past and future as part of their reasoning practices and that queerness was entangled (Philip & Sengupta, 2020) with their mathematical reasoning. Findings call for centering these trajectories as productive, critical aspects of learning such that youths' queer orientations in and across contexts are an essential aspect to advancing equity in mathematics teaching and learning.

Theoretical framework

This paper is centrally interested in meaning-making—and therefore learning—as culturally, spatially, and temporally mediated. We explore this interest by bringing together sociocultural and queer theories to episodes under analysis. Guided by sociocultural theory, we take up the conceptualization of *learning as movement* (Gutiérrez, 2008), developed across settings (Jackson, 2011) and through shifts in participation in activities (Lave & Wenger, 1991). We look to queer perspectives (Ahmed, 2006; Butler, 1990) to highlight the power relations that shape identity performances and learning. Butler reminds us that all identities are composed of self-making acts, composed through "corporeal signs and other discursive means," (Butler, 1990, p.333), through which people become socially intelligible. From this perspective, identity is not an expression of what one is, rather it is something that one does. Critical to Butler's theory of identity as performative is the understanding of performativity as contextual and structured by powered relations. Thus, identities are not only dynamic, but contextually situated, non-neutral social constructions, and understanding positioning thus requires analytic attention to both the in-the-moment efforts to perform and to the context in which these performances occur.

A queer phenomenology involves facing the back (p. 29), allowing the researcher to make sense of a scene by deliberately attending to the background, or, in other words, the systems and labor that sustain what comes to be foregrounded. Calling for a re-orientation to the back or background necessitates that something or things occupy the fore from which we deliberately turn. Ahmed specifically calls for this move as an explicit resistance of white, cis-, and heteronormative narratives. Like Butler, Ahmed (2006) conceives of gender and race as "effects of the kinds of work that bodies do" (p. 60). In turn, the raced and gendered labor of bodies frames the kind of work it becomes possible for those bodies to engage in. Historically othered bodies, having arrived in places that refuse them, regularly resist dominant imperatives by occupying space (literally and figuratively) in

new and unprecedented ways. Such resistances are a result of "different orientations, different ways of directing one's desires" (p. 68). Occupying a space with new desires has the potential to extend it in new ways, making possible new ways of doing, being, and thinking. We view the resistance of the othered body as a performance of queerness and seek to understand how queer orientations shape collective and individual sense- making. By conceptualizing meaning-making as a process that extends across space-times (Nespor, 2004) the analysis examined queer orientations as part of mathematical and interpersonal sense-making by attending to the social practices of both the collection and analysis of data to meet activity-related goals, the phenomena described by the statistic itself, and the sociocultural and/or political concerns made relevant to sense-making by the participants themselves. In the empirical examples that follow, these theories supported understanding the ways interactants' subjective experiences of queerness were part of whole-group statistical meaning-making.

Data and methods

Data comes from a larger study of mathematical learning pathways (Ma & Kelton, 2017) at Digital Studio (DS), an afterschool documentary filmmaking program that engaged underserved youth in documentary film production and civic engagement. In one school semester, Youth Producers (YPs) and an adult facilitator worked together to produce a documentary that addressed a student-selected social issue. Data included field notes, audio and video recordings, interviews, and material artifacts. Analysis occurred iteratively at two interrelated levels, the ethnographic (Spradley, 1980) and microethnographic (Streeck & Mehus, 2005). Analyses of episodes identified as "hot spots" (Jordan & Henderson, 1995) iterated between microanalytic methods of interaction analysis (Jordan & Henderson, 1995), and methods borrowed from the construction of grounded theory (Charmaz, 2006). Ethnographic analysis of the full data corpus through thematic memo writing (Schatzman & Strauss, 1973) supported microanalysis of episodes, focusing on how the desires of different bodies occupied with a shared task collaboratively shaped reasoning practices. Finally, analysis traced chronotopic laminations (Bhaktin, 1981) to attend to participants' social relations and histories of arrival (Ahmed, 2006) that were made relevant in interaction. Attending to how spacetimes were brought together over the course of talk and interaction (e.g., Leander, 2002) illuminated how participants continuously co-constructed stories about themselves and others across time and space, influencing their social positioning. Analysis traced how queer orientations, as one such cross-spacetime resource, emerged as part of ongoing individual and collective sense-making.

Analysis

In the following episodes, four youth worked at a shared computer to compile research for their film about LGBTQ youth's experiences in schools (see Figure 1). They had spent the last few days looking for statistical information that describes the LGBTQ community, what their facilitator described as, "hard numbers - quantitative supporting evidence," (Fieldnote, 11.16.2017).

Figure 12
(From left to right) Zeena, Xane, Lucas, and Cai sit around a computer searching online for statistics for their documentary, "The LGBTQ Youth Experience in Schools in 2017."

Zeena, not feeling well that day, sat silently through the episodes. She was an old-timer in relation to the other three YPs, and she openly identified to her peers as "not straight," but she had not come out to her family. Lucas,

a self-identified queer ally, was leading the online search. He paused on one website and began to read aloud, "Gates estimates that approximately 3.5% of Americans identify as lesbian, gay, or bisexual while 0.3% are transgender." Xane, who identified as straight and "previously anti-LGBTQ", reflected in a remorseful tone, "Wow, that's a lot." After some quick mental calculations Lucas offered Xane and Cai, an openly gay youth, an estimation that 3.5% represented "about, still 10 million" Americans.

[1.1] Xane: Yeah, that's a lot. I'm saying… Now I feel bad
[1.2] Lucas: Uh, it's also - you have to keep in mind that not everyone is comfortable to s-
like - [1.3] Xane: To say what th[ey are
[1.4] Cai: [there's probably more than that,[just like=
[1.5] Lucas: [yeah =they just aren't
comfortable with sharing the information
[1.6] Xane: Yeah I understand
...(15 seconds of silence)..
[1.7] Cai: Nine million people and not one for me ((Laughs))

Xane and Cai accepted Lucas's estimation. Xane affirmed the estimation represents "a lot" of LGBTQ people [1.1] and after the youth discussed the reality of estimation through cascading utterances, Xane reconfirmed his understanding [1.2]. An analysis of mathematical activity that attended only to the talk and action that was explicitly mathematical, in a schooled or disciplinary sense, might interpret the students' lack of discussion as evidence that the youth had come to a taken as shared understanding (Yackel & Cobb, 1996). However, by attending for and with queerness we see that they continued to reason with the statistic, recruiting memories and future imaginings. Xane's personal experiences as the brother of a gay sibling and his actions in a spacetime outside of DS emerged as intertwined resources for sense making. This included both his mathematical interpretation of 3.5% as representative of a large number of people and his personal reflection of "feeling bad" [1.1] Although there is no verbal evidence in this clip as to what Xane was referring to in his utterance, Xane had shared in previous whole-group discussions that he had a gay brother whom he has not treated kindly in the past, actions about which he was remorseful. Then they built an argument questioning the accuracy of that same percentage.

Beginning with Lucas, then Xane, then Cai, and finally book-ended by Lucas, their cascading utterances co-operatively (Goodwin, 2017) built to produce an agreement that the percentage was most likely not a complete representation because of the social stigmas attached to being categorized as LGBTQ. Xane deployed agreement utterances shifting his footing from regretful and guilty to in alignment with Lucas and Cai. He built on Lucas's use of safety by legitimizing people's right to "say what they are," [1.3] and then confirmed his understanding of the argument they collectively produced [1.6]. Finally, Cai's sense about the percentage was embedded in his future imagination of finding a partner. Unlike Xane's earlier interpretation as a large number of people [1.1], Cai determined 3.5%, when converted to an approximate number, as too *small* for him to have hope in his search for romance [1.7]. Cai's queer orientations to the statistic, which were shaped by his romantic desires, further orientated the group to the data. Analytically, one might cast Cai's comment as a comedic aside as it did not get an immediate response from anyone. But, as their work continued, Cai's queerness and future hopes became key resources in the joint mathematical reasoning.

Xane and Cai's contrasting interpretations of the largeness of the same statistic highlights how orientations towards data are aligned with sexual orientations. Xane's encounter with the statistic invited and challenged memories of his interactions with his gay brother; interpreting the population as large appears to have shifted his understanding of the marginalized experiences of the LGBTQ community. On the other hand, Cai oriented to the statistic through desires for a queer future with a partner; to him, nine million seemed like too small a number of people to make this imagined future a real possibility. Minutes later Lucas typed, "What percent of LGBT in [This City (2)]" into the search engine. He copied the results in the group's research packet and placed the packet on Cai's desk. When Cai returned from break, he read what Lucas wrote, leaned over, and read from the screen, and asked, "What does that mean?"

[2.1] Lucas: There's more - there's a better ratio.
[2.2] Xane: Maybe that's cuz it just [there's - there's more people here
[2.3] Cai: [Ohhh, so like San Francisco has - is
mostly - [2.4] Lucas: Uh:: It's because This City has more [people
[2.5] Xane: [more [people, yeah so
[2.6] Cai: [more people, yeah, yeah
[2.7] Lucas: And San Francisco has more LGBT people to the uh:[to the=

[2.8] Cai: [But they have-
[2.9] Xane: =To the population, yeah.

Lucas began by describing the phenomenon as due to "a better ratio," which Xane added to as being about a city having "more people." Together they reasoned that "a better ratio," [2.1] had to do with the part-whole relationship between the number of people who identify as LGBTQ (the part) and total population of people in a city (the whole). At this point the youth had co-operatively produced an answer that satisfied Cai's initial sense-making question. Here, Cai's musings about his future and finding a romantic partner extended their talk.

[2.10] Cai: Yeah. (3 seconds) That's cool. Better move to San Francisco ((laughs)).
[2.11] Lucas: It's not that much higher. It's like, I think -
[2.12] Xane: So
[2.13] Lucas: ((Scrolling through the article)) I think, it's like - a 2.2% difference
[2.14] Cai: Oh.
[2.15] Lucas: And you're gonna be dealing with a bigger gay community.

The group's mathematical understandings about how the statistic was constructed and Cai's identity as a gay youth were recruited as resources for discussing how Cai's imagined future might unfold. Cai initiated this when he verbalized an intention to move to the city with the highest percentage of LGBTQ members [2.10]. In laminating a future spacetime as part of their discussion in the present spacetime of DS, Cai re-framed the meaning-making about the percentage as big or small as interwoven with his option to move to another city. That is, 2.2% being a large or small difference could influence his decisions about where he might live in the future. In fact, a year later, one semester into college, he expressed the desire to move. He doesn't cite this conversation but does mention the "larger gay community." Cai's desires for a queer future thus occupied the space of statistical meaning-making in the episodes, shaping an understanding of the statistics the group encountered.

In terms of a queer phenomenology, Cai reaches for the data in non-normative ways (Ahmed, 2006), so that how the data are perceived becomes inextricably linked with how they were reached for, which in turn is a consequence of Cai's queer desires being present in the traditional discipline of statistical thought. Such an analysis also shows how meaning-making, or "coming to know," is necessarily affective: we draw here from Leander and Ehret (2019), who argued that while engaged in literacy-gathering activities such as data interpretation or data collection, subjects affectively interpret and collect meanings with and in relation to other subjects. Cai, Lucas, and Xane extend the space of statistics through their own subjective orientations to the data and to each other, collapsing time so that "present-past-futures of reading, imaging and researching come into contact, where here-and-nows are visited by there-and-then's or imagined-there's-and-could-be's" (p.144). A queer telling of the episodes thus illuminates more than queer stories. By invoking participants' histories and relationships, it draws out shifts in their reading, interpretation, and use of the data. For instance, Xane's affective response to the Lucas' estimation of the LGBTQ population in the U.S. only emerges when one attends to the histories Xane (who identifies as straight and cis) brings into DS. Lucas (who identifies as straight and a queer ally) joined Cai in his narration of this imagined future spacetime when he added the percentage difference as a possible deterrent to Cai's hypothetical plan to move [2.13]. Attending to Cai's queer identity as the grounds for their continued discussion makes visible how Cai's individual experiences and desires shaped the group's reasoning in the moment. 2.2% as a large or small difference was entangled with and mediated by Cai's lived experience to date. Cai initially interpreted it as large and San Francisco as a place where he might have better odds at finding a partner. When Lucas challenged Cai's interpretation [2.11;2.15], he merged his (Lucas's) percentage calculation about the percent difference with their collaboratively constructed understanding of the mathematical difference between percent and total population. Understanding the difference between percentage and total population and interpreting the statistical difference of 2.2% as large or small had implications for the group, and Cai specifically, which stretched beyond the spatial- temporal boundaries of the interaction.

Discussion

In the analysis of these episodes, we have detailed processes of learning, illuminating how youth bring their experiences and positionalities as resources for mathematical reasoning, and how their knowledge of mathematical concepts interplay with their reflections on past experiences and future possibilities. By combining queer phenomenology with microanalytic methods of interaction analysis we have shown that students' orientations to, of, and with queerness were woven into their math reasoning, as they continually worked to draw connections across their lifeworlds to "make sense of one's own identity in the broad context of time," (Gutiérrez & Jurow, 2016, p.567). These efforts shaped individual and collective learning, and the practice of statistics in a

way that was relevant to the filmmaking task before them. Additionally, mathematical understandings youth co-operatively developed were used as tools for finding and interpreting statistics for their film and as part of traveling on multi-sited, person-centered trajectories into the past and future in relation to queerness. The past and future spacetimes Xane and Cai laminated were legitimate parts of the group's mathematical reasoning and youth's individual reflections about their queer positionalities and/or identities. Xane's sense-making about the statistic, and Lucas's estimation that followed, was entangled with a past spacetime in which he had engaged in homophobic actions. Cai's sense-making about the second statistic and ratio relationship was embedded in his future imagination of finding a partner. Additionally, the personal relevance of the statistics to Cai's imagined future became a resource for extending the whole-group mathematical investigation. In these ways the youth queered (Mendick, 2006) their mathematical reasoning through their knowledge and use of mathematical concepts and their past and future experiences.

These findings extend empirical and theoretical understandings of the interrelationships between identity and mathematics learning beyond practice-related conceptions by suggesting that mathematics content itself can be a context for identity work (Radke, 2021); that is, embedded in relationships, memories, and desires rather than abstract skill that is enacted identically across different settings. What made these findings possible was our deliberate attention to the non-mathematical aspects of participant conversation, such as Xane's comments about "feeling bad" and Cai's stray remarks about finding a partner. This intentional turn toward what is often categorized as background information, if it is attended to at all, was critical to our emerging understanding of mathematical meaning-making as situated, historical, relational, and affective. We accomplished this turn through a queer phenomenology, by facing the back to examine how it sustains learning (Ahmed, 2006). To make visible the intimate nature of all learning—here mathematical learning—we sought to queer our own orientation as researchers. A queer turn in research thus has the potential to paint more nuanced pictures of learning as intricately tangled up with memory, history, desire, and hope.

Significance

Equity-focused research has long argued for supporting students in recognizing mathematics as valuable to their own lives (Kilpatrick, et al., 2001), seeing themselves in the mathematics (Gutstein, 2007), and having their family/home knowledges valued in schooling spaces (González, et al. 2005). The findings of this paper move beyond explaining marginalized youths' struggles by illuminating how students' construction and use of mathematical knowledge was shaped by their social, personal, and political stories. Recognizing the personally relevant ways youth took up and reasoned about content as part of learning illuminated one way to move towards epistemological shifts in our understandings of math meaning-making, driven by change-making desires (Takeuchi, et al., 2020). Implications call for research and pedagogical efforts to center these past and future stories as productive, critical aspects of learning so that youths' queer orientations are seen as essential to advancing equity in mathematics teaching and learning. We must prioritize how youth make math content relevant to their lives in the moment and follow youth as they recruit experiences and knowledge across spacetimes to ask new questions, reflect on their pasts, and set future goals.

The various approaches that fall under queer theory are committed in their refusal of fixed identities and are invested in apprehending and disrupting the binaries that emerge in discourse (Mendick, 2014). This refusal feels especially relevant to the task of telling humanizing stories of mathematics education, where mathematical knowledge continues to be conceived of as objective, neutral, and fixed, although these ideas have seen a challenge in recent years (Gutiérrez, 2013; Martin, Gholson, & Leonard, 2010). In the episodes analyzed above, a queer research orientation surfaced the ways in which the same statistic drew different affective interpretations from participants, thereby disturbing the very premise of a singular mathematics. A statistic is never *objectively* large or small, it depends (for instance) on how it is recruited into personal relationships, memories, and hopes. A queer lens on research into mathematical learning emphasizes a relational view of the discipline so that what mathematics is becomes inseparable from who reached for it, how they reached for it, and with whom (Ahmed, 2006). Implicit in this view is a conception of mathematics as many things, as plural and not fixed (Gutiérrez, 2013). It positions us to retrieve the stories of learning we may have lost to the dangerous myth of an apolitical mathematics (Martin, Gholson, & Leonard, 2010).

Endnotes

(1) A note about language; we use the acronym LBGTQ to broadly refer to students who do not identify as heterosexual or cisgender. The acronym serves as a tool to synthesize the many different queer identities, and we also recognize that there are differences and fluidity among these identities.

(2) Lucas named the city where the study took place. The transcript has been amended to anonymize the data.

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Examining How Cognitively Guided Instruction (CGI) Professional Development Influences Struggling Students' Mathematical Problem Solving

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Abstract: When students solve complex mathematical problems by themselves, many will experience and encounter difficulties, struggles, and tensions. Existing research provides little guidance on how teachers might productively respond to students' various struggles. Using the video data from the second year of *Cognitively Guided Instruction* (CGI, a professional development program) and comparison classrooms, this study examines the effects of CGI on struggling students' problem solving and investigates the mediation effects of enacted instructional practices on students' problem solving. Struggling students in the CGI classroom had higher problem-solving scores than their counterparts in the comparison classrooms. The mediation analyses showed that the two instructional practices (for student agency support and for extending student thinking) had a positive and significant impact on struggling students' problem solving. While the other two instructional practices showed a negative and non-significant impact.

Keywords: Struggling students; problem-solving in mathematics; enacted instructional practices

Introduction

Primary grade students often make errors and get mired in struggles during problem-solving processes. Struggle in problem-solving has not always been seen positively. Some early researchers saw struggle as a sign that students had failed the mathematical tasks, and they perceived struggle as something that needed to be overcome and to be avoided (Brown & VanLehn, 1982; Radatz, 1980). Hiebert and Grouws (2007) argued that struggle does not mean that students are undergoing needless frustration or extreme levels of challenges caused by nonsensical or overly difficult problems; instead, they argued that certain kinds of struggle indicate that students are expending intellectual efforts to make sense of mathematics and to figure out something that is not immediately overt. Their interpretation of struggle reconfirmed the importance of struggle in mathematical problem solving; that is, the process of struggle is essential for constructing deep mathematical understanding. Moreover, students engaged in productive struggle with meaningful mathematics are experiencing math as more than procedures and correct answers (SanGiovanni et al., 2020).

The significance of struggle has been recognized since the time of Dewey, who dedicated much attention to the importance of struggle. Deep subject knowledge is "the fruit of the undertakings that transform a problematic situation into a resolved one" (Dewey, 1926, p. 242-243). In developing deep knowledge, students inevitably encounter "some perplexity, confusion, or doubt" (Dewey, 1910, p.12). Struggle provides instructional opportunities through which students can delve more deeply into the mathematical structure of problems and the relationships among multiple mathematical ideas and concepts (Baker et al., 2020; NCTM, 2014). Though the importance of struggle in problem solving has been investigated, the specifics of how teachers might more effectively respond to students' struggles and support students' productive mathematical learning remain less well understood. Even less is known about the kinds of professional development programs that could increase teachers' awareness of their students' struggles and help teachers capitalize on those struggles in their mathematical teaching.

This study is embedded in the CGI setting, a professional development (PD) program based on the research of students' mathematical thinking. Teachers who have taken the CGI PD use their students' thinking to inform and to guide their instruction (Carpenter et al., 1989; Carpenter et al., 1996). The purposes of this study are to look at the influence of CGI on struggling students' problem solving and to investigate paths and mechanisms for how interventions on teacher PD would promote students' engagement in problem-solving. By focusing on teachers' enacted instructional practices in classrooms, this study addresses the important and complex link between teacher learning from PD and students' learning outcomes. The guiding research questions were the following three:

1. What are the effects of the CGI on struggling students' problem-solving? To what extent are CGI's effects on struggling students' problem-solving moderated by students' gender, grade, and struggle levels?

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2. What mediation effects of CGI on struggling students' problem solving through teachers' interactional time and enacted instructional practices emerge after controlling students' gender, grade, and struggling levels?

3. How did the teacher-student interactions look like in the CGI classrooms, when teachers often used the enacted instructional practices but did not result well in students' problem solving?

Method

Data sources and participants

The teacher and student samples for the current study were extracted from a large random controlled trial (RCT) study that explored how CGI influenced teachers' beliefs and knowledge and further impacted students' mathematical learning (Schoen et al., 2017; 2020). Twenty-two elementary schools from two Florida school districts were randomly selected as the participating schools. Eleven schools were randomly assigned to receive CGI PD, and 11 schools provided their usual PD and served as the comparison schools. Over two years, volunteer teachers in the CGI schools participated in extensive CGI PD workshops. In the first year, 157 teachers from the CGI schools received a total of eight days of CGI workshops; and 171 teachers from the comparison schools followed the district's PD plans. In the second-year stage, 156 teachers were assigned to the CGI group and 172 teachers to the comparison group. This study targeted the year-2 sample in order to investigate teachers' support for struggling students who may have been more sophisticated in implementing CGI.

All 47 teachers in the year-2 sample were videotaped for one lesson based on teacher consent and students' parental permission. First-grade teachers accounted for 57.45%, and second-grade teachers accounted for 42.55%. All the teachers were females. White teachers across each condition accounted for 91.67% in the CGI condition vs. 91.30% in the comparison condition.

Data analysis

The use of video data has become widespread practice within education research studying teachers' behaviors or social interaction in classrooms (Knoblauch et al., 2006). In this study, video constituted the main data corpus; hence, the preliminary analysis step was to analyze classroom videos.

Identifying mathematical struggle

A mathematical struggle episode was coded when students showed difficulties, confusion, or uncertainty while they endeavored to solve a problem. Multiple signs and sources were used for identifying a mathematical struggle episode. A clear indicator is students' spoken words, such as "I do not know what to do", "It is so hard", "I do not know how to do the problem", or "I need help". Other sources included students' written work, gestures, facial expressions, body movements, long pauses, and modal particles.

The coding of struggle types followed the three categorizations from Warshauer (2014): Struggle to start, struggle to carry a process, and struggle to explain and sense-make. His fourth type of struggle (expression of misconceptions and errors) was not considered since it could occur at any of three previous stages, and sometimes, the misconceptions are the reasons for students' struggles. Thus, the categorizations of student struggles came from one of the following: (1) confused (consciously or unconsciously) about what the task is asking and did not know how to begin and initiate the task, which was coded as struggle to start (level 2), (2) encountered difficulty or impasse in carrying out a process, using an algorithm to do the computation, or transferring information among representations, which was coded as struggle to carry out a process (level 3), (3) unable to and/or had difficulty in justifying their work, explaining their solving processes, giving reasons for their choice of strategies or solutions, which is coded as struggle to express and explain (level 4). Level 1 of struggle is more than one type. The assigning of levels to struggle types is based on the closeness to the success of problem solving.

Developing codes of instructional practices

The development of a coding manual for teacher instructional practices for struggling students was a combination of deductive and inductive approaches (Guest et al., 2011). First, a prior coding scheme of teachers' instructional practices for mathematics struggles was developed based on a wide range of perspectives in the literature concerning teachers' pedagogical behaviors. Meanwhile, a grounded-theory method was adopted to identify all the other potential instructional practices that were not found in the literature. This inductive-deductive cycle allowed for building a more systematic and complete framework of teacher instructional practices for struggling students. In the end, four groups of instructional practices were identified (see Table 1). To establish inter-rater reliability of video coding, at least 17% of lessons were separately coded by three coders who have a background in and knowledge of CGI. The post-discussion interrater reliability for coding struggle types is 97%, and 90% for the coding of the instructional practices.

Table 1
The coding framework of teachers' instructional practices for struggling students

Dimensions of instructional practices	Sub codes
Supportive strategies that direct to resolve the struggles	1. Support the use of home language 2. Suggest the use of cubes, manipulatives, or other tools 3. Simulate problem situations through embodied actions 4. Remind students to use another strategy 5. Ask open-ended/close-ended questions as scaffolding 6. Give hints/cues
Encourage perseverance and/or agency	1. Tell students it is okay to make mistakes/stuck 2. Praise students' efforts or specific aspects of mathematics work 3. Encourage students to persevere on mathematics tasks 4. Allow students to use any strategies that they prefer 5. Ask students' opinions about the using strategies/solutions 6. Encourage them to think independently
Encourage learning through others	1. Remind struggling students to listen to how someone else solves the problem 2. Ask students to diagnose/resolve struggling students' errors or misconceptions 3. Invite other students' explanation or interpretation
Extending students' thinking	1. Pursues further clarification/elaboration/justification, 2. Ask students to write/revise the symbolic notations, 3. Connect strategies with mathematics concepts, 4. Connect/compare multiple strategies/representations, 5. Direct students to multiple strategies.

Scoring of students' problem-solving

The instrument for scoring students' problem-solving performance was based on Gojak's (2013) rubric. For adapting this rubric to assess students' problem-solving performance in a CGI learning environment, two new dimensions—representation and explanation/communication, were added. Those two aspects were also highlighted in other problem-solving rubrics, for instance, Lopez's (2008) holistic scales. The dimensions for scoring struggling students' problem solving include:

Task understanding assesses whether students show a complete understanding of the task and can use and translate all the important information in the task.

Use of strategies assesses whether students can generate an efficient and appropriate strategy by themselves and whether the using strategies would lead to a complete solution.

Mathematics accuracy assesses whether students execute the computations correctly and reach an accurate solution/answer. When computation was not required, the scoring focused exclusively on whether the student got an accurate solution/answer.

Representations assess whether students use models, drawings, tools, and/or symbols to represent the task, strategies, and/or solving processes.

Explanation and communication assess whether students can clearly and coherently use mathematics language and/or notations to explain their solving strategies, thinking process, and/or answers.

Inter-rater reliability for problem-solving scoring was checked. Seventeen percent of lessons were scored by three raters for each dimension. There was substantial agreement in all the scoring dimensions; Krippendorff's alpha value was greater than 0.75 across all dimensions (Krippendorff, 2004).

Analysis methods

Overall, this study takes a sequential explanatory mixed-methods approach (Creswell et al., 2003), with initial quantitative methods to examine the effects of CGI on students' problem solving, then followed by an explanatory qualitative method to further explain the previous quantitative results.

To answer RQ1, a series of linear regression models were run on students' problem-solving scores as the outcome after adjusting their grade, gender, and struggling levels. To address RQ2, a two-way mediated path analysis was conducted by using interactional time and the four types of instructional practices as the potential mediators. Interactional time is transformed from the length of the struggle episode, which is the amount of time

that teachers interact with the struggling students to help their problem solving. Path a_x was to investigate the CGI effects on the mediators, and path b_x was to investigate the direct effect of mediators on struggling students' problem-solving after adjusting for students' gender, grade, and struggle levels. The specific indirect effect of CGI on struggling students' performance through interactional time was $a_1 \times b_1$, whereas the specific indirect effect through four instructional practices was $a_2 \times b_2$, $a_3 \times b_3$, $a_4 \times b_4$, $a_5 \times b_5$, respectively. In RQ3, a macro and in-depth interactional analysis (Jordan & Henderson, 1995) was used to explore the teacher-student interaction during students' problem-solving struggles within the CGI classrooms. Interactions involving struggling students with low problem-solving scores but receiving a lot of the selected instructional practices were chosen for this analysis. The conversations between students and teachers, as well as their actions, gestures, body movement, and eye gaze, were transcribed. Talk turns, especially in the whole class setting, were coded to examine the teachers' attention distributions among the initial struggling students and their peers.

Results

RQ1: The effects of CGI on struggling students' problem-solving

The treated effect estimates from the two models (without and with controlling for other covariates, Table 2) both showed a positive, large, and statistically significant impact of CGI on struggling students' problem solving (β = 6.30, SE = 0.50, $p < .001$; β = 6.06, SE = 0.51, $p < .001$, respectively). In addition, struggle levels were positively and significantly associated with struggling students' problem solving (β = 0.63, SE = 0.27, p = .02), showing that students with higher levels of struggle had higher scores in problem-solving. With one level increase in students' struggle, their problem-solving scores would increase by 0.63 points. There are no grade differences (grade 1 vs. grade 2) or gender differences (female vs. male) in students' problem-solving performance.

Table 2
Model estimates for the treated effects of CGI on struggling students' problem-solving

	Main effect model (Baseline model)		Model controlling for other covariates	
	Estimate	*SE*	Estimate	*SE*
CGI	6.30	0.50***	6.06	0.51***
Grade2	--	--	0.54	0.52
Female	--	--	0.04	0.49
Struggle level	--	--	0.63	0.27*

Note: *** p <0.001, **p<0.01, *p<0.05, ~p<0.10 (marginally significant). The reference group for condition is the comparison group, grade 1 is the reference group for grade, male is the reference group for gender.

After estimating the main treatment effects, three moderator models were run separately to test whether the effects of CGI on struggling students' problem solving get differentiated by their grade, gender, and struggle levels (Table 3). However, no significant moderator effects were found based on the three tested moderators in this study. On the other hand, the treated CGI effects were repeatedly found across the three moderator models. It showed that even adding other moderators in the model, a robust and consistent effect of CGI on struggling students' problem solving was still found. The highest estimates were found in the grade moderator model with a coefficient of 6.22.

Table 3
Model estimates for three moderator (grade, gender, and struggle level) effects on struggling students' problem solving

Moderators	Estimate	*SE*
Grade moderator		
CGI	6.22	0.64***
CGI*Grade2	-0.44	1.05
Gender moderator		
CGI	5.93	0.69**
CGI*Female	0.29	1.00
Struggle level moderator		

CGI	4.53	1.56**
CGI*Struggle level	0.58	0.56

Note. *** p <0.001, **p<0.01, *p<0.05, ~p<0.10 (marginally significant).

RQ2: Mediation effects of CGI on struggling students' problem-solving

Since significant CGI effects were found on all four instructional practices, they were all used as mediators to probe the mediating effects of CGI on struggling students' problem-solving outcomes. As shown in Table 4, the direct effects of interactional time, instructional practices related to student agency support, practices related to extending student thinking are found to be statistically significant and positive on struggling students' problem solving (β = 0.009, SE = 0.004, p <. 05; β = 0.98, SE = 0.26, p <.001; β = 1.35, SE = 0.23, p < .001, respectively).

Table 4

Direct and indirect effect of CGI treatment on struggling students' problem solving

Mediators	Direct effects of mediators on outcomes (Paths b_x)				Indirect effects of CGI on outcomes (a_x * b_x)			
	Estimate	*SE*	95% *CI*		Estimate	*SE*	95% *CI*	
			Lower	Upper			Lower	Upper
Interactional time	0.009*	0.004	0.001	0.01	0.93*	0.44	0.09	1.86
Supportive strategies	-0.12	0.12	-0.38	0.12	-0.16	0.18	-0.58	0.15
Agency support	0.98***	0.26	0.50	1.56	0.70**	0.22	0.33	1.20
Learning through others	-0.36	0.26	-0.85	0.18	-0.15	0.11	-0.40	0.06
Extending thinking	1.35***	0.23	0.93	1.83	1.79***	0.33	1.19	2.47
CGI	2.91***	0.59	1.73	4.04				

Note. *** p <0.001, **p<0.01, *p<0.05, ~p<0.10 (marginally significant).

In the full mediation model, the PD effects of CGI on struggling students' problem solving were significantly mediated by teachers' interactional time with a positive indirect effect of 0.93 (SE = 0.44 p < .05). Among the four types of instructional practices, the treatment effects on struggling students' problem solving were only mediated by the instructional practices related to agency support and extending student thinking with positive and significant effects of 0.70 (SE = 0.22, p < .01) and of 1.79 (SE = 0.33, p < .001), respectively. The magnitude of estimated effects for extending student thinking, both direct and indirect, was larger than the estimates for the other mediators. However, the direct and indirect estimated effects for instructional practices related to supportive strategies and of learning through others were negative though not statistically significant.

In sum, the total effect of CGI on struggling students' problem solving, without taking any indirect effects into account, was statistically significant and positive, with an estimate of 6.19 (p <.001). After adding the indirect effects of mediators, the effects of CGI were still found to be statistically significant and positive with a smaller estimate (β = 2.91, SE = 0.59, p < .001).

These findings support the conclusion that providing teachers with CGI-based PD is an important lever for improving students' mathematical performance when they encounter problems that elicit struggles. The path by which these effects are felt to be through increased instructional time and implementation of some instructional practices (i.e., supporting students' agency development and extending student thinking), Some instructional practices, such as supportive strategies that directly resolve students' struggles and encouraging their learning through others, did not support students' problem solving. An in-depth analysis of teacher-student interaction was used to investigate what actually happened between teachers and students and to better interpret this result.

RQ3: Teacher-student interaction patterns

Due to the page limitation, we only presented the interactional analyses when teachers frequently encouraged struggling students to learn through others. This instructional practice often happens in a small group or whole class setting, urging struggling students to learn from other students' problem-solving demonstrations and sharing, discussion of alternative strategies, and mathematical explanations. By examining the talk-turn distribution among struggling students and other peers in a big group, we could know how teachers assign their attention to students. It was found that some teachers unequally distributed their attention to students in the whole-class interaction and marginalized the original struggling students from participation in class discussion. On the other hand, using this practice might have the benefits of creating a collaborative learning environment where all students have the chance to participate in the co-construction process of the struggling students' problem solving.

The danger of marginalizing students who are struggling

The case of Nicklaus was selected as his teacher (Lara) frequently invited others to resolve and discuss his problem solving. At five minutes of Nicklaus's struggling episode in a whole-class setting, Lara had implemented the practice of "encouraging students to learn through others" five times. Four students joined the whole class discussion. Table 5 summarizes the key participation metrics for all the students in this episode.

Table 5
Participation metrics by persons in the struggling episode for Nicklaus (the struggling student)

	Talk turn		Words spoken		Word per turn	By teacher's call		By students themselves	
Teacher (Lara)	35	44.30%	384	58.81%	10.97				
Nicklaus	11	13.92%	50	7.66%	4.55	10	90.9%	1	9.1%
Jian	10	12.66%	58	8.88%	5.80			10	100%
Nishan	10	12.66%	48	7.35%	4.80	3	30%	7	70%
Stena	7	8.86%	73	11.18%	10.43	2	28.57%	5	71.43%
Janiya	2	2.53%	26	3.98%	13.00	1	50%	1	50%
Class	4	5.06%	14	2.14%	3.50				
Total	79	100%	653	100%	8.27				

These metrics allow us to examine Nicklaus' participation distribution as compared to other students' contributions in resolving his mathematical struggle. Each student' s talk turn and the word spoken are presented. The teacher spoke the most, took the most talk turns, and spoke the most words. Nicklaus took a similar amount of talk turns (13.92%, 11 turns) as Jian (12.66%, 10 turns) and Nishan (12.66%, 10 turns); but he spoke fewer words (7.66%, 50 words) than Jian (8.88%, 58 words) and Stena (11.18%, 73 words). Nicklaus also had shorter talk turns (avg. 4.55 word/turn) than Jian (avg. 5.8 word/turn), Stena (avg. 10.43 word/turn), and Janiya (avg.13 word/turn). Nicklaus' spoken chances were mainly reflected in elaborating and clarifying his own problem-solving process and strategies. Most of the time, Nicklaus was called by the teacher (90.9%); he seldom volunteered to speak in the group. Jian is the most active student; He initiatively suggested alternative problem-solving strategies and consistently made comments on Nicklaus's work.

Co-construction of struggling students' problem-solving

By inviting other students into the conversation, a collaborative learning environment can be created where more students are involved in the co-discovery and co-constructive process of struggling students' problem solving. The previous case of Nicklaus was still presented to show how students join and navigate each other in struggling students' problem solving.

Nicklaus' teacher selected his work for discussion is because of the uniqueness of his problem-solving approach and strategies (using addition to do a subtraction problem and utilizing an open number line). Interestingly, his teacher did not directly point out Nicklaus' mistakes, but rather, she allowed other students to discover them. In the beginning, the teacher led Nishan (another student) to figure out the answer based on the number line model. "How are you going to figure out what goes here? Do not tell him", this open-probed question left enough space and time for him to think about it. Nishan's first response is very blurry ("he used 28 to add up"). The teacher followed up with a series of probing questions for Nishan' s elaboration on how to add the number together to get 28. Importantly, the teacher did not say any comment that the computation was wrong. Instead, she asked another student—Janiya—if there was an alternative way to add those numbers quickly. This task did not seem easy because many previous demonstrations had shown that 28 is the correct answer. Therefore, Janiya got the right answer by adding one by one, but at the same time, she was very uncertain about this solution and consistently changed it ("Wait, 14 plus 8 is 22. 22 plus 8 is 30…". "Wait, is 28 (deep sign), wait"). Janiya is the first student who realized something was wrong with Nicklaus' problem solving, but she was not that sure. Nicklaus's mistakes were then affirmed by another volunteer student—Jian ("He messed up. It is not 6"; "He missed something"). Instead of rushing to give correct or wrong feedback in this whole process, the teacher left students with enough time to find out by themselves.

Discussion

The debate regarding which instructional approaches (student-centered vs. teacher-led) are more effective for students' mathematical learning continues to be intense among educators and researchers. This study, using the data from CGI PD, indirectly sheds some light on that debate since it investigated teachers' instruction of students who were engaged in mathematics struggles within a problem solving and student-centered learning environment.

It is important to note that not all students from this study are struggling students in the sense that the term is generally understood in the literature. Some students in this study could have been high performing, but they were engaged in mathematics struggles involved in very specific problems that they found difficult.

Although this study did not compare the two types of instructional approaches, results showed that the instructional practices that were more student-centered learning, such as allowing students to use strategies that they preferred, encouraging students' independent thinking, and directing students to use multiple strategies, etc. were positively related to students' high performance in their problem solving. On the other hand, the instructional practices that were more on the side of teacher-explicit instruction, including suggesting alternative strategies, giving hints/cues, and suggesting representations and tools, did not support students' performance as they struggled with problems.

The findings discussed above have important implications for both the design of CGI professional development and classroom instruction. First, the findings of this study offer exciting news as well as some insightful suggestions for improving the CGI program. Results from this study suggested that participation in the CGI program did benefit engaging students in struggles. Those benefits include increased interactional time and teachers' use of practices that help students successfully solve the mathematical tasks, even though some of the practices are not the specific focus of the CGI workshops. This might suggest that CGI focusing on building a conceptual model of students' mathematics thinking has the potential for teachers to develop equitable practices in real classrooms. This indication was also confirmed by Moscardini's (2009; 2010; 2014) year attempts to transplant the CGI program to the Scottish context, especially for students with special needs (i.e., students with learning disabilities and low-performing students). His observation studies demonstrated that special-needs learners have the capacity to make sense of mathematics and show engagement in classroom learning activities if the teachers adopt a CGI-approach instruction. Second, the results from this study help teachers recognize that struggle is a valuable part of learning with understanding. Students' various struggles are not something that should be avoided; instead, they offer teachers instructional chances to engage students in productive mathematical learning (i.e., collective discussions of unresolved problems, devising alternative problem-solving strategies).

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Critical Biomaking: Socioscientific Issues as Contexts for Life Science Maker Education

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Advancements in life science education technologies have expanded contemporary perspectives on making—to now include biomaking where organisms can be altered to produce personalizable and useful products. These innovations have brought with them concerns about the consequences of material production, including impacts on society. It also raises questions about learning environment designs to support engagement with these issues in both life science and traditional maker contexts. In this exploratory study, we examine a group of six adult participant perspectives and artifacts in a biomaking workshop that uses socioscientific issues (SSIs) to frame learning. Our analysis suggests that biomaker activities provide a viable access point to engage complex SSIs. We also observed that participants took up making to solve personal and societal problems, they also critically posed problems about material production and its impact. We discuss how these implications might advance what we know about maker affordances in STEM teaching and learning.

Introduction

The maker movement has undoubtedly made significant inroads in science, technology, engineering, arts, and mathematics (STEAM) teaching and learning (Blikstein, 2018; Dougherty, 2012; Papavlasopoulou et al., 2017). This progress is reflected in the growing body of literature that examines making in relation to such areas as access, learning, and equity (Halverson & Sheridan, 2014; Russo et al., 2021). Despite progress maker perspectives have had on how the learning science community understands learning environments, processes, outcomes, and scales (Cohen et al., 2017; Peppler et al., 2016; Searle et al., 2019)—we know far less about how makers themselves contemplate and grapple with the accompanying social or cultural tensions that sometimes surround their productions (sometimes referred to as socioscientific issues or SSIs) (Zeidler, 2014). Examples include computer programs whose algorithms place end users at security risk, or maker products and practices that reify participation exclusion or stereotypes (Ames, 2018; Vossoughi et al., 2016). Thus, many of the SSI-based insights we have about making involve activities where objects are used to draw attention to social issues (e.g., the democratization of technology) rather than stances that highlight how objects themselves might create them (e.g., critical making) (Chou, 2018; Deibert, 2014; Greenberg et al., 2020; Lachney, 2017; Ratto, 2011). This raises questions about public awareness and literacy surrounding material production (Walker, 2021) and how, if at all, making attends to this educational priority. These concerns thus underscore an important need to examine how makers engage more critically with SSIs associated with production in the maker sphere.

A challenge in addressing this need is that most maker activities in education involve inanimate objects whose life cycle reaches an apparent stop once productions are no longer in use—and are out of sight and out of mind. This issue is reflected in learning science and education research where there are fewer perspectives on learning experience and design to support engagement with the complex social and cultural ramifications associated with maker productions or material artifacts long after they have been produced (Shaw et al., 2019). Synthetic biology—where organisms can be genetically modified for practical uses (e.g., art, food, sensing, etc.)—provides a unique frame within which to examine how makers contend with the relationship between their productions and society. This is, in part, because the lifespan of biological materials continues long after use—these material artifacts can proliferate into the environment.

To explore these issues, we use a biomaker themed workshop (Lui et al., 2019; Kafai et al., 2017; Kafai & Walker, 2020; Walker, et al., 2018) as a frame to investigate the ways a group of six adult participants grapple with the potential impacts synthetic biology products have on their local communities. Set in an informal learning environment located in a western borderland region of the United States, this exploratory research uses workshop artifacts and interview data to qualitatively examine what happens when biomaking is the access point for participants to critically consider SSIs associated with production. This study is guided by two research questions: (1) what do participants have to say about SSIs surrounding synthetic biology products and (2) what do workshop artifacts reveal about how participants view synthetic biology production and utility. We highlight two case examples drawn from our workshop and discuss the affordances and constraints biomaking has as a lens to critically engage SSIs associated with synthetic biology. We also address implications for other areas of making.

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Background

Maker education

While there are a number of conceptualizations for making—many of which are distinguished by context and practice—central characteristics of this movement include material construction, interest-driven pursuits, and social engagement as learners build, design and share their productions (Dougherty, 2012; Papavlasopoulou et al., 2017). Maker approaches to K-12 STEM education have illuminated important insights about the nature of material artifacts and their role of mediating important learning processes and outcomes (Ames, 2018; Valente & Blikstein, 2019). Research along this trajectory includes examination of the various affordances making has in promoting STEM learning and is especially prominent in engineering and computer science education (Peppler et al., 2016)—areas where many efforts have sought to address learning outcomes as well as persistent issues related to domain access and participation parity (Calabrese Barton & Tan, 2018). From using Lego blocks, wood cutters, and 3D printers to design and construct robots, to sewing conductive thread in LEDs and microcontrollers to fabricate electronic textiles, making has shown to be a promising context for designing and examining learning in STEM domains. This includes research on how making encourages and sustains learner interests, knowledge acquisition, skill development and mindset shifts (Chou, 2018; Lin et al., 2020).

A growing area of research has examined making beyond digital and computational areas of STEM and into life sciences (Kafai, et al., 2017; Lui et al., 2019; Viñas et al., 2020). Momentum in this area of STEM learning science and science education research is the result of enabling biotechnologies (e.g., bioengineering, synthetic biology, biodesign, etc.) that have recently made use of these tools less costly, portable and thus accessible for educational purposes. Examples include tools that enable the genetic modification of bacteria or yeast to produce fruit or wintergreen scents, vitamins, or color pigments for use in food products or art (Kuldell et al., 2015). Learning science research in this area has emphasized learning design affordances and constraints of this approach to K-12 life science education. There is also a growing corpus of literature that examines ways to support material construction consistent with maker perspectives (Lui et al., 2019) in this genre of making with life science often referred to as biomaking. Biomaking has now made it possible for non-expert audiences to participate in biology-based material productions not ordinarily found in nature. Synthetic biology is distinct from other forms of biotechnology in that it borrows perspectives from computing to frame cells as programmable units that can be designed to generate novel outcomes (Kuldell et al., 2015). This technology is responsible for next generation innovations in medicine, manufacturing, and agriculture. Biomaking extends this perspective by leveraging synthetic biology for teaching and emphasizing materials, rather than genes or DNA exclusively, where learners can make art, bake, or produce other materials of personal interest. These developments raise questions that far less research has addressed—about how learners consider or grapple with the impact production and objects have on the community and society overall. For instance, plastic consumption and computer programs are rife with thorny SSIs around who has access to maker products, where those products end up in their life cycle, and how those products (and especially in their digital form) manifest and shape the world around us—after all computer programs can take on a life of their own after reaching global networks where they can be modified by others. Biomaking, synthetic biology for maker-style teaching and learning, makes these issues more apparent due, in part, to the fact that biological materials require special handling to mitigate the potential impact they might have on society and the environment. Thus, biomaking provides a unique vantage point to begin examination of maker production in the context of teaching and learning, including around areas of how we might begin to support upfront and critical engagement with material production in STEM maker education and the accompanying SSIs associated with those objects.

Socioscientific issues

Socioscientific issues (SSIs) are controversial science topics that require complex considerations often grounded in cultural, ethical, and/or moral values (Zeidler, 2014). Examples include topics related to climate change and its impact on society and the planet, or the risks associated with digital technologies and privacy. In STEM education and research, SSIs are frequently used to support literacy practices such as data analysis, argumentation and decision-making where learners reason through the often complicated social and cultural issues associated with these topics (Presley et al., 2013). Significant research in the learning science and science education literature has revealed a number of affordances of using SSIs as a frame for teaching and learning STEM (Dauer & Forbes, 2016) including opportunities for learners to make meaningful connections between science topics and their everyday lives. This line of research is especially prominent in life science education, where burgeoning biotechnologies have, for decades, drawn attention for the ethical and moral dilemmas they present. Examples

include issues associated with consuming genetically modified food products, the implications of consuming genetically cloning livestock, the risks associated with gene therapies to treat inborn disease, or the use of HeLa human cell lines that were taken, grown, and exploited for science discovery (Leiden, 2000; Savadori et al., 2004; Skloot, 2017; Solter, 1998).

Despite the influence maker education has had in STEM education, there is a dearth in the literature on topics at the intersection of making and SSIs (Shaw et al., 2019)—this is despite the fact that scholars have mostly examined related topics like how learners use digital productions to critique or disrupt complex and often thorny social and cultural issues related to STEAM and its impact on society. This gap in the literature also exists at the intersection of SSIs, making and the life sciences. This is due in part to the fact that the latter two areas—making in life science—have only recently been possible. Areas like biomaking therefore present a whole new wave of SSIs, and accompanying public attitudes (Walker, 2021), where material production and considerations span beyond scaled medical and agricultural applications, and into an era where genetic modification has proliferated locally. These developments create an early opportunity to examine life science maker learning in relation to socioscientific issues in a shift from discussing largely hypothetical scenarios or biotechnologies that have existed for decades, toward engagements that involve actual material products with real world implications. This research seeks to examine this context in order to shed early light on how biomaking affords, constrains, or extends what we know about SSIs in the context of production in life science education.

Methods

Context

This study took place as a workshop in a fabrication lab (FabLab), a not-for-profit organization that provides community access to fabrication tools and used for skill development, workforce training, creative collaboration, prototype development, and product manufacturing. The site is located in the western region of the United States near the Mexican border. The study consisted of a workshop that incorporated synthetic biology lab activities. The workshop ocurred over a period of five days for about four to six hours each day. The workshop included tasks: cell-line genetic modifications, design application prototyping, socioscientific issue discussions, and speculative design presentations (shown left to right in Figure 1a-d). These tasks are summarized in the next section.

Figure 1a-d. Biomaker Workshop Tasks in Genetics, Design Application, Discussion, and Presentation. (left to right) Participants: (a) Genetically modifying E. *coli* bacteria to produce color pigments, green, purple. (b) Use their genetically modified bacterial cells to make bioart designs. (c) Use case studies to discuss the impact of microbial-based synthetic biology applications on the environment. (d) Participants present on synthetic biology-based applications to manufacture solutions for flash floods.

Workshop design, participants, and data sources

The BioMaker workshop was structured along four main tasks. Participants, first, carried out genetic modifications (shown in Figure 1a) developed by the BioBuilder Educational Foundation (BioBuilder Educational Foundation, 2021). In this process participants produced bacteria that emitted wintergreen or banana smells, green, purple, and black pigments, as well as vitamin A. The second task (shown in Figure 1b) involved design prototyping where participants used genetically modified cell lines in a design application of their own designed applications for their synthetic biology lab products. This included such applications as making bioart and baked products infused with yeast they genetically modified. The third task (shown in Figure 1c) involved a series of SSI-based case study discussions about biomaker and synthetic biology-based applications and the impact those applications could have on society and the planet. Here participants had the opportunity in a think-pair-share

format to develop and express their opinions about biomaking used to genetically modify organisms (as they had done). In the last task (shown in Figure 1d), participants put together and presented speculative applications for future biomaker projects. In these presentations, they highlighted the benefits and potential harms of using biomaker projects in the community.

The biomaker workshop included six participants (ages ranging from 25-52)—four of whom self-identified as female and two of whom did as men. All self-identified as Latinx. Participants ranged in professional background that included a: high-school biotechnology teacher, homeschool teacher-mom, trained professional designer, elementary grade teacher, a Fab-Lab employee and adjunct social science instructor, and a mechanical engineer. While participants had diverse reasons for taking up the workshop, they all coalesced around a desire to learn and access Fab Lab activities, which offer ways for adults to do so informally and affordably.

Primary study data sources were workshop artifacts including: worksheets participants completed during SSI-based case study discussion (see Figure 1c) and presentation slides (see Figure 1d) participants used to present their own biomaker speculative design application. Secondary data sources included semi-structured interviews (conducted by authors two, three and four) and surveys (administered using an online survey instrument) where participants shared their opinions about biomaking and genetic modification in general. These secondary data sources were used to corroborate insights gleaned from workshop artifacts.

Analysis

Data sources were analyzed using a qualitative approach. First, workshop artifacts (e.g., worksheets and presentation slides) were digitally scanned and/or uploaded to an encrypted electronic cloud drive shared by authors. Workshop artifacts were then analyzed and coded by two researchers (authors two and three) using an inductive approach (Ravitch & Carl, 2019) wherein researchers identified themes related to what participants wrote about real world biomaker or synthetic biology-based products. In this process, authors two and three identified code categories (e.g., application type, context, and consideration type) based on what participants wrote in response to prompts about biomaking in relation to its impact on themselves, their community, and/or the planet as a whole. Those codes were discussed and developed iteratively in collaboration with authors one and four. A final codebook was then developed and applied to artifacts independently a second time by authors two and three. Code application disagreements were discussed and deliberated with all authors until 100% consensus was reached. Authors two and three then generated frequency charts and pie graphs (not shown in this paper) to visualize data and patterns. Those observations were then used to develop illustrative case study accounts. Interview data were used as secondary sources to triangulate ideas represented in workshop artifacts. This included participant comments about biomaking and its myriad uses.

Findings

Biomaking provides entry point for SSI discussions about production in life science

When analyzing written responses during biomaker SSI workshop activities, we observed that participants collectively considered a wide range of factors in relation to synthetic biology-based products and the potential impact they could have in society. Those considerations varied across application type (e.g., which organism to which synthetic biology was being applied), context (e.g., the purpose of the synthetic biology product), and values (e.g., moral/ethical consideration, risk/benefit assessments, etc.). We present two case examples of written perspectives to illustrate what participants had to say about these applications—including what they expressed about the various tensions associated with synthetic biology and the myriad impacts their products pose to the environment and society as a whole.

Alexis Padilla, a department chair in the biology department in a local high school, and Alejandra Garcia, a fashion designer trained at a school of design in a city located in the northeastern region of the United States, both joined the biomaker workshop for professional reasons. Alex had an interest in finding ways to innovate and expand curricular offerings at the school where she teaches. Having had significant training in fashion on the use of novel and biologically-produced textiles, Alejandra joined the workshop in hopes to continue, at a low cost, her explorations and experiences with materials. After reading an advertisement for the biomaker workshop in an email distribution list associated with the local Fab Lab—both registered as a way to support these personal goals. During the workshop, there were opportunities to learn and carry out synthetic biology, which involved genetically modifying cells and then using them in maker-like ways such as to design, personalize and fabricate products (e.g., baked products and bioart). In between these activities participants had opportunities to reflect and discuss their thoughts about synthetic biology overall through case studies and prompts provided by a worksheet. When presented with applications involving the use of synthetic biology in plants (to produce vitamin infused rice for

human consumption) or microbial (to spider silk for shoes) applications, both participants had a lot to write about regarding the issues these applications raise (shown in Figures 2a-d.). Alexis addresses (Figure 2a.) the potential social and environmental impacts these areas of production could have as she wrote, "of course if it works to the positive, the individual is fine as is society, but if it goes bad, the risk has a trickle-down effect. These researchers need to think long term not if it can be done" (Think-Pair-Share Argumentation Worksheet, Workshop Day 1). In another instance, Alexis weighed such concerns as the consequences that could result if an application is not used, and in relation to the potential risk to an individual person as she explained, "If I have limited or no access to fresh food, I probably don't have access to health care so something that cannot only provide nutrient but [also] create health benefit as well would be something I could use" (Think-Pair-Share Argumentation Worksheet, Workshop Day 3). These instances reflect how, for Alex, production using these biotechnologies creates competing perspectives and potential consequences, in broad terms for the environment all the way down to single individuals. In addition to environmental factors, Alejandra grappled (Figure 2c) with additional factors as she described, "it's a privilege to be healthy in this highly industrial world so if we can create a democratic solution to provide healthy options for everyone we should" (Think-Pair-Share Argumentation Worksheet, Workshop 3). Alejandra grounds her viewpoint around a geopolitical landscape—taking a stance beyond her personal benefit and in relation to society overall. Alejandra, like others, took similar positions about children who "can't make [decisions] themselves" and other species that "have been on this planet" and whose "disappearance could cost our eco-system" (Think-Pair-Share Argumentation Worksheet, Workshop 3). Participant considerations (shown in Figure 2a-d.) were expansive as they contemplated the impact these life science productions could have at the intersection of SSIs with consequential implications (e.g., personal, environmental, socioeconomic, geopolitical, etc.).

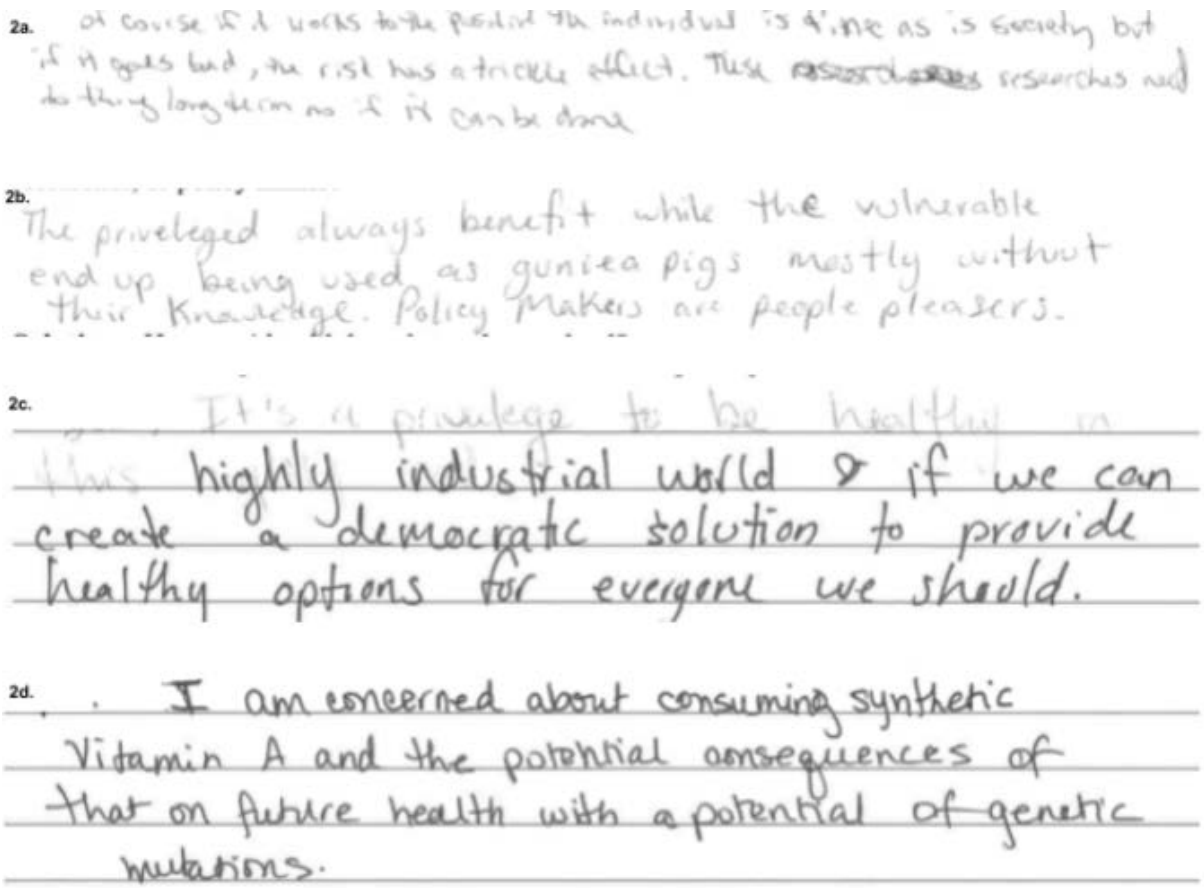

Figure 2a-d. Biomaker Participants Consider a Variety of SSIs Regarding Synthetic Biology.

Participants use biomaker projects to address personal and social issues

Examination of participant biomaker presentations involved synthetic biology applications that cut across a variety of personal and social issues related to interests (e.g, making products for pets), community infrastructure (e.g., creating ways to mitigate monsoon-driven floods), and the environment (e.g., undoing harm to endangered

wildlife). We present projects from case examples to illustrate participant views about synthetic biology utility in relation to themselves and their community. Alexis Padilla presented about how synthetic biology could be used to fabricate synthetic and animal friendly essential oils scents that could be used for household pet cats. Alexis argued that cats have important personal and household value (e.g., rodent control, companionship, longevity, etc.) that could be enhanced through the use of calming essential oils. She went on to point out that these products pose harm risks because they contain an ingredient (e.g., glucuronidation protein) that is not metabolized by cats, leaving them "vulnerable to organ failure" (Final Presentation, slide 3, Workshop Day 5). Alex speculated that synthetic biology could be used to synthesize essential oils without the protein deleterious to cats. During the workshop, Alexis shared her fondness for cats and expressed how she cared for her own—pets that meant a lot to her personally. Taken together, this evidence showed that to Alexis synthetic biology could be used as a tool to address an issue endemic to household feline pets. In a different instance, Alejandra considered using synthetic biology in a markedly different way—raising concerns about the environmental impact of the U.S./Mexico border wall on native species in the region. She argued that the binational barrier was primarily a "human problem" that "threatens the lives of over 90 endangered species" in the region (Final Presentation, slide 2, Workshop Day 5) shown in Figure 3a-c below. Alexis speculated the possibility of using synthetic biology approaches to isolate a gene found in a steel metabolizing bacteria (*H. Titanicae*) discovered on the sunken Titanic that could then be inserted in a native Ocotillo plant species (*F. splendens*) native to the Chihuahuan desert region. She argued that this plant, with its barbed branches, would create a structurally feasible human barrier that over time—using *H. Titanicae*-derived metabolic processes—decomposes the existing border wall while simultaneously allowing native species to pass unobstructedly throughout the region. In conversation with Alejandra we learned that her idea was consistent with her ideological concerns about the border wall in addition to concerns for the environment.

Figure 3a-c. Participant Biomaker Project Uses Synthetic Biology to Problematize Local SSIs
(left to right) Participant: (a) Presents a case example and background research of how the border wall in a binational region has an impact on endangered species, (b) Identifies microbes and native plants that would be suitable starting points for using synthetic biology to solve border wall ecological impact (c), Provides explanation for how steel metabolism would word in decomposing the existing border wall.

Implications

Socioscientific issues and maker education

Maker education, with its paradigmatically distinct focus on design and material production has had an undeniable impact on active approaches to STEM education and research. In this study we build on traditions that engage making to draw attention to social issues in participation (Greenberg et al., 2018; Searle, Tofel-Grehl, & Breitenstein, 2019), learning (Russo et al., 2021), and practice (Vossoughi, Hooper, & Escude, 2016) by also examining maker activities that address social issues that are the result of material production. Our biomaker activities, framed in the context of SSIs, revealed that biomaking—powered and enabled by biotechnologies like synthetic biology—is rife with complex issues that include both discipline-specific considerations (e.g., those related specifically to life science and its impact) and those that span across fields (e.g., those connected moral values or ideological orientations). This is reflected in the well-developed opinions participants had about synthetic biology and its various uses. We also observed in our workshop that these opinions reflect sentiments typical of SSI views about biotechnology (Solter, 1998; Savadori et al., 2004; Leiden, 2000; Shaw, Walker & Kafai, 2019), and included a myriad other considerations (e.g., personal, societal, socioeconomic, geopolitical, etc.). We consider this a reflection of the fact that the synthetic biology field brings with it a whole new set of possibilities (e.g., manufacturing pigments, food ingredients, etc.) that expand the corpus of SSI cases to engage.

This could also be because maker perspectives often involve broadly encompassing and interdisciplinary fields and practices that connect well with a variety of issues. These connecting points also highlight the affordances making has as a context to have productive discussions around production and SSIs topics that have been shown to be successful in promoting STEM literacy (Presley et al., 2013). Future research along this trajectory might consider how making with electronics and computational artifacts might also extend traditions (Zeidler, 2014) about how learners critically discuss, argue, and develop literacies around SSIs in innovation and production.

Critical biomaking: A context to solve and pose problems

Our examination of final presentations suggests that participants fundamentally viewed synthetic biology utility in two ways—as a tool to either solve or pose problems. Alejandra's presentation, distinct from Alexis who pursued a personal interest, showed a synthetic biology application designed and used as a provocation—around a complex geopolitical landscape rife with socioscientific implications. Rather than the typical frame of being a service *to* the community, both cases framed synthetic biology's utility as an instrument in service *of* the community, its interests, and politics. This critical biomaking approach is consistent with views in critical making (Deiber, 2014; Vossoughi, Hooper & Escudé, 2016) where participation enables both problem solving and the problematizations of practice. In a genre of making that continues to flourish as a field and method for enhancing STEM education, future research should examine critical biomaker focused learning designs that might be leveraged to support learning outcomes and reevaluate perspectives about making and its utility in the practice of modern science teaching and learning.

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Translanguaging as a Tool to (Re)Connect: Co-designing Land-Based Learning Environments with Refugee Children

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Abstract: For many racialized and linguistically minoritized refugee youth and children, schooling can be experienced as a space of being assimilated into the dominant norms including the detachment from their home languages and community practices. In this paper, we examine how the participating school-aged refugee youth and children in our co-designed land-based program, Soil Camp have contributed to co-creating spaces to challenge dominant norms imposed upon them, together with facilitators (who were mostly racialized multilingual teachers). Our paper is centered around the question: How did the participants co-construct agency to shift away from dominant monolingual norms in their interactions during the land-based Soil Camp? Based on video-based interaction analyses, our findings illustrate how the co-constructed translanguaging interactions contributed to redefining geopolitics surrounding the participating refugee youth in moment-to-moment interactions. Our findings also show how translanguaging interactions can extend to creating connections between more-than-human lives and these youth and children.

Introduction

During the COVID-19 pandemic, community gardens and urban farms served as one of the few places people could safely gather and socialize, yet access to green space has not been equally distributed. In collaboration with community partners, we tried to address this inequity through the co-designed land-based learning pedagogy, *Soil Camp* (Takeuchi et al, 2021). With many Yazidi and Syrian refugees coming from agricultural backgrounds (Takeuchi et al., 2021), Soil Camp can help refugee children learn about the soil, plants, and animals along with key concepts in Science, Technology, Engineering and Mathematics (STEM), while being part of community and reconnecting with their family members' wisdom on sustainable farming. Our co-designed pedagogy respect and learn from land stewardship and land-based embodied knowledge of Indigenous communities (Simpson, 2014; Marin & Bang, 2018). We acknowledge the colonial history of lands and aim to work with Indigenous communities toward the revitalization of Indigenous food systems and knowledge of food and environment.

Through our community-based research, we worked closely with refugee children, youth, and families who experience oppressions of racism, classism, and gender-based violence as well as trauma from war and genocide. Within the last 10 years, Canada has had 302,890 persons making claims for refugee status (Government of Canada, n.d.). For many racialized and linguistically minoritized refugee youth and children, schooling can be often experienced as a space of being assimilated into the dominant norms including the detachment from their home languages and community practices. In this paper, we examine how the participating children were co-creating spaces to challenge dominant norms imposed upon them, together with facilitators (who were mostly racialized multilinguals). Our paper is centered around the question: How did the participants co-construct agency to shift away from dominant monolingual norms in their interactions during the land-based learning program?

Theoretical Framework

Learning happens as people move across multiple contexts and borders that bring forth the heterogeneous histories and power relations (Vossoughi & Gutiérrez, 2014). In the midst of movement and as learners imagine new mobilities in the places salient to them, learners actively make places, reconnect with lost relationships, and build new relationships (Marin et al., 2020). Engaging with the land and places for Indigenous communities is an act of resurgence where Indigenous youth reconnect with their ancestors' relationship to the land and Indigenous ways of knowing the land (Marin & Bang, 2018). Considering many Yazidi refugees who participated in Soil Camp are considered Indigenous in their countries of origin, reconnecting with the land is the act of *presencing* (Nxumalo, 2019) their intergenerational wisdoms in the predominantly white farmland landscape. Focusing on the gathering power of places, we pay attention to resistance, agency, and transformation in the everyday acts of Othered bodies by making their presence visible through occupying, gathering, and renewing the place (Takeuchi & Aquino Ishihara, 2021).

Learning is never politically neutral and reflexive of societal hierarchy and imperialism (Philip & Sengupta, 2021). Our design centered hybridity in the third space (Gutiérrez et al., 1999) by de-normalizing

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English imperialism and monolingualism in pedagogical spaces. In light of the criticality and activism that teachers of color have pushed forward (Pham & Philip, 2021; Strong et al., 2016), we highlight interactional co-construction of linguistic fluidity and anti-colonialism in relational spaces situated on the land. Central to our analysis is the notion of translanguaging. García and Wei's (2014) definition of translanguaging is an extension of the term coined by Cen Williams in their work on the pedagogical approach of bilingual language use in receptive and productive literacy contexts. The term translanguaging has evolved to encompass the fluid and dynamic practices of bilingual individuals' language use (García & Wei, 2014). Translanguaging challenges colonial monolinguistic norms and dominant deficit discourses on language minoritized individuals and communities by recentering the speaker and their unique lived bilingual language experience and repertoire (García et al., 2017; Suárez, 2020). By challenging the monolingual norms, we are also challenging the colonial matrix of power imposed by English imperialism (Takeuchi, 2021). Translanguaging also refers to the pedagogical approaches employed for leveraging such language use and practices (García et al., 2017). These pedagogical approaches allow for the streamlining and designing of learning environments that are reflective of the "actual languaging practices" of students and their lived experiences (García et al., 2017, p. 2). Additionally, this noted tool positions the bilingual identities and the individual's unitary linguistic system as working in conjunction with their lived experience for learning and knowledge sharing. The term, translanguaging stance, as described by García et al., (2017) refers to "the belief that bilingual students' different language practices need to be leveraged together and performed collaboratively with others" (p. 184). The *translanguaging stance* allows for the employment of features of language that best foster understanding and connection. The notion of translanguaging shifts away from the traditional bilingualism conceptualization of language, which sees languages as independent named autonomous systems that one employs as deemed appropriate by dominant listeners in the contextual climate (García & Wei, 2014). This limiting perspective demobilizes the rich unified linguistic resources that language minoritized individuals and communities hold and the potential for the co-creation of "new social realities" (García & Leiva, 2014, p. 204).

Extending this definition, we propose the reframing and extension of translanguaging as a pedagogical tool for (re)connection with each other, intergenerational knowledge, and more-than-humans. Thus far, the conceptualization of translanguaging has been anthropocentric, focusing on human communications. Marin (2020) reminds us that those who research STEM education should develop systems of analysis and ways of seeing and listening that allow us to "re-member (Grande & McCarty, 2018; Wa Thiong'o, 2009 as cited in Marin, 2020) relationships between land, humans, and more-than-human relatives" (p. 31). As children engage closely with more-than-human lives on lands (Marin & Bang, 2018), they could engage in translanguaging practices that go beyond human-to-human communications. In this paper, we aim to explore the possibility of extending the notion of translanguaging to include our communications with more-than-humans. This theoretical push is particularly important considering the influx of displaced refugee families who embody agricultural experiences being stripped from their generation connection to more-than-humans in the resettlement process.

Methodology

We draw from participatory social design research methodology (Gutiérrez & Jurow, 2016) that centers historicity, diversity, equity, and ecological resilience as design principles and aims to co-design just practices and futures in partnership with a range of communities. We are also guided by Indigenous ways of knowing and decolonizing methodology that acknowledge colonial relationships reinforced by research and honour and carefully listen to the voices of Indigenous people (Smith, 2001; Marin, 2020). Our co-design aims to foster collective actions for food justice and environmental restoration through Soil Camp (as discussed in Takeuchi et al., 2021). This co-design process started in January 2021 and our collaboration is ongoing.

In total, 65 youth and children (aged from 5 years old to 15 years old) and over 20 families joined our program in 2021. All attendees were refugees from Syria, Northern Iraq, Kurdistan, New Guinea, Pakistan, South Sudan, Ethiopia, and Eritrea who had resettled in Canada within the last five years. Thirteen teachers and teacher candidates (who are mainly racialized multilinguals) joined as facilitators of Soil Camp.

Data

A team of researchers collected the following datasets from two weeks of Soil Camp in July 2021: 1) video data collected using three different cameras (Go-Pro cameras worn by both the participants and by the researchers, Handycam video cameras held by the researchers, and still cameras with video functions taken by both the participants and the researchers). A total of 31.43 hours of video data was collected and analyzed by the team. In addition, each member of the research team has taken fieldnotes right after each activity. On-site interviews with the participants were conducted to elicit the participants' backgrounds in farming, their sensory experiences on the land (what they see, feel, smell, and hear), and their developing sense of soil and the land.

Analysis

We draw from critical and decolonial interaction analysis (Philip & Gupta, 2020; Marin, 2020) to bring forth the interactional phenomenon of translanguaging. As we analyzed the interactions, we closely attended to the power dynamics surrounding the participants, colonial histories (between humans and between humans and non-humans), and linguistic norms reproduced or challenged in particular interactions. As a first step, we content logged all the video data and revisited our fieldnotes. From there, we coded segments of data where the participants were bringing in non-dominant (and often censored) languages in institutionalized schooling spaces. We transcribed key segments of data as compelling enactment of translanguaging initiated by the participating youth and children.

Sophia Thraya (Author 1) is a current graduate student and a trained and certified teacher in Alberta, specializing in Elementary English as an Additional Language education. I (Thraya) am a second-generation Canadian of the Lebanese diaspora and self-identifies as bilingual, holding both English and Arabic in her linguistic repertoire and dear to her heart. To the field of the learning sciences, I bring in prior research experiences and engagement in sociology with both the resettled Syrian and Yazidi populations centering on the lived educational experiences of school-aged Yazidi refugee children. During the planning stages, I was an active collaborator and held the roles of program facilitator and researcher during the Soil Camp. My associations and position with and within the community(s) have shaped the ways in which she has approached her research, community engagement, and educational practice. I draw from these lived experiences as a guide for analysis. Collective viewing of data and collective analysis were followed to bring multiple voices into video data analysis.

Findings

In this paper, we highlight two episodes that depict themes that emerged from our analyses: co-creation of translanguaging interactions toward a renegotiation of relationships with each other and with more-than-human lives. As seen in these episodes, the participants collectively challenged the dominant discourses in education through the shift away from deficit casting gazes on linguistically minoritized learners. These episodes present evident inward listener reflection and co-created reenvisioning of the resettled refugee youth and children's linguistic and educational potential. Overlapping themes of both episodes include the active presence of racialized bilingual facilitators who modelled the strength in multilingual identities and language use. These facilitators followed the dynamic flow of participant connections, curiosity, and agentic understanding through translanguaging, which in turn allowed them to contribute to the co-construction of a hybrid third space (Gutiérrez et al., 1999). These episodes also exhibit the rich relationships fostered through the tool of translanguaging and the translanguaging stance between anti-colonial land-based pedagogy, participants, and more-than-humans.

Episode 1: Walking together and fostering relationships through a translanguaging stance

Figure 1

Facilitators and Children Walking Together

This segment of interaction begins during a transitional period where participants were moving from an activity in the plot area to the tipi that was built by a local Indigenous community. The tipi was situated roughly one hundred meters away at the start of this interaction. The group of participants independently walked across the land and during this time an interaction between Sophia (Author 1 and a teacher facilitator) and a girl-identified Yazidi participant, referred to as Viyan (pseudonym), was recorded on a wearable Go-Pro camera. This participant had previously been observed to be quite reserved and quiet in whole group settings. When Sophia approached her, she was walking alongside a same-aged peer with whom she developed a close bond. Sophia began the interaction by asking the girls whether they were going to come to see the tipi—due to the flexible design of programming that honored participants' choice, they had the agency and autonomy to choose whether to join. Both girls responded with a nodding motion showing that they were coming and joining the teaching inside the

tipi. Their use of physical response rather than verbal was in fact not "abnormal." Rather than continuing to walk and leaving the girls, Thraya chose to continue the interaction and walk alongside the girls. It became apparent that without such an effort for connection on Sophia's end, this could have been the end of this engagement. Thraya followed up with additional questions and Viyan began to engage in conversation with Thraya, employing her linguistic repertoire—Kurdish, English, gestures, and movement—as she saw fit.

After approximately one minute of personal interaction and conversation, Viyan asked Sophia a question that was quite pivotal in the conversation (see Table 1).

Table 1
Episode 1 Interaction 1

1	11:05:54-9	Viyan	You speak Kurdish and Arabic (posed as a question but intonation indicated statement).
2	11:05:56-4	Sophia	I can speak some Arabic, yeah ↑!
3	11:05:57-1	Sophia	I would love to learn Kurdish though.
4	11:05:59-6	Viyan	I speak little bit of English and Kurdish.

Above, there is a clear and observable foraging of connection (see Table 1). Viyan is communicating and showing Sophia the parallel between Sophia and herself, as she has "some" Arabic in her linguistic repertoire and Viyan has "a little bit of English" within her own. The evident use of quantifiers can be due to the ideal of "linguistic perfection" imposed by the dominant society and monolingual normativity. Within the translanguaging framework, such semantic micro politics (as seen in the case of such quantifiers in utterances 2 and 4) cease. Policing of language proficiency and mastery sentiments relating to national language agendas were not present in this interaction. Rather, experiences with and within the bilingual communities of each were validated in the above excerpt; regardless of being deemed fluent within them.

Viyan observed Sophia communicate in earlier interactions with Arabic-speaking peers. Knowing that Sophia holds a bilingual/multilingual identity, Viyan spoke up and asked Sophia what features and modes of language she uses. Viyan, without prompting, shared her own language identity. Sophia then proceeded to acknowledge the value in her repertoire and how she would love to learn Kurdish (see Table 2). She then shared with Sophia some features including the phrase 'how are you' (Chawa yee) and 'good' (ez bashem).

Table 2
Episode 1 Interaction 2

1	11:06:04-1	Sophia	That is awesome!
2	11:06:07-8	Sophia	I would love to learn some Kurdish; would you like to teach me some Kurdish?
3	11:06:13-7	Viyan	Yeah, like if someone says Chawa yee, you say Ez bashem
4	11:06:17-9	Sophia	[Chawa yee, yes, ez bashem]
5	11:06:20-2	Sophia	Is that hello ↑?
6	11:06:21-7	Viyan	Yeah, it says how are you, you say good.
7	11:06:21-7	Sophia	Ez bashem is good, okay. So, to say how are you, I say?
8	11:06:38-0	Viyan	Chawa yee.
9	11:06:43-3	Sophia	Perfect, I am going to practice!

The connection made between Sophia and Viyan is one that was built upon the shared sense of commonality regardless of the modes of language in their individual unitary repertoire. Both acknowledged and celebrated the rich value of holding bilingual identities and confidently employed their linguistic resources as they felt comfortable. Sophia and Viyan together transformed the space from one of silencing to one of rich connection—and co-constructed interactions that affirm translanguaging space to validate each other's full repertoires of language practices. This interaction ended with smiles and the emergence of a non-hierarchical teacher-student relationship stemming from their shared language experiences.

Episode 2: Cocreating the multilingual ecology—translanguaging through music with one another and more-than-humans

Figure 4

Children Listening to the Voice of the Lemon Plant

Episode 2 showcases a whole group interaction during an activity titled Listening to the Voice of Plants. This activity was led by Anita, another multilingual and racialized preservice teacher, and one of the community partners. This group comprised of multilingual participants from Kurmanji (a dialect of Kurdish), Arabic, and French-speaking communities. A majority of these participants were Yazidi children. This activity involved introducing an instrument to the children that converted plant biorhythms to synthesized musical notes. Electrodes were placed on the leaves of a lemon plant and the device began translating the electromagnetic waves from the leaves into musical notes. The children were quite astonished by this, many vocalized their learning, identifying patterns, emotional expression, and potential meaning behind the music. Many were curious as to how this technology could allow us (humans) to hear what the plant was vocalizing. After the explanations on the mechanisms behind this technology and plant systems, Anita introduced the next segment of the activity—interacting with the plant by singing to it.

Figure 5

The Group Singing to the Plant

Anita began this part of the activity by drawing on the children's knowledge of songs. One child suggested Twinkle Twinkle Little Star and Anita counted them in, and the group began singing. Once they finished the song, they all listened to the plant's response. Anita then asked the children if there was any difference in the sound of the music after they sang to it and they collectively agreed that there was a noticeable change. Following this, many disciplinary questions arose related to plant communication and cognition. This episode shows multilingual children's connection and communication that transcended language borders and boundaries between species. Anita then led them to sing another song, this time a child suggested another children's song Baa Baa Black Sheep in English. This song was a little more challenging as some of the participants were not familiar with the lyrics. The plant sounded quite somber, and this is when Anita asked the children if they could sing a song from their language communities (see Table 3).

Table 3

Episode 2 Interaction 1

1	00:14:40-1	Laylan (Yazidi Participant)	I speak Kurdish, almost everyone [here] speaks Kurdish

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2	00:14:45-8	Anita	Do you guys know any Kurdish songs?
3	00:14:59-1	Laylan	سنة حلوة /begins singing Happy Birthday in Arabic to the plant/
4	00:15:03-9	Nali (Yazidi Participant)	/Joins in/ That's Arabic!!
5	00:15:05-4	Mahmoud (Arabic-speaking youth volunteer)	That's Happy Birthday!
6	00:15:07-6	Laylan	But I wanna sing Happy Birthday so bad. سنة حلوة يا جميل /Continues to sing Happy Birthday in Arabic again/
7	00:15:14-8	Anita	Okay, let's sing Happy Birthday. Do you guys know how to sing Happy Birthday [in Arabic]?
8	00:15:17-1	Laylan	[He can sing with me] /pointing at Mahmoud/
9	00:15:18-5	Anita	In Arabic?
10	00:15:18-5	Salima (Arabic-speaking participant)	Yeah!
11	00:15:18-8	Mahmoud	Okay, سنة حلوة يا جميل سنة حلوة يا جميلسنة حلوةسنة حلوة سنة حلوة يا جميل /All join in/
12	00:15:31-5		Note: *All Yazidi participants, Arabic speaking participants, half of the youth leaders as well as Anita joined in and began singing Happy Birthday in Arabic.*
13	00:15:37-2	Laylan	Happy Birthday to Mr. Lemon

It is observable that the teacher facilitator Anita and the children together established a translanguaging space. Anita followed the flow of these bilingual children's lead, democratically letting the children be the experts which then allowed for a space for the exchange of knowledge. This series of interactions also allowed for connection across linguistic, social, ethnic, and geopolitical boundaries. Laylan employed the Arabic Happy Birthday song from her repertoire as a means of connecting with fellow participants, including those of her ethnoreligious community, even though it was not the language of her community.

This episode is particularly significant as Arabic was the national language of the dominant majority in their country of origin and the oppressive powers that unjustly subjected their community to violence and genocide. The very language of the oppressor, a language that older generations of Yazidis who resettled in Canada deny knowing and communicating in—due to the associated trauma—was repurposed by this young girl and sung in a playful manner. It is unbeknownst to the researchers as to where these children learned the Arabic version of this song, but an overwhelming majority of the Yazidi participants sang along without hesitation.

As showcased in these interactions, these land-based translanguaging interactions contributed to a space for renegotiating past experiences and geopolitics and redefining historically imposed relations among ethnic groups. These children engaged in a cross-linguistic exchange between one another; the children, junior leaders, facilitators, and more-than-human life cocreated a translanguaging environment to connect and reconnect. Even though Anita did not share the same linguistic backgrounds as the participants, as a teacher, she modelled a translanguaging stance—embracing fluid and agentic linguistic repertoires to maximize communication potential. She employed translanguaging within the activity design and was unafraid to follow the flow of what García et al. (2016) describe as the translanguaging *corriente*—current.

An additional noteworthy interaction occurred following this rich moment of interaction. After Happy Birthday was sung in Arabic, Anita asked if anyone could sing Happy Birthday in Kurmanji. Much back and forth between the Yazidi girls occurred in Kurmanji, but there appeared to be some confusion and some shyness when it came to sharing. This group did not end up singing Happy Birthday in Kurmanji, but Anita did not pressure and then leveraged other language identities within the space. Anita knew that a youth volunteer member spoke French and as such, she asked him if he could sing a song. A young French-speaking girl referred to as Esme immediately looked up and visually lit up. It was as if she was waiting for this moment for her linguistic identity to be acknowledged. At that moment a child from the back of the space asks if the group could sing Happy Birthday in French. Before anyone could say a word Esme looked back for a second and began to independently sing Joyeux Anniversaire. This was a powerful and validating moment: when such an opportunity arose to take on the expert role, she took it on proudly without hesitation or invitation. She was met with acceptance and support from all members of this activity shown through loud hand-clapping and high-fives—including the lemon plant which played a bright and melodic tune.

Discussion

The design that embraces translanguaging practice and stance creates learning spaces where traditional educational hierarchies can be challenged. For language minoritized children like our participants who have experienced situations that have demobilized their whole linguistic repertoire, being in translanguaging spaces can be transformational as it affirms their active role in co-constructing learning environments. The land-based translanguaging interactions could lead to a re-imagination of colonial institutionalized school learning. Reframing the dominant, deficit-oriented perspective imposed upon bilingual speakers is long overdue. As evident in the aforementioned findings, translanguaging can serve as a transformational tool for deconstructing the colonial views of what it means to learn in educational spaces and with what languages.

Taking full consideration of affordances of land-based pedagogy (Simpson, 2016; Marin & Bang, 2018), we offer a theoretical shift to include translanguaging as a tool for connecting with more-than-human life. As shown in our findings, facilitators, youth and children mobilized technology as a tool to translanguage with more-than-human lives. In this process, the more-than-human life came to teach the children the beauty of language and its communicative power beyond human-to-human communications. This shift away from an anthropocentric view of language could allow humans to better learn with and through land and more-than-human living things. In Episode 2, we can see children's desire for connection with the lemon plant. This theoretical push is significant, especially within resettlement work with refugee populations where families are renegotiating relations with land after their experiences of being stripped from the lands which they had intimate connection with. Our co-design could allow for remembering and reconnecting with traditional knowledge and ways of life through land-based experiences.

Multilingual educators of color were integral and central in establishing the Soil Camp's translanguaging spaces. Within the field of the learning sciences, teacher-child interactions have been rigorously analyzed and seen as a significant element of the learning experience, yet the significance of teacher identity has just begun (as seen in the works of Pham & Philip, 2021). Collectively, educators and facilitators that were racialized multilingual women of color challenged the dominant representation in education (where the majority of teachers are white English monolinguals in the local context) and modelled the strength in multilingual identities and language use in teaching and learning. We will further our inquiry into the experience for both the preservice and in-service teachers who had yet to see such an environment that empowered their own multilingualism and acknowledged their positionality.

Although there is little to no literature pertaining to the translanguaging stance on the so-called "silent period" phenomena (Dulay & Burt, 1974), we argue that linguistically minoritized individuals, especially those of refugee and immigrant backgrounds, are not *going through* a silent period when acquiring new linguistic features of their host countries, but rather are oppressively *silenced.* This is especially present in our educational settings, where it is widely accepted that newly resettled children will *go through* such a period, and in that time, they will follow along but not verbally engage. As we discussed in our findings, for children like Viyan, expectations in dominant society are such that the options of accepted communication are English or silence. Therefore, if the individual has yet to learn enough linguistic features of the society to communicate monolingually, their only option is to remain silent. Due to experiences in English-only environments, children like Viyan could have been silenced. The common view of the silence period can position bilingual children in a deficit perspective, as it categorizes individuals adding to their linguistic repertoire as infant-like, even though these individuals have rich linguistic repertoires to draw from, but it is not in the "desired" language. We take a stance that this phenomenon/hypothesis is nested in colonial logic of linguistic superiority and goals of assimilation. English-only spaces disregard bilingual children's full repertoires and can have damaging socio-emotional effects, including retraumatization, internalized cultural and linguistic stigma, and disconnection from traditional ways of knowing.

Reflecting upon our research question, it is evident that the participants co-constructed environments that were affirming to their multilingual identities and empowered agency within the teaching and learning spaces. There was a significant shift away from monolingual norms that can be seen in traditional schooling and dominant societal settings. Our study demonstrates the transformational power of bringing forth fluid and agentive translanguaging practices—to carefully listen to historically silenced voices and the voices of more-than-human beings.

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Consequential Agency in Chemical Engineering Laboratory Experiments

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Abstract: Despite being at the center of undergraduate engineering education, laboratory experiments have remained unchanged for decades, resulting in assignments lacking in opportunities for students to learn and grow. We used a survey to measure students' sense of agency in prototypical design and laboratory courses at research universities. We found students in laboratory courses at both levels experienced significantly lower framing agency than their peers in senior design, and that even those engaged in authentic course-based research did not perceive the experiments as more agentive or authentic. We infer students drew upon abundant low-agency experiences in laboratory experiments; maximizing learning in laboratory courses may hinge on clearer communication about authentic experiments or systematic redesign of earlier courses.

Purpose

While understandings of theory and ability to solve complex engineering problems on paper take up much of students' time, their time in laboratory courses and design projects offers the opportunity to test these ideas firsthand and direct their own investigations and problem framing and solving processes. Laboratory experiments in particular vary in offering students opportunities to make decisions about what question to pose, how to design an experiment, how to collect and analyze data, and how and with whom to share results. Upper division engineering laboratory experiments are typically more complex—and sometimes more authentic, involving students in aspects of faculty research—than those encountered in their supporting, introductory science classes, which tend to be cookbook in nature (Hauwiller et al., 2019). Yet, those foundational experiences may shape students' perceptions of the laboratory courses as being an opportunity to demonstrate their capacity to deliver the known answer, rather than participating in a discovery process (Chen et al., 2016).

We sought to understand how students perceived their agency in upper division chemical engineering laboratory courses. Specifically, we investigated students' agency in two domains: (1) experiment and analysis and (2) communication of their work. We compare this to students' framing agency—their capacity to make decisions consequential to the framing of design problems—to evaluate their perceptions of consequentiality within laboratory experiments. Making all such experiments high-agency is not feasible due to the high enrollment of these courses, as well as the specialized equipment and potentially hazardous nature of experiments. Understanding more about how students perceive their agency could provide insight about comparatively simple changes that encourage students to take more agentive roles. We sought to answer three research questions:

1. To what extent are students' perceptions of their agency similar across classical engineering design and experimental design contexts?
2. To what extent do students view their experiments as authentic to chemical engineering practice?
3. To what extent do students' perceptions of their agency differ across the two domains of (a) design of experimentation and analysis and (b) communication of results and across more and less authentic laboratory experiment contexts?

Theoretical framework

We frame our study by considering research on student agency across the learning contexts of prototypical design, experimental design, and communication. Across these, we consider the influence of authenticity, defined as having a "primary purpose and source [that is] a need, a practice, a task, a quest and a thirst existing in a context outside of schooling" (Strobel et al., 2013, p. 151).

What is framing agency?

Design problems are ill-structured, meaning these problems have more than one solution and path to solution, as opposed to a single answer (Jonassen, 2000). Designers direct the process of framing and reframing problems (Runco & Nemiro, 1994). This ability is consequential as the framing determines the ultimate choices and outcomes a designer can make. The empowerment to make such decisions is a specialized form of agency, termed framing agency (Svihla et al., 2019, 2021). The bounds on agency can be thought of as set by the opportunity

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structure (Narayan & Petesch, 2007), which shapes not only which and if decisions can be made, but the consequentiality of those decisions. For instance, traditional, well-structured classroom problems that have a single right answer limit the opportunity structure and students make few or no consequential decisions. In contrast, design problems, especially authentic problems sourced outside of school contexts, offer significant opportunity structure, allowing students to decide how to frame problems and proceed in their work. Designers make decisions about what they need to know, which in turn leads to learning, such as from consulting stakeholders (Basadur et al., 1982).

How does framing agency relate to laboratory experiments?

Laboratory experiments vary from authentic experiments conducted as part of research to cookbook-style experiences that are highly prescriptive, with a limited opportunity structure (Mohrig, 2004). As students advance in their programs of study, labs become more complex, meaning the number of variables and the relationships between variable increases (Jonassen, 2000). While this opens the opportunity structure somewhat as students make choices about which variables to control or vary, the problems typically remain well-structured, with the answer known ahead of time. In contrast, ill-structured experiments that engage students in discovery can support learning about the relationships between variables and the design of experiments (Flora & Cooper, 2005). Such problems may even be part of authentic research process, such as when faculty bring their research into the classroom through course-based undergraduate research experiences (Chase et al., 2016). More authentic problems should support greater agency. However, the preponderance of experience with well-structured problems could sabotage the sense of authenticity for students.

Making experiments fully authentic – meaning, based in problems that exist externally (Strobel et al., 2013) – is unrealistic in terms of time, cost, and capacity, including the acknowledgment that ill-structured problems are difficult to propose, implement, support, and evaluate, evidenced by the limited uptake of such approaches. And, more authentic tasks can also limit participation, as students may report low agency if they perceive the requisite decisions as beyond their reach (Hagvall Svensson et al., 2021). Thus, there is a need for investigations into ways to enhance agency in ways that is impactful for student learning and development yet feasible for faculty to manage.

How does framing agency relate to communication?

Writing tasks, encountered in both laboratory and design courses, also fall on a continuum from well- to ill-structured. The lab report is a quintessential form that narrows the opportunity structure, sometimes down to the sentence (Hicks & Bevsek, 2012). These reports can reinforce the idea that work is judged for accuracy, rather than authentically communicating new knowledge to an audience (Abidin et al., 2013). Yet, authentic technical communication, even when fit into genre and journal expectations, can be an ill-structured, iterative process much like design (Howell, 2015), in that authors define stakeholders (audience), purpose, and make decisions to reach those goals (Sharples, 1998). While more authentic forms of communication may enhance the consequentiality of students' agency, their expectations about lab reports may reduce the opportunity structure.

Methodology

We conducted comparative analysis of agency in design versus laboratory courses in engineering. This involved analysis of post-instructional surveys completed by students. We additionally had insight into course instruction via participant observation of the courses (Atkinson & Hammersley, 1994).

Participants and setting

We collected data in senior design courses (n=109) and in two laboratory courses (n=31 in the junior course; n=31 in the senior course). The senior design courses partially met the definition of authenticity, in that students selected projects that had originally been sourced in the world, but that had been reformulated as instructional projects (they included a client but were narrowed in scope by the instructor, or they lacked a client but were based in a prior authentic project).

The junior laboratory experiment asked students to evaluate and then calculate the friction and corresponding pressure drop of water flowing through pipes with different fittings and bends during turbulent flow. Students measured the pressure of water at the beginning and end of two (out of ten) different pipes of different lengths, and—combining their information with that of four other groups to form a complete data set—calculated information about how the bends, length, and fittings of the pipes differently affected the pressure drop and the relative friction. They were scaffolded on how to conduct analysis with an Excel worksheet and on how to communicate their results with a presentation outline. Each group created a 20-minute presentation detailing their findings.

The senior laboratory experiment focused on selective hydrogenization of acetylene into ethylene while minimizing the conversion of ethylene into ethane to be used later to create the plastic polyethylene. The catalysts used by each group was one of several catalysts synthesized in a research laboratory at the university and are part of a larger research study attempting to develop new catalysts to maximize the ability to create polyethylene. Students ran optimization experiments on their unique catalysts by determining the selectivity of converting acetylene to ethylene without converting ethylene to ethane by varying the proportions of starting gases, the flow rate, and the temperature. Students then calculated the kinetics of each reaction and evaluated the effectiveness of their own catalysts. Students worked in groups of five. They individually wrote a short technical report on their findings modeled after a short technical journal article. After peer review, the students in each group combined their individual reports into a single report.

Data collection and analysis

We used two versions of the framing agency survey (Table 1), a survey which has previously undergone validation procedures. In the design course, we used the original framing agency survey, which includes 18 items covering six factors—individual consequentiality; shared consequentiality; learning as consequentiality; constrainedness; shared tentativeness/ill-structuredness; and individual tentativeness / ill-structuredness (Svihla et al., 2020). We adapted questions to the context of experimental design and laboratory decision making within the original factors (Table 1). In addition, we added two questions about authenticity, in which students reported the likelihood their results would be used to inform future research or be shared with others outside the course, in a research lab, a publication, or similar.

We calculated descriptive statistics and used independent samples t-tests with effect sizes to selectively make comparisons between the two laboratory courses, and between design and laboratory courses. We used repeated measures two-way ANOVA to evaluate differences between the laboratory courses and domains (experimental design versus communication).

Table 1

Framing agency survey. All questions on a 7-point bipolar scale, with poles named in question stem.

Factor: Individual Consequentiality. [contextualized to design / contextualized to experimental design]
How responsible or not responsible did you feel for the outcomes of the [*design project/experiment*]?
Considering the (individual) decision you described, how important or unimportant was the decision?
Considering the (individual) decision you described, how important or unimportant was the impact of that decision on your [*design process / experimental design and interpretation of results; final presentation/report*]?
How responsible or not responsible did you feel for making decisions personally?
How responsible or not responsible did you feel for coming up with your own ways to make progress on the [*design project / experimental design and interpretation of results; the preparation of the presentation/report*]?
Factor: Shared Consequentiality
Considering the (team) decision you described, how important or unimportant was the impact of that decision on your [*design process / experimental design and interpretation of results; final presentation/report*]?
Considering the (team) decision you described, how important or unimportant was the decision?
Factor: Learning as Consequentiality
How much or little did you learn as a result of decisions about the [*design problem / experimental design and interpretation of results; presentation/report preparation*] a teammate made?
How much or little did you learn as a result of decisions about the [*design problem / experimental design and interpretation of results; presentation/report preparation*] you personally made?
Factor: Constrainedness
Considering these constraints, how free or restricted did your teammates seem when making decisions?
Considering these constraints, how free or restricted did you feel when making decisions yourself?
How free or limiting did the [*design problem / experiment*] seem to be?

Factor: Shared tentativeness / Ill-structuredness
How certain or uncertain do you feel that you have to [*solve the problem / carry out the experiment*] as given to you?*
How certain or uncertain do you feel that [*your design project has a single right solution / there is a single right way to conduct the experimental design and interpretation of results*]?*
How certain or uncertain do you feel that you have to just [*develop what was asked of you / collect data as you were asked to*]?*
How certain or uncertain do you feel that you know the optimal [*solution / experimental design and interpretation of results*]?*
Factor: Individual tentativeness / ill-structuredness
How certain or uncertain do you feel that you understand the [*design problem / experimental design*]?
Considering your [*design project / the experiment*], did you have many or few opportunities to make decisions as a team related to your [*design project / experimental design and interpretation of results*]?

*Reverse scored items

Results

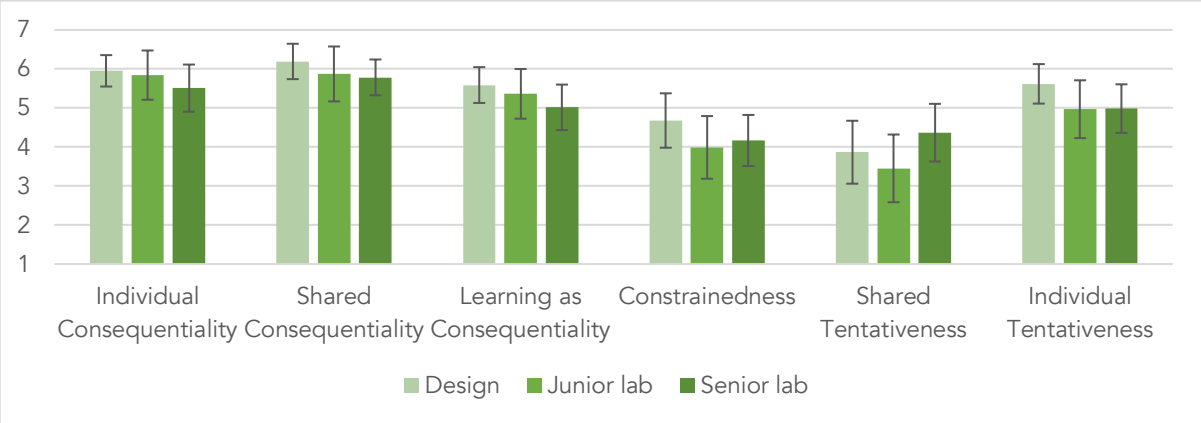
We organize the results by research question.

To what extent are students' perceptions of their agency similar across classical engineering design and experimental design contexts?

Overall, we found design students experienced higher levels of agency across all factors (Figure 1, Table 2). One exception was the senior lab which reported higher shared tentativeness on average. Responses range from 1, which is the lowest or most negative, to seven, which is highest or most positive). Scales differ by question.

Figure 1

Average scores by course on each factor. Refer to table 1 for definitions of Likert scales, as items are bipolar and construct-specific, and poles are named within the question stem.



Students enrolled in design courses reported significantly higher learning consequentiality than those in laboratory classes, $t(169) = 2.40$, $p = 0.017$, $g = 0.38$, a medium effect size. This suggests the kinds of decisions made in the former resulted in more learning opportunities about framing problems. Students enrolled in design courses reported significantly higher individual tentativeness than those in laboratory classes, $t(169) = 3.50$, $p < 0.001$, $g = 0.56$, a medium effect size. This suggests students in the design courses tended to believe there was not a single correct answer to the problem. Students enrolled in design courses reported significantly lower constrainedness than those in laboratory classes, $t(169) = 2.66$, $p = 0.009$, $g = .42$, a medium effect size. This indicates students in laboratory courses felt more limited by the structure of the problem than in design courses. These results indicate that students in laboratory courses experienced less agency than their peers in design courses.

Table 2

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Descriptive statistics. All measures on a 7-point scale

Factor	Design courses (n=109) Mean (SD)	Junior Lab (n=31) Mean (SD)	Senior Lab (n=31) Mean (SD)
Individual Consequentiality	5.95 (0.81)	5.84 (1.26)	5.51 (1.21)
Shared Consequentiality	6.19 (0.91)	5.87 (1.41)	5.78 (0.92)
Learning as Consequentiality	5.59 (0.92)	5.36 (1.27)	5.02 (1.16)
Constrainedness	4.68 (1.39)	3.99 (1.61)	4.17 (1.31)
Shared tentativeness / Ill-structuredness	3.87 (1.61)	3.45 (1.74)	4.37 (1.48)
Individual tentativeness / ill-structuredness	5.62 (1.01)	4.97 (1.48)	4.98 (1.24)

To what extent do students view their experiments as authentic to chemical engineering practice?

The second research question compared the inauthentic junior experiment to the senior experiment, which was part of faculty research. Overall, students reported relatively low authenticity. Students in the junior course reported somewhat lower authenticity ($M = 3.06$; $SD = 1.87$) than seniors ($M = 3.67$; $SD = 1.65$), but this difference was not significant, $t(78) = -1.33$, $p > 0.1$, $g = .34$, a medium size effect. This indicates that even experiments designed to be authentic do not necessarily translate to perceived authenticity.

To what extent do students' perceptions of their agency differ across the two domains of (a) design of experimentation and analysis and (b) communication of results and across more and less authentic laboratory experiment contexts?

We found no significant interaction effect and no difference between courses. This corresponds to students' reported sense of authenticity. Students reported significantly higher agency in the domain of communication than in experimental design, $t(62) = 2.82$, $p = .0064$, $g = .36$ for a medium effect size, indicating perceptions of agency vary across domains (Table 3).

Table 3

Repeated measures ANOVA of agency in two domains (experimental design and communication) between junior and senior courses

Source of variance	*df*	*Sum of Squares*	*Mean Square*	*F*	*p*
Between subject effect	**61**	**78.23**			
Junior v. senior (A)	1	3.28	3.28	2.62	0.11
Error	60	74.95	1.25		
Within subjects	**62**	**20.52**			
Experimental design v. communication (B)	1	2.37	2.37	8.29	0.0055*
A*B	1	0.97	0.97	3.39	0.071
Error	60	17.17	0.29		

Discussion

Framing agency in laboratory and design courses

Students in capstone design report greater agency overall. This is unsurprising as students in design must make decisions about elements such as the scope of the problem and where to source information, which is consistent with greater opportunity structure (Narayan & Petesch, 2007). While the laboratory courses varied in the number of available consequential decisions, constraints like procedure and time limited the students' abilities to frame the problems for themselves. Because of these limitations, students do not have as much space to reframe the problems win whichever ways they see fit, making the problem more well-structured than design problems (Jonassen, 2000). We can also see that the option to make decisions doesn't necessarily translate to empowerment

to make decisions, which is the key component of framing agency (Svihla et al., 2019, 2021). Students in junior and senior labs have completed many well-structured experiments previously in their coursework, and this may have shaped their expectations about these labs.

Framing agency in experimental design

While the intended opportunity structure of the junior and senior labs differed, we found no significant difference between junior and senior students' overall perceptions of their agency. Even though the senior students had many more consequential choices (particularly when it came to design of experiments), this did not translate into sense of consequential agency. We consider the contextual factors that may have contributed to this.

First, felt time constraints meant that students in both the junior and senior courses had limited opportunity to reframe the problem presented to them or even to revise their method of solving it. However, students in the senior course did revise the parameters they used for data collection in response to unsuccessful results or additional information. Students had to frame the ways in which they interpreted their data and used it to make decisions moving forward by balancing variables and deciding their relevant importance. This is the type of framing through making decisions about importance and outcomes we would expect to be demonstrated in students' reports of their agency.

Second, we found that students perceived both the junior and senior laboratory experiments as inauthentic. Research suggests that taking part in authentic research can be sufficient to bring greater impacts to students (Chase et al., 2016). However, our findings indicate that the mere presence of authenticity was sufficient to convince students of their own agency. Students struggle to view assignments in their class as part of authentic research, given the many experiments they have done where the answer has been known for decades (Mohrig, 2004).

Framing agency in communications

Previous experience with lab reports as a genre may limit students' perceptions about the types of choices they may make (Hicks & Bevsek, 2012), with an emphasis on making the "correct" choices in their communication rather than communicating to an audience. In both the junior and senior laboratory courses, instructors emphasized that students needed to consider audience expectations. Students in both courses were asked to evaluate the specific target of their communication as well as choices that they should make to better meet the needs of that audience. While the communication was not authentic, meaning, students did not actually communicate their results to an audience outside the classroom, students still made genre considerations and framed the ways they wanted to present their results with the audience in mind (Sharples, 1998).

Students reported greater consequentiality in the communications of their results over the experimental design itself. It is much more feasible for instructors to support students to make decisions in their communications where there are no concerns about things like resources or safety. In addition, the line between decisions students make in the communication and the impact on the final product is much clearer, leading students to better understand the ways that their decisions are consequential.

Fostering framing agency to support professional identity formation

Having opportunities to make consequential decisions appears to support the development of engineering identity (Du & Naji, 2021; Godwin et al., 2013, 2016; Morelock, 2017). Indeed, engineering practices that depend on such decisions—analyzing data and designing—contribute to students' identities as engineers (Choe et al., 2019; Meyers et al., 2012). This is in part because, fundamentally, professionals have the capacity to make consequential decisions, and displays of doing so position one as belonging (Holland et al., 1998; Tonso, 2014). From this perspective, engineering identity is also double-sided, meaning the individual positions themself as an engineer, and they are recognized by others as belonging in engineering. Opportunities that foster consequential agency in line with what professionals do simulates professional practice, and this is one of the few forms of interventions shown to enhance professional identity formation (Morelock, 2017). In contrast, a preponderance of experiences with low-agency tasks can signal to students that engineers are skilled technical problem solvers who possess little agency (Chua & Cagle, 2017; Kirn & Benson, 2018). Thus, framing agency may shed light onto learning experiences that offer the kind opportunity structure needed to develop professional identity. While instructors may intend to offer ill-structure, students may not perceive this as consequential, instead treating it as just another chance to demonstrate the accuracy of their knowledge.

Conclusions

We found students in design courses reported greater framing agency, compared to laboratory courses. This highlights the importance such courses have in students' preparation. We contrasted laboratory experiments with high or low authenticity. We found no differences between perceived authenticity or agency. This contrasts with research suggesting course-based research experiences seem more valuable to students (Auchincloss et al., 2014). We interpret this finding as revealing the challenge of overcoming students' expectations about such experiences. In future, we plan to investigate ways to make the authenticity more apparent to students. Students in both laboratory courses reported higher agency related to communication, compared to experimental design. Future studies will investigate ways to enhance agency related to experimental design, while retaining the feasibility.

Limitations and implications

The study comes with limitations, including a relatively small sample size and relying on self-reported data. The methods did not include a means to control or randomize participants, and all data from laboratory courses comes from a single institution. Further steps include collecting data from additional laboratory courses, including at institutions with different contexts.

Our findings suggest that more needs to be done to support students' perceptions of their agency beyond simply providing them with opportunities to frame problems. However, the endeavor of supporting students' agency and interaction with realistic complex problems is vitally important to their understanding both of what engineers do and how they develop identities as engineers. Writing can be a potential avenue to feasibly enhance agency.

Our results more broadly inform the ways that agency and perceptions of agency are related in students. Perceptions of agency can be informed by the problems at hand but can also be influenced by other external factors like prior experiences and time pressure. Ideas about authenticity and ill-structuredness can inform each other, with students viewing their task with less agency, but also less belief about the authenticity (even when the problem is very authentic).

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International Society of the Learning Sciences

Instructor facilitation of STEM+CT discourse: engaging, prompting, and guiding students' computational modeling in physics

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Abstract: The integration of computational modeling into instruction in science classrooms is complex in that it requires the synergistic application of students' developing science and computational thinking knowledge. This is not only difficult for students, but teachers often find it hard to parse the science content from the computational constructs to guide students when they have difficulties. Leveraging past literature that highlights the beneficial impact instructors can have when they immerse themselves in group problem-solving discussions, this paper examines the instructors' role in facilitating students' construction of and problem solving with computational models. We utilize a case study approach to analyze instructor-facilitated, synchronous group discussions during applications of synergistic learning processes to understand how instructors may elicit students' knowledge, misunderstanding, and difficulties to help guide, prompt, and engage groups in this complex task for more productive integration in K-12 science classrooms. We hope that this will lead to better scaffolding of students' learning, and better support for teachers when they use such curricula in classrooms.

Introduction

Computational modeling has received increased attention as a vehicle for integrating computational thinking (CT) in existing K-12 science classrooms (Wilensky & Reisman, 2006; Hutchins et al., 2020). This constructivist approach has been shown to be effective in helping students learn STEM and CT concepts (e.g., Sengupta et al., 2013), and develop problem-solving skills (Hutchins et al., 2020). In addition, it provides environments for encouraging productive, socially-shared collaborative problem-solving skills development (Emara et al., 2021). However, integration of STEM and CT in K-12 science classrooms comes with its own set of challenges for both students (Basu et al., 2016; Hutchins et al., 2020) and instructors (Wilkerson-Jerde et al., 2015). In this paper, we target two key challenges: (1) limited understanding of how instructors can engage in students' integrated learning of science and CT during computational modeling (Wilkerson-Jerde et al., 2015), and (2) student difficulties in communicating about applying complex, synergistic learning processes, such as initializing and updating variables during computational model building, and leveraging data tools and debugging processes to generate correct models (Snyder et al., 2019). To do so, we examine instructor engagement in student thinking and knowledge construction during computational modeling through instructor-facilitated, small group discourse, a pedagogical tactic that has shown to support problem-solving skill development (Fung et al., 2016).

While student discussions during learning and problem solving have been shown to be beneficial to student learning (Chi & Wylie, 2014), group discussions are not always effective (Dillenbourg et al., 1996). These difficulties can be exacerbated during scientific modeling due to the open-ended nature of the problem-solving task, as students collectively manage the complex integration of STEM and CT concepts and practices (Snyder et al., 2019), limiting applicability of common collaborative interventions. In this context, interventions must consider students' STEM and CT prior knowledge and their ability to (1) apply complex synergistic processes, such as translating prior knowledge into computational forms, and (2) communicate these processes to group members. This may provide a unique opportunity for instructors to engage in students' STEM and CT knowledge construction and problem-solving processes to support and to facilitate STEM+CT classroom integration.

This paper examines the research question: *how can instructor-facilitated small group discussions support our understanding of students' learning and problem solving during scientific computational modeling?* To answer this question, we define a framework that captures the roles instructors play in classroom instruction and group discussion. We adapt this framework to evaluate the instructor-facilitated, small group discourse during scientific computational modeling tasks. Our analyses revolve around two case studies examining how instructors guided small-group discussions linked to their students' computational modeling tasks. We study how instructors prompted students to elicit their knowledge in CT and the target science domain, exposed misunderstandings, and helped students develop complex, synergistic learning processes to support their

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learning tasks. We hypothesize that targeted instructor-facilitated discourse may support a deeper understanding of students' STEM and CT knowledge that may be difficult to assess through traditional summative assessment approaches. We illustrate how instructors, through explanation prompting, encourage discussions on translating conceptual knowledge to the computational form and support the groups' knowledge co-construction processes.

Integrating the C2STEM learning environment

C2STEM is designed to support the synergistic learning of physics and CT through the building, testing, debugging, and use of computational models to solve physics problems (Hutchins et al., 2020). The learning environment includes a block-based programming environment, an extension of Snap! (snap.berkeley.edu), equipped with a physics *domain-specific modeling language* to allow students to focus on constructing computational models of physics processes. The system includes *data tools* that provide students a means for checking and evaluating their physics models as they build them. In the curriculum students build increasingly complex models and complete a series of formative and summative assessments to help students and instructors monitor their evolving STEM and CT knowledge. The curriculum for this study was divided into three modules: (1) 1-D motion, where students build a model of a truck speeding up from rest to a specified speed limit, cruising at that speed, and then slowing down (decelerating) to come to rest at a stop sign; (2) a drone task where students build a computational model of a flying drone dropping a package onto a target; and (3) a second drone task where students model a flying drone dropping two packages in succession on two different spots on the ground.

For C2STEM implementations, we have developed instructor material to support modeling tasks based on prior classroom experience. Teachers also have access to the correct computational models. We have collected frequently-observed difficulties students face in building computational models. Difficulties include errors in domain-specific concepts and practices (e.g., setting an object's y-velocity to the gravitational constant, and errors in initializing and updating variables in CT). For example, Figure 1 shows a student's incorrect code for updating the *x*-position of an object. In this illustrated code, the *x*-position is set to '*x velocity in m/s * Δt in s*' but the student should have used the change *x*-position block. This demonstrates a potential misunderstanding about the difference between setting and changing variable values. We recommend instructors should prompt students to explain the behavior of the object by running the simulation and walking through the execution to let the student gain an understanding of how the simulation model executes and identify potential errors in their model. Another instructor move may involve prompting students to use the data tools to evaluate the position values and discuss how this information compares against their intuitions and knowledge of the physics phenomena.

Figure 1
Example student CT difficulty in a student's computational model code

Analyzing instructor facilitation during an C2STEM implementation

The impact of instructors during group discussions has been shown to help students' problem-solving processes as they think about the salient features of the problem and develop their problem-solving strategies (Webb et al., 2009). Research has identified strategies for facilitating online discussion that includes developing a social presence and emphasizing student-to-student interactions (Rovai, 2007). Our research is primarily focused on asynchronous online discussions and their effects on students' learning. In this research, we analyze facilitation strategies for synchronous discussions that are supported by our instructor material to improve our understanding of instructor engagement and to facilitate computational modeling of scientific processes.

Figure 1 shows the analysis framework used in our research. This approach is inspired by Berge's (1995) four instructor roles for online learning: (1) pedagogical, (2) managerial, (3) technical, and (4) social. Students may face multiple difficulties in understanding, applying, and integrating science and CT concepts in practices when building computational models (Basu et al., 2016). Instructors can mitigate these difficulties, once identified, to help students overcome these difficulties. In other words, *pedagogical support* is essential to helping students progress in their computational modeling tasks. Previous work has demonstrated that students need help in developing and applying productive synergistic learning strategies to help them translate their knowledge and understanding into successful computational structures for model building (Hutchins et al., 2020). In the form of *managerial support*, the instructor may guide the students discourse or model construction towards applying a

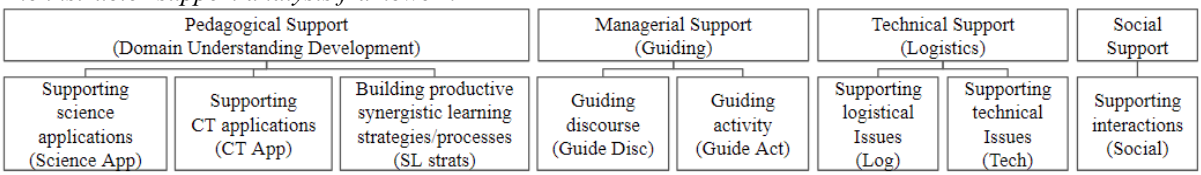
strategy by identifying relevant goals or guiding students to think about how they translated their knowledge in a previous task. The difficulties students face can be compounded by an unfamiliarity with the environment which can be mitigated with *technical support*. Instructors may also facilitate the discussion via *social support* by prompting and encouraging students to state viewpoints and discuss them with each other.

In C2STEM, *pedagogical support* manifests as (1) *supporting CT* applications, such as how to correctly implement the updating of a variable necessary in the physical phenomenon; (2) *developing physics knowledge*, such as the relationship between velocity and acceleration to ensure correct object motion; and (3) *building synergistic learning strategies,* such as translating conditional behavior changes to the right form of conditional statements, initializing and updating variables, debugging, and using data tools to construct or problem solve. *Managerial support* encourages students to reflect and plan, such as guiding students to remember how something was implemented in a previous task or suggesting a modeling-in-parts approach to develop more complex models. The complexity of the C2STEM modeling environment (e.g., the large variety and number of blocks) necessitates *technical support* to help students navigate an unfamiliar environment. Finally, the complex nature of tasks creates an opportunity for collaboration between students, which can benefit from *social support* from instructors.

Previous work has revealed unproductive collaboration in terms of difficulties students face in applying STEM and CT constructs, as evidenced by inability to co-construct knowledge, and inability to interpret and explain model behaviors (e.g., Emara et al., 2021). Facilitating discourse is considered to be an important task and responsibility of a synchronous instructor. These instructor facilitations are often delivered in the form of instructional statements, group participation encouragement and prompting questions. Instructor's question prompting may help students clarify confusions when explaining model behavior (Grover et al., 2019), identify and understand errors during debugging (Hutchins et al., 2020), justify their problem-solving strategies, and correct their misconceptions and suboptimal use of strategies (Kinnebrew et al., 2017; Webb et al., 2009). Moreover, instructors could use various guiding support as means to make the students' interaction more thought-provoking with the aim of translating STEM concepts and practices into computational form (Kinnebrew et al., 2017; van Vondel et al. 2017). For this analysis, we coded discourse based on the lowest level of Figure 2.

Figure 2

The instructor support analysis framework



Study description and data analysis methods

This study was implemented in the Southeastern United States with 22 high school students and 5 researchers who played the role of instructors for the study. The intervention included synchronous, small group computational modeling tasks, which were completed individually and asynchronously. They targeted students' abilities to apply what they learned during their small group work. Students worked in groups of 3 or 4 and the groups did not change through the course of the study. The synchronous, small group work occurred once a week for five weeks over Zoom, necessitated by COVID19 protocols. During these sessions, students had 10-15 minutes of instruction and 15-20 minutes of group discussion in a Zoom breakout room facilitated by the same instructor every week, except for week 3 when a full 30 minutes was used for instruction. Prior to the study, the instructors met for one hour to discuss the curriculum and review the instructor material discussed above. Following each synchronous session, instructors met for 15-30 minutes to review student progress and discuss their experiences.

Data collected for this study included students' pre- and post-assessment results, final computational model project files (scored using a predefined rubric from Snyder et al. (2019)), and the recorded Zoom sessions. When student groups collaborated, the student responsible for constructing the model (e.g., connecting the blocks, running the simulation, etc.) shared their screen on the Zoom session. For this analysis, we focus on two groups that had the same instructor in order to systematically compare differences in (1) the instructor's evidence-based responses to different group combinations and (2) each group's responses to the instructor's feedback.

We use a descriptive case study approach to analyze how instructor-facilitated small group discussion can support our understanding of students' learning and problem solving during scientific computational modeling. Specifically, we identify how instructors *identify* and *address* student misunderstandings and knowledge gaps through instructor-facilitated discussions of students' model construction steps. We examine the instructor-facilitated group discussion dialogue segments by coding the instructor utterances using the scheme in

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Table 1. Note that due to the overlap between support, we combine the two types of guiding into one code label. Two coders coded the utterances with very good agreement ($\kappa = 0.89$). We analyze students' individual computational model scores and prior knowledge, measured through pretest scores. The two groups selected for analysis had the same instructor and a mixture of prior knowledge, measured through a pretest, in both STEM and CT. The physics portion of the test had a total score of 17 points, with a student median of 12 points ($\sigma = 2.35$). The CT portion of the test had a total score of 16 points, with a median of 9.25 points ($\sigma = 2.81$). We categorized students as high or low prior knowledge based on their scores relative to the median. In the two groups we analyze in this work, the CT scores ranged from 13 to 6 points and physics scores ranged from 14 to 9 points.

Table 1
Coding scheme for implementing the instructor support analysis framework

Code	Description	Example(s)
Log & Tech	Helping the students log on, open projects, other technical or logistical issues, etc.	"S3 could you be the navigator and open the form today?"; "The block is in that section"
Guide Disc & Guide Act	Stating goals, guiding students to look at something	"Your goal for the next six minutes is to build and answer this question as a group."
Science App	Utterances focused on physics concepts	"What causes velocity to change?"
CT App	Utterances focused on CT concepts	"So, the simulation step repeats every time"
SL Strat	Utterances referring to synergistic learning processes or strategies	"That's an interesting way to debug"; "Definitely use the data tools to help you here'"
Social	Encouragement of social interactions	"Hi everyone", "S4, are you there?"

Results

The case studies presented target instructor-facilitated, small group discourse, of two groups, focused on key synergistic learning processes - initializing and updating variables, debugging, and using data to debug models. The first group (G1) has four students: two students, S1 and S2, with high prior knowledge in physics and CT, and two students, S3 and S4, with low prior knowledge in both domains. S1 and S2 contributed the most during the three discussion sessions (30% and 25% respectively) while S3 and S4 contributed 3% and 13% of the total utterances. The instructor contributed 28% of total utterances. The second group (G2) has three students: S5 who has low prior knowledge in both domains, S6 who has high physics prior knowledge and low CT prior knowledge, and S7 who has low prior knowledge in physics but high prior knowledge in CT. Unlike G1, the instructor contributed most to the group discussions with 39% of the total utterances over the three days. S5 and S6 contributed 31% and 21% respectively while S7 contributed the least with 9%. As seen in previous work (Snyder et al., 2019), students with low prior knowledge, S3, S4, S5 and S7, particularly improved over the course of the study. We hypothesize this may be due to the effectiveness of the group discussions facilitated by the instructors. In the following analysis, we explore the different ways the instructor facilitated these discussions in each group.

Instructor facilitation

We analyze the instructor-facilitated discussions utilizing the framework described above. Although facilitated by the same instructor, the role the instructor played is very different across the two groups. The role of the instructor in G1 discussions was primarily in the form of *technical support*: 38% of the utterances dealt with logistical and technical issues, 32% of utterances were *managerial support*, 26% *pedagogical support* and 4% *social support*. The role of the instructor in the G2 discussions was primarily *pedagogical support*: 46% of the utterances were classified as applications of physics, CT or synergistic learning process, 33% *technical support*, 11% *managerial suppor*t and 5% *social suppor*t. We hypothesize this difference in the support focus is due to the distribution of prior knowledge in each group. While the instructor was not aware of the prior knowledge of the students at the time of the discussions, the instructor's focus was impacted through the students' misconceptions and knowledge gaps that became apparent through their explanation prompting efforts, illustrated below.

Explanation prompting episodes

The three vignettes shown in Tables 2-3 illustrate how our instructor facilitated successful group discussions during the computational modeling of physics phenomena. To support successful model construction and integration of STEM and CT concepts, the instructor utilized explanation prompting to identify key misunderstandings and knowledge gaps; and group management prompting to encourage students to share knowledge learned to support group computational model construction. We illustrate a common CT misunderstanding students have between the use of the set and change blocks in Table 2 over the course of two

days. On Day 1, the instructor prompts S1 to check if they understand which block is appropriate for initializing variables. On Day 2, the student has an error in their model (Figure 3(a)) that is causing the truck to go from 0 m/s to 15 m/s instantaneously, instead of starting from rest and speeding up to 15 m/s.

Figure 3

Computational models prior to instructor engagement for G1 (a) and G2 (b).

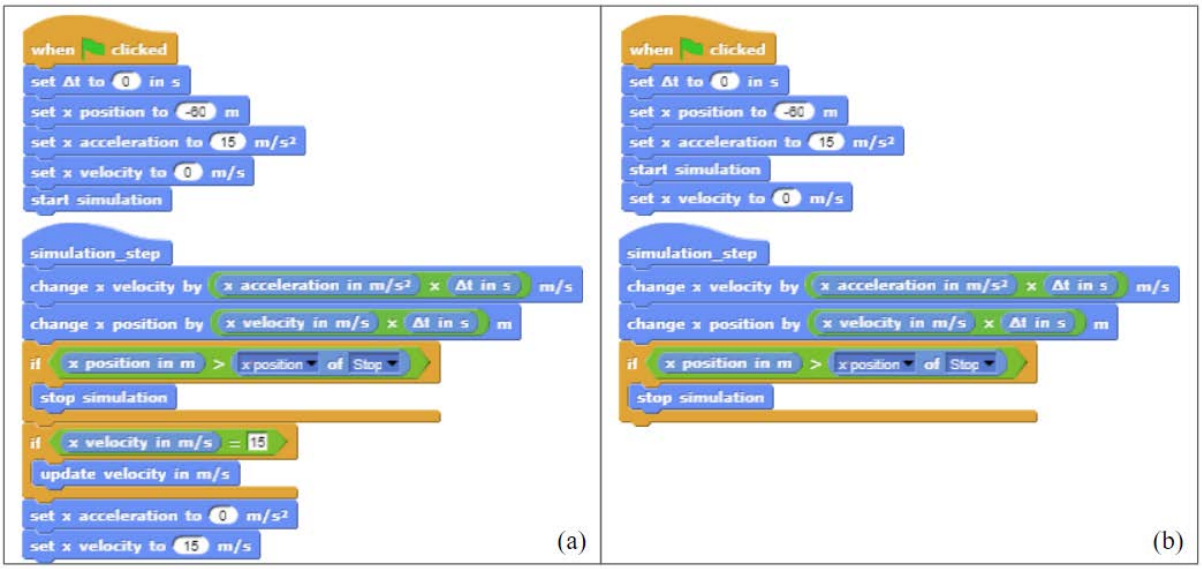

Table 2

G1 truck discussion across two days

Utterance	Description
Day 1: *G1 is initializing needed variables for the truck stop task.*	
Instructor: What do you think...should you set or change the position in order to start at -15m*?*	**CT application**: The instructor is prompting the student to select the relevant block(s) for initializing the position of the truck.
S1: Set I think, I think it's set. I don't know, let me try.	*S1 correctly identifies and utilizes the appropriate block.*
Day 2: *S1 has already determined what behavior in the model does not follow physics principles.*	
Instructor: Why do you think the velocity stays at 15?	**Guiding**: The instructor guides the student, through questioning prompts, to identifying the CT error.
S1: I think because of this, this update velocity because I try to put if velocity equals meters per second goes 15. I tried to put these ones in there instead of the update last one. But it didn't do anything	*S1 correctly identifies that the update velocity block is incorrect and explains their debugging process implemented in the conditional. S1 is showing a lack of understanding in which block is used to update velocity and what the set block does.*
Instructor: I can see.... So one thing to remember is the set and the change. So under the green flag, you have that you're setting that initial value. And then for the simulation step, that's where you update the behavior. So that repeats every time (step), so at the end of your simulation block you have a set	**CT application**: After identifying the lack of knowledge, the instructor is explaining how the *set x velocity position* block, the last block in the simulation step, is going to set velocity to 15 m/s every step of the program.
S1: So I should make it change velocity	*S1 tries to confirm the way to debug their model.*
Instructor: You have it correct at the top though. But you just have some extra blocks. If that makes sense.	**CT application**: The instructor helps the student understand that they are correctly updating velocity with the *change x velocity* block but then are incorrectly setting velocity to 15 m/s. This setting of the velocity effectively overwrites the updating process. The instructor refers back to S2's model which was shown and discussed previously.
S1: I think so…	
Instructor: So you set the velocity after you change it. That what's happening	
S1: So set it and then change it.	

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Instructor: If you remember with S2's code, and you'll want to set acceleration to zero but not the velocity because you're already doing everything right You're changing the velocity. Yeah.	
S1: So I set this back.	*S1 confirms that they are understanding correctly*.

In the first episode (Table 2), the instructor first prompts the student in G1 about how they should implement the initialization of variables on Day 1. While S1 correctly identifies the block to use, they express uncertainty, which underscores a lack of knowledge about the differences in initializing variables versus updating variables as the simulation advances in time. This is elicited, through explanation prompting, by the instructor during the group discussion on Day 2. Due to the S1's further explanation of what is causing the issue with their model, the instructor can identify that the student does not have a physics misunderstanding but has a CT knowledge gap about the correct blocks to implement the updating of velocity.. It is interesting to note that while the group demonstrated success on the CT pretest, the instructor's prompting provided additional insight into students' understanding of the difficult CT concept (i.e., student difficulties in translating conceptual understanding of variables from the pretest to the construction of their computational model).

The second episode (Table 3) shows an excerpt from one of G2's discussions. This instructor-facilitated discussion begins with the introduction of a synergistic learning strategy, the use of data tools, and is followed by a discussion that switches between the application of physics and CT concepts. S5 has incorrectly modeled the speeding up of the truck to 15 m/s as seen in Figure 3(b).

Table 3
G2 truck discussion

Utterance	Description
S1: And then, for the speed limit, I just changed set x acceleration. Instead of four, I changed it to 15. And that caused it to go 15 miles per second squared, and stop at the stop sign. And that's it.	S1 is describing how they tried to model the truck speeding up to 15 m/s. They have incorrectly initialized the acceleration value to 15 m/s^2.
Instructor: So click on the x position, there's a box right next to it, there's a checkbox. And then the x velocity below... Now try running your model...what do you guys see? What happened with the velocity?	**SL strategies:** By encouraging S1 to check the box next to x velocity, the instructor is helping the students monitor how the variable is updated in their computational model by using an inspection window that outputs the value. The instructor is encouraging the synergistic learning use of data tools to identify the error.
S5: Did it change?	*S5 runs the model and points out the changing velocity*
Instructor: So yeah, so when you have acceleration at 15, that's changing the velocity by 15 every time you repeat it.	**Physics application:** The instructor is explaining to the student that the velocity value is changing by 15 m/s at each time step, it is not being set to 15 m/s.
Instructor: If you...one thing I might switch here is… I'd just switch the x acceleration to... What was it...4? **S1:** Yeah. So change it back to 4?	**Guiding:** The instructor is encouraging the student to initialize the acceleration value back to the given value of 4 m/s^2 after explaining that setting acceleration to 15 m/s does not make the truck speed up to 15 m/s.
Instructor: Yep. Okay. And then one other quick thing that we just never taught you guys, as if you can move the set x velocity up above the start simulation.	**Guiding:** The instructor is addressing another error in the model (initializing velocity to 0 m/s after the simulation step block).
Instructor: A computer is like a baby, it's just gonna go line by line and you did it right in that it is under the green flag. But what the computer does is it's calling the start simulation and then it's doing the velocity, and you just want it to do that one before the start.	**CT application**: The instructor is pointing out that the student is right to initialize velocity under the green flag however, through an explanation of how the model is going to be executed by the computer, is emphasizing it should happen before the *start simulation step* block. The student may use this to perform line by line debugging.
Instructor: Perfect. That's perfect. So now try, so you'll see and then stop.	**Guiding**: The instructor is encouraging S5 to see the behavior of the model by running it now that the two errors have been identified and fixed.

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Instructor: Um, so you can see that it keeps going up and…. right about there is where you want to stop accelerating, right?	**Physics application**: Moving onto the next component of the task, slowing down the truck, the instructor is helping the students understand what the behavior of the model should be, according to physics principles.
Instructor: How would you guys do that?	**Guiding:** The instructor is encouraging the other two students in the group to contribute to the discussion.
Instructor: S7 or S6, you there?	**Social:** The instructor checks in with the other two students in the group who have been quiet.
S6: I'm a little bit lost because I thought that list is...like the initial one was right so I'm a little bit confused about what the changes we made are doing. I'm just trying to keep up the best as possible. Could you try and re-explain it for me, please?	*S6 expresses confusion about the identification of an error in the model and asks for clarification*.
Instructor: So actually S5, do you want to describe how you found what was wrong? Because you were, you're right with what was wrong with that first model?	**Guiding**: Instead of answering the question, the instructor encourages S5 to explain to S6. The discussion continues with S6 explaining the error to S5.

In the second episode (Table 3), the instructor is helping the students debug their model using the data tools. After walking G2 through how to view the values of the variables as the simulation runs, the instructor then prompts the students to explain what they are seeing. There are two errors in the model: a physics-focused misunderstanding of the relationship between velocity and acceleration and a CT-focused misunderstanding of how the ordering of blocks affects the updating of variables. The instructor emphasizes how acceleration and velocity relate, as well as explaining how the computational model runs to promote CT understanding. In this discussion, the instructor integrates physics and CT, using a strategy of switching between CT and physics concepts. It has been shown that this switching between domains leads to more successful modeling processes (Snyder et al., 2019). We can also see the instructor use prompting to encourage better collaboration.

Discussion

In the two episodes above, we illustrate how instructors support students' synergistic learning of STEM and CT concepts and practices. We look at how instructors *identify* and *address* students' misunderstandings and knowledge gaps. The instructor often utilizes the strategy of explanation prompting to identify student difficulties and gain additional insight into the students' knowledge that a pretest may not provide. This is illustrated in G1, where S1 is stronger in CT than physics according to their pretest scores but they require more CT support in the group discussions as seen in the first episode. We may assume that more of S1's difficulties will be physics-focused when looking at his/her pretest scores, however, our analysis shows that even students with high prior knowledge may face difficulties in translating that knowledge to the computational form (Basu et al., 2016).

In addition to identifying student difficulties, the above episodes illustrate the strategies used by the instructor to address student issues. In the second episode, we can see the instructor uses explanation prompting to point the students towards the error in their model, followed by guiding instructional statements that both explain the physics and CT errors in more detail and guide the students towards correcting the issues with the model. When another student expresses confusion over the instruction, instead of repeating the explanation, the instructor guides S5 to explain what was discussed. This prompting strategy allows the instructor to assess the impact of previous instruction on S5's knowledge gaps, and it encourages discussion between group members. In the continuing discussion, S5 correctly explains the CT issue but doesn't address the physics misunderstanding which leads the instructor to emphasize how velocity is incorporated into the model. We also see the instructor consistently assessing a possible student difficulty in the first episode. The instructor's revisiting of the difference between set and change blocks during the truck task leads to successful knowledge understanding by S1, as seen in their following drone tasks where they correctly implement initializing and updating variables.

Conclusions and future directions

Students often have issues translating science concepts and relations into executable computational structures, and this could be because they have difficulty in mapping the science concepts to the scenario they are modeling or a problem in understanding the basic computational structures. While we can identify the domain where students may have difficulties by analyzing their pretest results, these assessments often have difficulty predicting

students' difficulties in building their computational models. In this work, we see how *explanation prompting* can identify knowledge gaps and misunderstandings that traditional assessments, such as pretests, may not. Instructor-facilitated group discussions, utilizing strategies such as explanation prompting, create an opportunity where misunderstandings and knowledge gaps can be identified and addressed on an individual level.

While these supporting strategies help students in their model building tasks, future work will analyze the impact of different types of instructor support on students' knowledge construction processes. Other literature, e.g., Webb et al. (2009), showed instructor explanation prompting varied as they used it to identify and address student knowledge gaps while encouraging group participation. While the instructors did provide some of this social support, it was minimal compared to their domain focused explanation prompting. In future work, we will expand the social support students receive from instructors and study the impact. Limitations of our analysis include the small sample size. In the future, we aim to expand our analysis with multiple instructors of differing educational backgrounds and experience with CT and computational modeling and more diverse student groups, with an emphasis on better understanding the impact of the socio-cultural context of the research.

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Children's Navigational Map Reading Strategies and Implications for Educational Geogames

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Abstract: Researchers emphasize the need for a deeper understanding of children's navigational map reading and an emerging interest in digital geogames for educational purposes. However, there are only a few related studies. We conducted a navigational map reading study with children aged 6 to 13. The children were asked to navigate to a destination within a virtual environment by using a map and to explain their procedures thinking aloud. Some children described how they recognized the destination from its nearer environment, whereas others described their route and stopover locations towards the destination. Based on the children's statements, we formulated educational implications for geogame features with the potential to represent successful navigational map reading strategies for training purposes.

Introduction

Navigational map reading (NMR), map-aided navigation between locations in the environment (Lobben, 2007), is highly relevant in geoscience education (Hemmer et al., 2008; Ishikawa & Kastens, 2005). Children differ in their success in using maps for navigation. One reason for these individual differences is the amount of experience children have in reading a map which underlines the importance of NMR trainings (Hemmer et al., 2013).

The literature mentions several "abilities" and "skills" related to NMR, e.g. being able to locate oneself on a map, to navigate to a certain destination, to recognize objects on the way by locating them on the map, as well as to know the direction towards destination and start location (Arthurs et al., 2021; Hemmer et al., 2013; Lobben, 2007). High NMR performance is defined by short routes to the destination and correct turns as well as by little hesitations or spins around the own axis (Hergan & Umek, 2017; Hemmer et al., 2013; Lobben, 2007).

Despite its relevance, research on children's NMR strategies and processes is quite rare (Arthurs et al., 2021). Geoinformation technologies such as geogames are promising tools for spatial learning, but research on the effectiveness of these tools and its features in educational contexts is sparse (Laato et al., 2019; Baker et al., 2015). This paper aims to fill the research gap by investigating children's NMR strategies and suggesting geogame features with the potential to address these strategies within NMR trainings.

Educational geogames

Geogames are location-based games working on mobile and geoinformation technologies (Bartoschek et al., 2018) with a game activity that "evolves according to players' location" (Avouris & Yiannoutsou, 2012). Numerous location-based games with educational and non-educational purposes exist. They were associated with positive learning outcomes in the context of navigation (Laato et al., 2019). This contrasts with studies that demonstrated negative short- and long-term effects of geoinformation technologies on spatial learning which is explained by the user's passivity when using the technologies (Ishikawa, 2019; Field et al., 2011; Münzer et al., 2011). However, the technologies investigated in these studies were not designed for learning purposes. Therefore, we want to focus on geogames that were created with an educational intention. One example is *Biparcours* (Actionbound) which allows its users to create map-based rallies for a chosen location on different educational topics. It includes two types of navigation tasks (navigation following an arrow and navigation via a map) and a street map that is fixed to north and can be panned and zoomed. Navigation is supported by displaying the location, the destination, and a compass. Feedback can be turned on or off and shows the accuracy of the player's task solution as well as the correct answer. With its game idea as well as its limited customizability and availability of features, Biparcours represents one of several educational geogames that are currently available on the market. Since geogames are adjustable to their application, research on educational geogames should focus on the variety of possible *features* and their potential in addressing NMR strategies for training purposes.

Navigational map reading strategies

Lobben (2004, p. 272) defines *map reading strategy* as a "specific method or tactic employed by a map user to complete navigational map-reading tasks". With a short review of related studies, Lobben highlights that researchers often make use of think-aloud methods to investigate people's strategies in reading a map.

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Adamina and Erzinger (2017) interviewed third to sixth graders on their procedures in map-related tasks and identified different strategies used. In map-based navigation tasks many children used a kind of *matching strategy*: they tried to find already known representations based on their spatial experiences and used these for orientation. Moreover, many children made use of a *landmark strategy* (i.e. orientation to prominent landmarks such as school buildings or playgrounds) and/or a *route strategy* (i.e. use of route knowledge, directions, and connections in space such as right, left, straight ahead) when solving tasks involving mental mapping, describing routes, or direction pointing or when explaining how to orientate in an unknown environment. Other children solved these tasks with an *overview strategy* (i.e. imagining being above the ground and looking down on it by changing the own perspective).

The scientific and educational interest in children's NMR strategies is high, but research in that field is still in its early stages and remains underrepresented (Arthurs et al., 2021). This paper answers to this gap by exploring children's strategies via think-aloud method. Additionally, it makes suggestions for geogame features that have the potential to address *successful* NMR strategies in educational trainings.

Method

We conducted a study in forms of a digital map-based game that was played by children in a virtual environment. Participants had to solve NMR tasks by navigating through the virtual world and interacting with the digital map. We chose a virtual setting for conducting this study, since virtual reality is proven to offer realistic simulations for spatial cognition research and full experimental control (Hardiess et al., 2015). As a *sub-aspect* of this overarching study, we investigated the children's procedures and strategies in NMR via think-aloud method which is the basis for this paper.

Participants and materials

This study is a sub-study of an NMR study with 110 boys and girls (balanced) aged 6 to 13. For answering the question of this paper, we reduced the data to 37 datasets as explained in the Data analysis section. With regard to its socio demographic information, the sub-dataset represents the total population. The participants were locally recruited via advertisement. They participated one after another and were rewarded with certificates of participation and science toys. The study took place during the schools' summer holidays in our institute in Münster, Germany, in conformance with the local Covid-19 regulations.

Experimental design und procedure

The NMR tasks were implemented in the location-based geogame *GeoGami* installed on a 10.2" tablet. The virtual environment was shown via a projector on a large screen. The participants were sitting on a chair in front of the screen with the tablet on a stand next to them and a controller in their hands (see Figure 1).

Figure 1
Experimental design: navigational map reading in a virtual environment.

GeoGami presented the different NMR tasks in text and audio format as well as a map of the virtual environment. Participants had to solve the NMR tasks by navigating through the virtual environment using the game controller or by interacting with the map on the tablet. The game lasted 30 to 60 minutes and included eight

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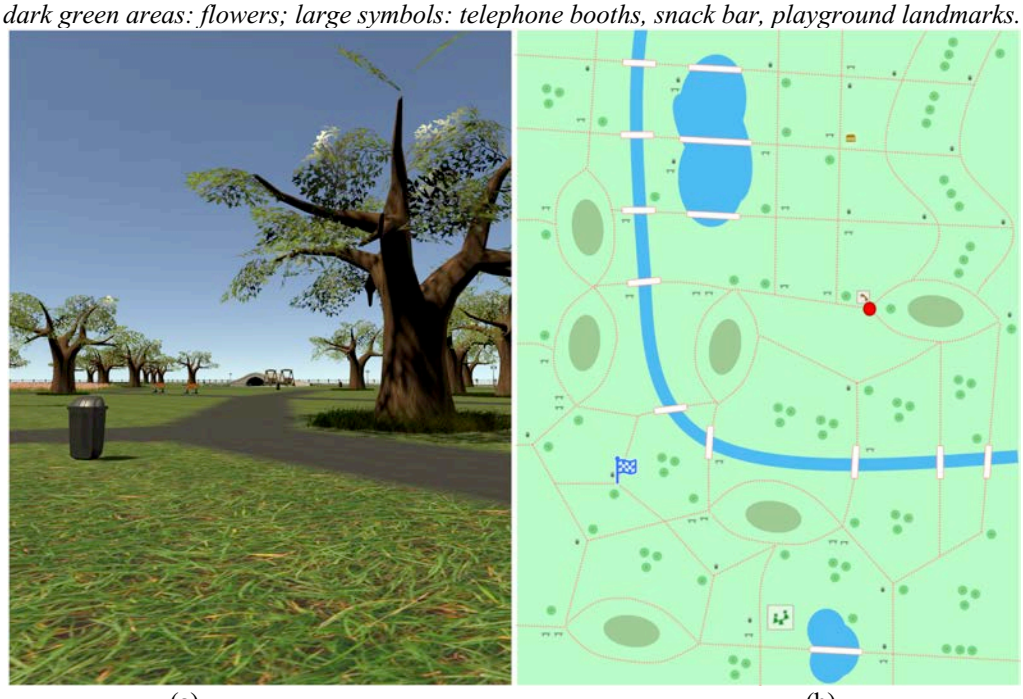
navigation-to-a-flag tasks as well as eight self-location tasks. In the navigation-to-a-flag tasks, the children were asked to navigate to a flag marked on the map. In the self-location tasks, the children were asked to locate themselves by tapping on the map. The map was fixed to north and the children were not allowed to rotate the device, but free to zoom and pan the map. The virtual environment represented a park area with several paths and crossings, grass, trees, flowers, benches, trash cans, bridges, a river, and lakes as well as three unique landmarks (a playground with two swings, telephone booths, and a snack bar). The start location of the total game was the playground located in the south of the map.

In the first step, the participants took part in a tutorial that explained the game, the tasks, the map symbols, as well as the controller usage. They have been given around 10 or 15 minutes to practice. The game did not start until the participants felt confident in the controlling and tablet handling. During the game, after two specific tasks —a navigation-to-a-flag and a self-location task—we asked the children to explain their solution to the experimenter in forms of retrospective think-aloud statements. This procedure does not influence the task solution itself and is still representative because of its temporal proximity to the task. Already at the beginning of the experiment, we informed the children on that procedure and explained them that we would like to learn how they read and use maps for navigation. Directly after a participant solved one of these tasks, we asked: *"How did you solve/do that?"* or—if this question was unclear—*"How did you know you had to go here?"* or *"How did you know you were in/tapped on the right place?"* The experimenter transcribed the children's answers directly in the experimental situation including notes on gestures if a child was pointing at objects in the virtual environment.

In the following, we will focus on the statements of the navigation-to-a-flag task since it represents the *navigational* aspect of NMR which we aim to investigate. In this task, the children were initially informed on their start location by presenting them a location marker on the map next to the telephone booths (see Figure 2). They started this task with the view direction fixed eastwards. Afterwards, the location marker disappeared and a destination flag was presented. The flag was located at a three-paths-crossing with a trash can and a tree. The children were asked to move to the flag in the virtual world and to press an OK-button on the tablet when they thought they have reached the destination. They had to move in southern direction with a map aligned to the north. In the virtual world, there were also other similar locations: some with same objects but a different arrangement and some with the same arrangement of these objects. This design of the virtual environment ensured that children could not find the destination just by randomly searching for it. In order to solve the task, the children had to think spatially by using the objects, paths, and landmarks around.

Figure 2

Virtual environment (Unity 3D, CityEngine) with view direction towards flag from NW direction (a) and map of the virtual environment (b)—red point: start; flag: destination; red lines: paths; green points: trees; small symbols: benches, trash cans; white lines: bridges; blue areas: water; dark green areas: flowers; large symbols: telephone booths, snack bar, playground landmarks.



(a) (b)

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Data analysis

In the first step, we identified participants who fully completed the game and who solved the navigation-to-a-flag task correctly. This way, the "successful" NMR procedures and strategies were accessed. They were of major interest for this sub-study since our implications for GeoGame implementations focus on the training of children in *successful NMR strategies*. The think-aloud statements were filtered for explanations with details on the procedure. Generic or general comments such as "I walked on the paths" or "I looked for benches and bridges" were ignored since they were not useful to understand the children's learning.

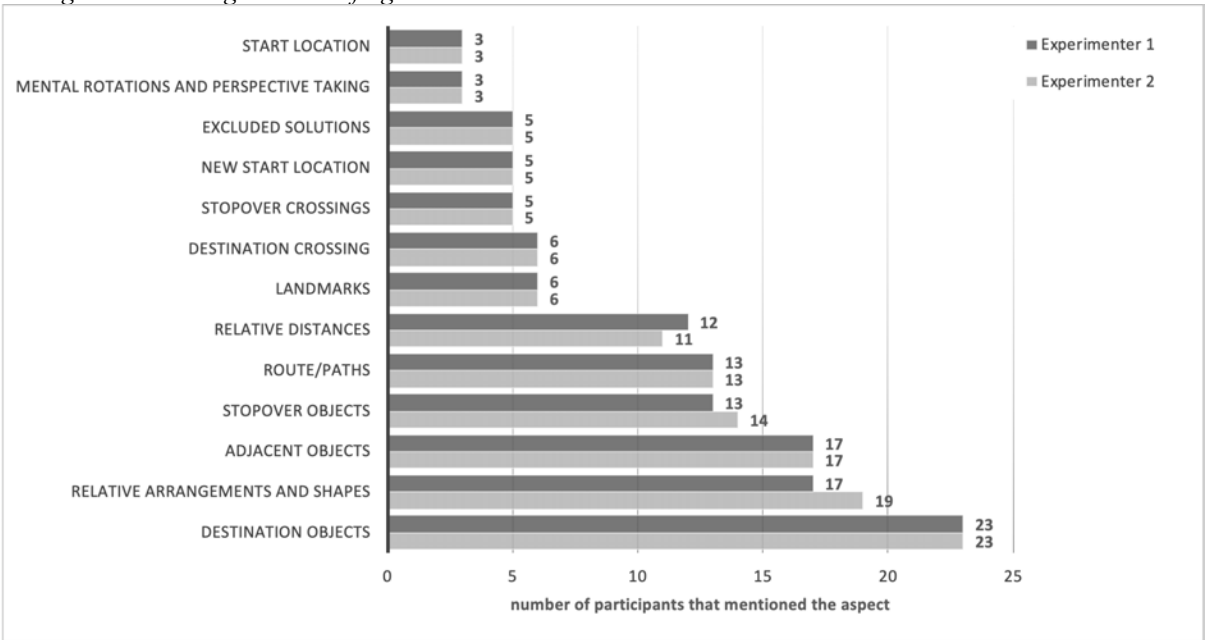
With the remaining 37 think-aloud statements, a content analysis was done by identifying and coding *aspects describing* the children's *procedures or strategies* in solving the navigation-to-a-flag task. The statements were coded by two experimenters with the software MAXQDA. In line with the literature, the focus of the analysis was on routes, crossings, objects, and landmarks as well as on mental rotation or perspective taking processes. Based on the children's statements, these categories were refined as described in the Results section. After comparing the first analysis' results among the experimenters, the codes were redefined to become clearer and more distinctive. Both experimenters rechecked their coding with regard to these definitions and overlooked aspects. Finally, the intercoder matching as well as the number of participants assigned to each code-category were determined with the use of MAXQDA. In order to learn more about possible strategies behind the children's statements, the aspects included in each statement were visualized with colors.

Results

By analyzing the think-aloud statements, we found 13 different aspects that were mentioned by the children in order to describe their NMR procedures or strategies in the navigation-to-a-flag task (see Figure 3). The intercoder matching (agreement) with regard to the existence of these aspects within the statements is 96.95 %.

Figure 3

Aspects mentioned by the participants to describe their navigational map reading (NMR) procedures or strategies in the navigation-to-a-flag task.



We distinguished between objects and crossings representing the start location, the destination, as well as "stopover" locations (i.e. objects and crossings that were visited while navigating to the destination). Additionally, we coded the snack bar and the playground as "landmarks" since they were unique in the whole environment (instead, the telephone booths were coded as "start location"). However, some children mentioned that they used the playground as an orientation point from where they restarted the navigation to the flag. We coded this procedure with "new start location". Objects that were near to the destination and mentioned for explaining the solution, but not explicitly described as stopover locations, were coded as "adjacent objects".

Most children (23 of 37) used the destination objects "tree" and/or "trash can" for their explanation (1), 6 children mentioned the destination crossing. 13 to 14 participants listed stopover objects like flowers, bridges,

trees, and benches and 5 used stopover crossings ("I have oriented myself a bit on the *crossings*"). Adjacent objects like flowers, bridges, trees, and benches were mentioned by 17 and the landmark "playground" or "swing" was included in the statement of 6 children. 5 children described that they restarted orientation from the playground ("I went to the *swing* first, from there it was *easier*"). This way, they changed the view and movement direction from south to north which simplified the original task. Only 3 children mentioned the start location when describing their procedure.

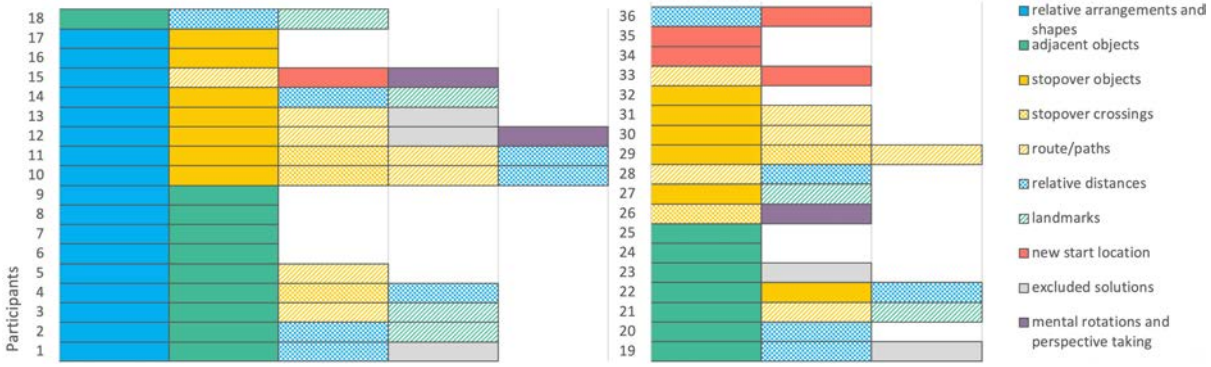
13 children described how they followed paths and route sections towards the destination ("Then I looked at *how I would have to run through the curves*"). Some children described the relative arrangements and shapes as well as relative distances of objects and paths to each other: 17 to 19 children mentioned how objects, paths, and stopover locations were arranged with words like "left", "right", "behind", and "between" as well as with terms describing shapes like "branching" or "edge". 11 to 12 participants also mentioned the relative distance of objects to each other or to themselves with terms like "near" and "far" ("I had to go to the trash can and it was the only one *near* the bridge").

5 children explained that they excluded routes or locations ("Then, I saw that there was a bench on the bridge, so *I didn't have to cross that bridge*."). 3 children were able to describe how he or she mentally rotated the map ("[I] turned it in the head to my perspective") or changed the own perspective ("If I were in there").

The color-visualization (see Figure 4) gives insight in the combination of aspects within the statements. Individual colors and pattern were chosen for each aspect. The visualization shows no distinct groups in the way aspects were combined. Rather, the results show combinations that were highly individual. However, two main tendencies can be observed in the data. A first group (14 children) described their procedure in a *dynamic way* by mentioning stopover objects, crossings, and/or the routes they took without explaining how the destination is located with regard to adjacent objects or landmarks. The 3 children that were able to explain how they mentally rotated or changed their perspective belong to this dynamic group. A second group (12 children) explained their solution in a *static way* by describing objects and landmarks that are adjacent to the destination. However, also explanations combining these two ways were observed. What additionally can be seen is that 3 of the 5 children that used the playground as their new start location mentioned neither the dynamic, nor the static way. One further child of these 5 children mentioned the travelled route (dynamic way) only very vague: "I then go to the playground, then I know where I am, because the game started there. I first looked from the playground, there were *paths* there, and with these *paths* I could see exactly where I had to go."

Figure 4

Combinations of aspects mentioned by the participants (unconsidered aspects: start location, destination objects, and crossings; coding: experimenter 1).



Discussion and suggestion for the design of a geogame

Children's navigational map reading strategies

Children differ in their procedure or strategy in how they solve navigation-to-a-flag tasks. In the specific task of this study, the children started at a landmark (telephone booths) and had to move in the southern direction to the destination. The destination was surrounded by objects that appeared also in many further places on the map. The nearest landmark was a playground which was several crossings away from the destination. Since it was no unique location, it was not possible for the children to find the destination just by accidently stumbling upon it. Therefore, we assume that the children's statements on the correctly solved task inform us on *successful* procedures or strategies in navigating with a map towards a destination. However, we suppose that the statements represent elaborated and less elaborated ways in doing so.

For each procedure or strategy aspect, we determined the number of participants mentioning it. The number gives us an idea on how aware a child was about the individual aspect as a part of his or her procedure. However, we cannot deduce from the statements whether the individual child did not consult further aspects. The number does not tell us how often children made use of individual aspects or if they were able to do so. Moreover, it is also conceivable that children noticed some aspects only afterwards, i.e. in retrospect. For future work, we suggest to ask for explanations also directly *in* the situation in order to prevent that children forget or add aspects in retrospective. This *concurrent* think-aloud method could also clarify which aspects are relevant to children at different decision points. However, it is possible that this method induces strategic procedures that would not have arisen with a retrospective think-aloud method.

The results show that children's successful NMR strategies incorporated the consideration of destination objects as well as adjacent objects and landmarks. The children included shapes, relative arrangements, and distances (closeness and farness) in their spatial analysis of the destination as well as the route towards it. Although the destination was distinguishable from other locations in the way the destination objects "tree" and "trash can" were arranged in relation to each other, the children did not explicitly mention this arrangement. The children's statements rather give the impression that the existence of and relative distance to other objects as well as their own way towards the destination played a greater role in their decision-making process: whereas some children predominantly analyzed the destination on site (static way) by mentioning adjacent objects and landmarks, others remembered how they planned and repeatedly checked the route towards the destination (dynamic way). Some children described that they mentally rotated the map or mentally changed their own perspective to support their route planning. Other children mentioned that they crossed decision points on which they decided on or excluded routes. These decisions were based on the existence, arrangement, and shape of objects, landmarks, and paths. It would be interesting to investigate if the "static" group took longer routes towards the destination (and therefore was less efficient in solving the task) than the "dynamic" group: could it be that the "static" group scanned the area in a trial-and-error way until they recognized the destination objects "tree" and "trash can" and verified their assumption with adjacent objects? Future work could also focus on self-locations tasks that are created to be solved *on site*: do children solve such tasks predominantly by focusing on adjacent objects or do some of them make use of their knowledge about their route towards the destination?

In addition to the so far mentioned procedures and strategies, there was another successful way in solving the navigation-to-a-flag task: some children looked for another, already known orientation point at the bottom of the map to prevent a non-alignment of view direction and map. They reorientated from the playground which was the start location of the total game. Although the children were successful in solving the task (and may have reduced their error probability this way), such a procedure causes significantly longer routes and is therefore less efficient than other strategies. As shown above, it occurred mainly isolated from the other procedures. Future work with a focus on children's statements on incorrectly solved tasks could possibly further illuminate such inefficient strategies.

Suggestions for the design and conception of a geogame

Based on our empirical findings described above, we developed a new concept for a geogame design. The focus is on geogame features that have the potential to represent or address successful procedures and strategies in NMR. Developing successful learning methods demands to understand the thinking of successful learners. The geogame as one possible methodic tool in geoscience education offer the potential to be adjusted to these educational needs.

Educational geogames are often map-based games using classical street maps that are fixed to north and can be *panned* and *zoomed*. Panning and zooming are useful in NMR situations because they allow the user to get an overview of the environment as well as to plan the route based on start location, destination, and possible stop-over locations. A north-oriented map activates the spatial thinking of the map reader when navigation is orientated to west, east, or south. But what is often missing in geogames is a customizability of the map in forms of a choice between automatic, manual, and no panning, zooming, and rotation. *Automatically or manually rotating maps* instead of fixed maps, for example, are helpful to address mental rotation and perspective taking or to facilitate the spatial perception of object arrangements (see Figure 5a). As an alternative to map rotations, *view direction markers* – either presented initially or during the whole NMR process – can visualize mental rotations, perspectives, and spatial arrangements without changing the map view (see Figure 5b).

Several educational geogames visualize the user's location and view direction. What is missing are customizable map marker settings. Location markers (see Figure 5c) can visualize start locations, destinations, and routes towards the destination. The absence of a marker activates the map reader in his or her spatial thinking. *Initial* location marker can support in the initial self-location and can then handover this process back to the map reader by disappearing during navigation. *Tracks* in forms of lines marking the route walked (see Figure 5d) or

highlighted streets representing the approximate location of the map reader (see Figure 5e) are further features with the potential to address route planning and self-location during navigation.

Point, line, or polygon markers are useful features to emphasize objects, landmarks, routes, start locations, and destinations, as well as the shape of landmarks for orientation (see Figure 5f). A *draw functionality* (see Figure 5g) allowing the map reader to mark objects, structures, and routes during the navigation process on his or her own is a helpful feature for making use of map details that are relevant to the individual map reader. In order to draw attention to relative distances and arrangements between objects or objects and map reader, a *buffer* (see Figure 5h) can be used that draws a circle around a certain location with a given diameter. All these features are no technical innovations, but missing in most educational location-based games.

Figure 5

Geogame features for representing and addressing successful NMR strategies: (a) map rotation, (b) view direction marker, (c) location marker, (d) track, (e) highlighted streets, (f) point, line, and polygon marker, (g) draw function, (h) buffer, (i) satellite picture and swipe function, (j) 3D map, (k) feedback on distance deviation, (l) feedback on task solution (GeoGami, map visualization based on OpenStreetMap and Mapbox).

Several educational geogames do not offer the option to change the map layer, but satellite pictures (see Figure 5i) and 3D maps (see Figure 5j) can help the map reader to recognize objects and special shapes of landmarks as well as to understand map visualizations. A *swipe* functionality (see Figure 5i) allowing the map reader to successively change the street map into a satellite picture and back is a further supportive feature for this kind of applications.

Already existing geogames give rather simple feedback on task solutions, but location-based technologies offer the possibility to give detailed feedback on task solution by highlighting deviation distances and angles (see Figure 5k), marking correct locations, view directions, and objects on the map (see Figure 5l) or giving custom messages on pre-defined errors. This is also missing in most educational geogames.

Although a huge variety of educational geogames exist, the customizability and availability of features like markers and layers, feedback, and map draw functionalities is very uncommon. Therefore, we are currently

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equipping our location-based geogame GeoGami with the above-mentioned features: some features are already implemented, others under development. Being interested in geoinformation technologies for school education requires rethinking these tools from an educational perspective. NMR training studies must consider tools that are adjusted for its special use. In this paper, we suggested enhancements for such tools based on an analysis of children's successful NMR strategies.

Endnotes

(1) The cited think-aloud statements were translated from German.

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Supporting Students' Critical Action within a Cultural Context: A Role for Arts-based Pedagogy in a Community of Learners

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Abstract: Transformative learning requires students to actively identify issues, question the narratives that surround them, and develop strategies for change (Freire, 1978). However, for such learning to be truly impactful it must be contextual and culturally relevant to learners. In this paper, we report on the design, implementation and outcomes of a performative learning workshop organized at a secondary school in Bengaluru, India. We highlight the importance of the co-design process and its influence on joint inquiry and increased community engagement. Data from student interactions, discourse and artifacts was analyzed to understand how a culturally relevant arts-based activity can engage students in critical action, collaboration, and embodied learning about local issues. The findings suggest that knowledge and action are both deeply embedded in and influenced by cultural experiences as represented in the students' collective creations. We discuss the implications of this research in the broader context of the learning sciences.

Introduction

This paper reports on a co-designed, culturally responsive learning experience that engaged students in arts-based critical action within a secondary school in Bengaluru, India. The activity took the form of a *Rangoli Utsav* (or Rangoli festival), as part of the school's Diwali celebrations. Rangoli is a traditional Indian art form that consists of multicolored drawings (typically circular patterns) designed on the floor using materials such as colored sand, powdered limestone, flower petals, etc. Over the past year, we have established a professional learning community for teachers in Southern India, comprising three workshops that focused on topics of critical action and culturally responsive pedagogies. This paper studies one of the curriculum activities produced by teachers, in which the *Utsav* provided a context for a performative learning workshop. Students were invited to use Rangolis to express their personal and cultural identities or address socio-environmental problems that concern them, as an exercise of critical action. This project is situated within a broader program of research and critical action called CALE: The Critical Action Learning Exchange (Carvalho et al., 2021). This research responds to a growing need in the learning sciences to nurture culturally responsive pedagogies in which students develop their own sense of local purpose (Enyedy et al., 2011, Paris & Alim, 2017) situated in authentic cultural contexts and belief systems (Hod et al., 2018).

The following research question guided our work: How can critical action pedagogy support students in developing understanding and expression about global issues within their local cultural context?

Theoretical Framework - Critical Action and Arts-based Pedagogy

In Freire's words, "Only beings who can reflect upon the fact that they are determined are capable of freeing themselves. Their reflectiveness results in the exercise of a profoundly transforming action upon the determining reality. Consciousness of and action upon reality are, therefore, inseparable constituents of the transforming act by which men become beings of relation." Critical action is here understood as the behavioural component in the Freirean concept of *conscientização*, which is the process of acquisition or development of critical consciousness. Critical consciousness is composed of three mutually reinforcing elements, namely critical reflection, critical motivation, and critical action (Diemer et al., 2015; Watts & Hipolito-Delgado, 2015). Critical reflection refers to the process of learning to distinguish culture from nature, or in other words, of acquiring a perspective that allows for social constructs and structures to be perceived as questionable and malleable, instead of being regarded as inescapable, naturally imposed realities. Critical motivation is an individual's perceived capability and commitment to contribute to social advancement through the reinvention of social structures that enable unjust, oppressive, harmful, or unhealthy conditions. Finally, critical action refers to the engagement in action dedicated to producing socio-political changes perceived as conducive to more just and healthy conditions (Freire, 1978; Watts et al., 2011; Jemal & Bussey, 2018). *Conscientização*, thus, can be understood in the words of Paulo Freire as the process of "learning to perceive social, political, and economic contradictions, and to take action against the oppressive elements of reality" (2000, p. 35)

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Culturally Responsive Teaching with Art

One form of critical action is art-making, given its capacity of encompassing the conceptual components of critical consciousness. Art is a powerful way to address global issues across cultural contexts. Teachers play a crucial role in this endeavour, enabling students to connect their lived experience to issues and ideas, culture and community. According to Stephen K. Levine:

> By creating an alternative world of the imagination, the artwork shows possibilities that are absent or dormant within our everyday awareness. Moreover, the work takes us away from this everyday world within which we experience ourselves as unable to act; we could say that it "decenters" us from this world. In so doing it frees us up for new possibilities that were not apparent within our limited horizon of understanding. […] Artmaking is itself a sensory-affective experience that gives participants an experience of their own capacities for action. Because it affects us through the body and the emotions, artmaking can provide experiences that restore us to a feeling of being fully alive. And in making the work, by acting within the limited frame of the materials and the time and space available, we recover our capacity to be effective in the world, something that we have lost in the helpless situation in which we find ourselves. (2011, p. 28)

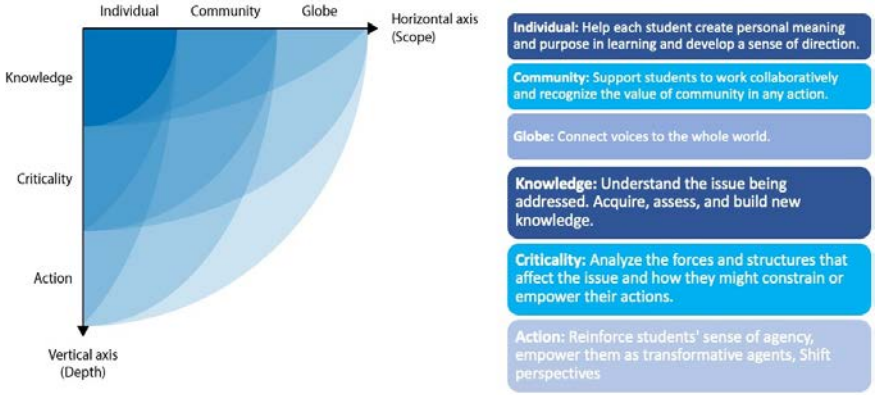
In this sense, the process of artmaking awakens our "dormant" ability for critical reflection, triggers our critical motivation by helping us to perceive ourselves as "able to act", and "recovers our capacity" for critical action. There is a long history of using art education to confront issues of race, cultural discrimination or various forms of othering. According to Ladson-Billings' (1995) framework, arts-based pedagogy should respond to students' cultural knowledge, prior experiences, frame of references, and diverse performance styles (Lai, 2012; Lee, 2012). The present study addresses cultural responsiveness through designing learning activities in what Lai describes as culturally familiar and creative ways (Lai, 2012) Moreover, the arts have repeatedly demonstrated a capacity of catalyzing social change. Art has the power to raise our consciousness, empower, advocate, and provoke (Estrella, 2011, p. 42).

Communities of Learners

A final theoretical element for this work is that of learning communities, which can support collaboration and progressive discourse (Brown & Campione, 1994) a deep focus on ideas (Scardamalia & Bereiter, 2005), and collective forms of inquiry in which the community creates a knowledge base that serves as a resource for individuals and small groups (Slotta, Quintana & Moher, 2018). Critical action that occurs within the context of a community of one's peers can add meaning and purpose to the community, democratize learning, and support individual members as they develop an identity within the community context.

This study was conducted in the context of a particular professional learning community called the Critical Action Learning Exchange (CALE), which helps teachers develop curriculum lessons that empower students in the face of social, economic and political issues in a rapidly changing world (Carvalho et al., 2021). CALE supports teachers in the design of culturally responsive learning activities that encourage students to connect to global issues through their own personal and cultural lens moving from knowledge to action as explained in Figure 1.

Figure 1
The CALE framework



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Methods

Co-design is a participatory approach that brings together researcher's knowledge and lived experiences of the participants (Roschelle & Penuel, 2006). Our workshop was designed in partnership with a teacher-leader from the school, five classroom teachers and administrators. Identified priorities and indicators of success of the workshop were negotiated and tailored to the needs of the school in their local, temporal context. The timing of the workshop around the Hindu festival of Diwali was important to the school, since the festival itself represents the victory of good over bad, light over darkness and the need to act against the evils of society. Indian teachers chose the traditional art form of Rangoli for its familiarity to students and cultural appropriateness. The school had previously organized similar Rangoli festivals (see Figure 2), celebrating a folk-art rooted in 5000 years of tradition. But it had never been done as a source of critical action.

Figure 2
Rangolis drawn by students in the school in previous years

As a CALE curriculum, the Rangoli activity was designed to link to the six components of the framework shown in Figure 1. Students set out to investigate social issues by participating in a school-wide brainstorming activity during the weekly assembly and continued building knowledge around these issues (Knowledge). They then came together as groups, bringing in their individual ideas and visions for change, and reflecting on their positioning. They also investigated the forces that impact their chosen issue (Criticality). Working together, they determined what should be depicted within the Rangoli and how it would hopefully affect an audience of the wider school community (Action). Each student was given the opportunity to bring in their unique competencies and artistic skills (Individual), engaging in peer exchanges of ideas within their group. A learning community approach was adapted to move students from a competitive mindset to a collaborative one (Community). Finally, the Rangolis were on display for the school and shared with the research group in Canada. Pictures of the Rangolis serve as discussion artifacts showcased on social media with the goal of increasing the engagement of educators, researchers and students around the world (Globe).

Participants

Six teachers (including one teacher-leader who coordinates teacher professional development) from a secondary school in Bengaluru, India were engaged in the design of this curriculum, along with six members of the CALE research team in Canada. Participation in the *Rangoli Utsav* was open to all students in Grades 6-10. Interested students submitted their names and themes of interest, individually, or in pairs to their respective teacher coordinators. A total of 82 students, 63 of whom identified as girls and 19 as boys, signed up to participate in the workshop. These participants were surveyed verbally on whether they have engaged in critical action-oriented activities or Rangoli art before. While 72% of participants indicated some experience with Rangoli, none of the participants indicated any previous participation in critical action-oriented activities. The teachers then collectively deliberated on group formations based on student requests, interests, experience, synergy and motivations. 12 groups were formed of 6-7 students each; 4 students excused themselves from the groups and opted to be community helpers through the planning and execution of the workshop.

Procedure and Data Sources

While the brainstorming for the issues of significance to the community took place as a collective whole-school activity, interested participants gathered in their small groups to share their ideas on specific themes of interest.

Each group shared their top choices with other groups a few days prior to the workshops. Collectively, with some mediation from the teacher-leader, themes for each design were confirmed and adjusted to suit the group's interest and the community's collective voice. Students worked in their small groups on design ideas over a weekend, sharing their hand drawings, topic research, artistic ideas, design recommendations and individual motivations with each other on Monday. They also finalized some images, symbols, materials or any other visual elements that could be included in their Rangolis. Three examples of their progressive visualization of the issues can be seen in the drawings in Figure 2. Finally, they created group artist statements that discussed the social or environmental issue their rangoli addressed and highlighted important information around the issue they wanted to share with their community.

Figure 2
Students' iterative visualizations of their Rangoli themes

On the day of the workshop, students gathered in their groups in a large auditorium and worked collaboratively alongside other groups for a little over 2 hours. Some pictures and videos of their group discourse were captured by the community helpers. These helpers also played music, fetched supplies and proved to be an idea-soundboard to the teams. The completed Rangolis (Figure 3) were on display to the whole school community for the day. Upon requests from parents and teachers from neighbouring schools, the Rangolis were kept on display for an additional day to enable students from the other school to visit.

Analysis and Findings

To understand the ways in which our critical action workshop supported students in expressing their understandings of global issues that mattered to them, we performed an interpretive analysis (Sgier, 2012) on the data collected through artist statements, student artifacts, teacher and student discourse, workshop pictures and videos. Throughout the analysis, we sought to identify patterns of coherence, as well as anomalies to these patterns. Trustworthiness (Shenton, 2004) was established through a debriefing with the participants, iterative questioning, member checks, peer-scrutiny and thick descriptions.

Co-design Analysis

The co-design method had many benefits, including grounding our workshop in the local context of the school community, and enabling enthusiastic participation. As the teacher-leader noted, in her reflection, *"…they (the participants) have been so enthusiastic about the whole event …. they were so engrossed in doing it and immersed in the experience they didn't even want to have a break"*. In this project, co-design of the activities with teachers at the school achieved informal-mutual learning through (i) sharing past practices of community activities (ii) building common understanding around critical action; (iii) construction of shared meanings on arts-based pedagogy; and (iv) idea-generation.

Critical Visual Analysis of Artifacts

Instead of looking at the formal artistic elements such as line, value, shapes, forms, spaces, colour and texture, we analyze students' artistic creation using a Critical Visual Analysis (Aiello, 2006) in which the primary concern is students' perception of the critical issues, the ideology behind their creations, the iconographies students employed, and the use of social semiotics in illustrating the problems and solutions. Students' creations show a range of evidence of their perception of global issues: five rangolis included a representation of the globe; four

included a representation of a Hindu deity, demonstrating that students are employing icons from their traditional culture; eight out of 12 groups also expresses students' ideologies through the implementation of texts, such as "Her tears will not correct this imbalance, actions will save the girl child". Among the 12 pieces, the *Woman Empowerment* (see Figure 3) is a good example of students creating meaning through redefining the social semiotics of an Indian goddess as a determined woman. Students' embodied, collective Rangoli art populated their physical space with critical messages that connected global issues with their local culture.

Figure 3
Students' completed rangolis

Learning Community Analysis

Working together as a learning community required learners to work cooperatively and collaboratively to actively engage in a variety of interactions and intercommunications (Slotta et al., 2018). The embodied nature (walking a large floor to see a physically distributed set of these) was also understood as an important aspect. All teachers and researchers commented that the community-oriented nature of this design was instrumental to its success: students from the whole school created a large, spatial, cultural and conceptual artform, which then became the focus of a community event. Students worked collectively to define themes, then broke into teams of mixed grade levels to create a community product. Table 1 presents a view of the major activities, in terms of the community elements (individual, group or whole school), and the interactions they supported.

Table 1
Analysis of activities before, during and after the workshop

Activity name	Community elements *(# participants)*	Interactions
Brainstorm	School Community *(418)*	Real-life examples of issues contributed by every student who wished to, Idea build-ons
Sign up	Individual/Pairs. *(82)*	Identify themes of interest, generalize, contribute new ideas
Group formation	School Community (12 groups)	Teachers' facilitation of group-forming process
Theme selection	Group (12 groups)	Argumentation, negotiation, collaborative discourse
Rangoli design - ideation	Individual (78)	Exploration of issues, visualization
Rangoli design - iterations	Group (12 groups)	Visualization, collective exploration, new knowledge sharing, problem-solving, idea improvement
Material sourcing	Individual (78)	Critical thinking, negotiations, reflection
Rangoli - creation	Group (12 groups)	Embodied, tangible, problem-solving, deliberations, group idea cohesion
Artist Statements	Group (12 groups)	
Peer feedback	Individual/Group	Self-reflexivity, explanation, interpretation
Gallery walk - online	Globe (5)	Self-reflexivity, explanation, interpretation
Gallery walk – F2F	Local Community (600+)	Self-reflexivity, explanation, interpretation
Online Social Media Display	Ongoing	Interpretation, critical reflection

Several important outcomes can be identified within Table 1 relating to the impact of the learning community. First, a knowledge base was constructed, in the initial brainstorming of possible issues, which led to a balanced set of issues distributed amongst the design teams. Students in any working group were all able to see this overall spread of ideas and understand their own product and creative activities within that wider context. Second, reflection was supported by activities such as brainstorming, theme selection, and the actual Rangoli creation process. Third, the definition of groups was an outcome of the brainstorming and student voice, supported by a group of teachers. Fourth, creative resources and products emerged from the community. And finally, there was a powerful source of feedback and reflection from the community gallery walks.

Teachers interviewed at the end of the workshop suggested that the performative learning experience was helpful in supporting students' knowledge building around critical issues. They were surprised by the variety of curriculum concepts (such as greenhouse gases, malnutrition, epidemiological methods etc) that were depicted in the student artist statements. One teacher observed: "*...even different (curriculum) concepts should be taught through art. That way they don't feel the pinch or the burden of learning, and learning is more joyous than just-you know - through textbooks or lecture*". When reflecting on the lack of formal assessment of learning, another teacher said, "*I'm pretty sure if we ask them a question in the next assessment about this (their issue), they can write a lot because of this Rangoli...*"

Connections to the CALE framework

To determine how the critical action components of the CALE framework (the vertical axis in Figure 1) were addressed by this workshop, a content analysis was performed on the artist statements and student interviews, with a particular focus on student reflections during the process of Rangoli creation. Table 2 presents a summary of these findings. The main finding that emerged was that all groups (n = 12) appeared to understand what their issue was, the challenges of addressing the same, and the types of knowledge needed to effectively address them. Six of the 12 groups included short text descriptions within their Rangolis, to help the user interpret the issues. Also, four out of the 12 groups used their content knowledge to improve their artist statement and explain "their action". Interestingly, all four of those groups (Covid Warriors, Save Water, Save the Trees, One Planet One Chance) addressed the issues through a scientific lens. The "Good over evil" Rangoli, which showed an evil mythological villain with multiple heads, was unique in that, while it artistically portrayed a range of the issues, calling for action, there was no treatment of how these issues might be addressed. Individual interpretations of the

issue varied and were deeply rooted in students' own personal contexts. For example, while one student working on the "Remove your Obstacles" Rangoli (which addressed the issues around mental wellbeing) reflected on the symbolism of the elephant (big ears so we can listen more, big belly to laugh etc.), another student visualized the elephant as "path makers in a forest that lead the way", and another interpreted the same from a religious viewpoint, "you pray to Ganesh…". Groups also built on each other's calls to action, "education is the way to bring people out of slums and out of poverty". The most common theme that was found in the analysis of their artist statements and reflection was a call to the collective, "We Indians need to…", "it is necessary for every person in the country." etc. Finally, while the actions called for were not always critical in nature, they informed the community of its role in tackling these issues.

Table 2
Analysis of Rangolis

Rangoli	Theme	Actions	Community Connections
1.One Planet, One Chance	Global Warming, Personal lifestyle, Carbon footprint	Plant more trees, reduce carbon emissions	Global warming recognized as a "world problem". Questioning role of cities
2. Save the trees	Sustainable lifestyle, Forestry, Cultural sustainability	Respect and pray to nature (tulsi pooja), don't cut trees, participate in social national movements	Chipko (national) movement, Worship trees as a family
3. Women Empowerment	Gender equity, social issues,	Need to respect women. Help our mom and other women every day. Big goals for careers (girls)	Durga (goddess of courage) reimagined. Government policy connections
4. Remove your obstacles	Whole person, Mental wellness, Positive thinking	Self-assertion is important, "you can, you will, you do"	Lockdowns hard on us (Bengaluru). Be a path maker
5. Pandemic Warriors	Social movement, Public health, Social health	Respect frontline workers, get your vaccine, encourage others to get their vaccine shot.	Recognition of 'warriors'. Role of media (portraying India on world stage)
6. Yoga for Health	Whole person, Health, Personal Lifestyle	Practice yoga every day. Include it as part of school day	Recognition of yoga as an ancient practice, leaf arms
7. Save Water	Climate change, Personal lifestyle, Water footprint,	Critical thinking, negotiations, reflection	Embodiment of water
8. Farmers are our Future	Food sources, Food waste, Food justice, Environmental justice, Social justice	Embodied, tangible, problem-solving, deliberations, group idea cohesion	Support local farmers that involved social movement
9. Save the Girl Child	Gender Equity, Gender justice, Social movement	Change the social view toward gender equity, Stop abortion	Make an awareness in the society
10. Gender Equality	Gender equity, Social issues, Equal Participation	Make an equal situation for all men and women in all areas	Bring equality needs efforts of the whole community
11. Good over Evil	Various socio-political issues	Awareness of various critical issues	Representation of Diwali, victory of Lord Ram
12. Population Explosion	Climate change, Food justice, Social equity, Personal lifestyle, Sustainable future, poverty	Control population, Increase the quantity of the food, Save more water	Over populations make various issues for the whole community that required the collective action

Discussion

The CALE framework encouraged students to bring criticality and voice to their artistic designs through knowledge sharing. This was evident in the significant divergence of the Rangoli activities that occurred during this year's Diwali festival from those of years past. The framework provided pedagogical support for increasing both the scope and depth of students' critical inquiry. It helped them expand the range of their ideas, building

connections beyond the individual level, to include their broader community (e.g., farmers, health care professionals, teachers, the police) and the whole world (e.g., global warming). It also supported students in going progressively deeper in their ideas, helping them build knowledge about their local issues, engaging them in critical reflection, and engaging in critical action through art making. Thus, arts-based critical making enhanced students' expression of their ideas. Through collective inquiry on critical issues, connected to local cultural contexts, students perceived a sense of relevance, participation, and empowerment during this process. This experiential learning activity became a practice of meaning-making by designing, implementing, and sharing with others in their own community.

Conclusion

During the ICLS 2020 symposium on "Reconceptualizing Learning: A Critical Task for Knowledge-Building and Teaching" (de Royston et al., 2020) highlighted the importance of understanding participation in cultural practices as being fundamental to the study of learning, calling upon the community to engage in and with such "foundational work" at this critical time. The present research demonstrates some of the challenges and opportunities of situating learning in and within the cultural practices of students in India. Yet this is just the start. More work is still needed on how to extend our learnings to other contexts and develop guidelines for culturally responsive curriculum designs that go beyond the traditional definitions of learning by supporting student agency, knowledge building and growth as empowered citizens.

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International Society of the Learning Sciences

The instructional legacy of COVID-19: Teacher adaptation in response to the pandemic

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Abstract: While being adaptive is a key characteristic of effective teaching, teachers can be resistant to change. In Spring of 2020, American teachers transitioned suddenly to distance learning because of the COVID-19 pandemic. This presented an opportunity to investigate teacher adaptations to extreme changes in teaching conditions. A survey study of 71 K-8 teachers conducted in Spring of 2020 found that teachers engaged in three of the core practices of adaptive experts. Moreover, most teachers planned to transfer what they learned to adapt future in-person teaching, and 30% of teachers planned to adopt transformative teaching practices. One positive outcome of the pandemic is that it promoted teacher adaptation and may have even prompted some teachers to develop lasting new practices.

Introduction

At the height of the COVID-19 pandemic in Spring of 2020, most K-12 schools in the United States closed, and teachers and students were suddenly forced into distance learning. Almost overnight, teachers were expected to shift from teaching in-person to teaching remotely under drastically new conditions. Many K-12 teachers had never taught virtually prior to this pandemic, and as such were required to adapt to these new conditions with very little prior experience or familiarity with digital tools and technologies (Herold, 2020; Mupinga, 2005). While these changes produced several challenges for teachers and students, they also presented a unique opportunity to study teacher adaptation to very novel conditions.

Teacher adaptation

When teachers adapt, they *change their teaching practices in response to new student needs, situations, or challenges*. For example, to support a new student who is an English language learner, a teacher might adapt his lessons to include visual instructions. To implement a new inquiry-based curriculum, a teacher might adapt her pedagogical style to include more questioning and challenging of student thinking. This kind of adaptivity has been lauded as a key characteristic of effective teachers (Borko & Livingston 1989; Corno, 2008; Darling-Hammond & Bransford, 2005; Fairbanks et al., 2010). Furthermore, research suggests that adaptive teaching can boost student achievement (Collie & Martin, 2017; Gambrell et al., 2011; Hattie, 2009). However, adapting teaching practices is difficult. For example, in observing 51 elementary literacy teachers over a 9-year period, Hoffman & Duffy (2016) found that teachers seldom adapted their instruction significantly, often sticking to preset scripts. Other studies have shown that teachers struggle to adapt in response to new curricula (Duffy & Roebler, 1986), technology (Cuban, 2001), educational reforms (Hiebert & Stigler, 2000) and professional development (Ketelhut et al., 2020; Hamilton, 2018).

Adaptive expertise and adaptive practices

Teacher adaptation has been associated with many overlapping constructs such as adaptability (Collie & Martin, 2017), improvisation (Borko & Livingston, 1989), thoughtful teaching (Fairbanks et al., 2010), teaching adaptively (Corno, 2008), and teachers' adaptive expertise (De Arment et al., 2013; Lin, Schwartz, & Hatano, 2005; Schwartz, Bransford, & Sears, 2005). In this paper, we view teachers' adaptations through the framework of adaptive expertise, which was proposed by Hatano and Inagaki (1986) to describe expertise in many domains.

Adaptive expertise is often defined in contrast to routine expertise. Routine experts are highly efficient and accurate when performing under conditions that do not change. In contrast, adaptive experts are able to adapt to the demands of a novel situation. They can invent new procedures when situational demands call for it, let go of old ways that are suboptimal, and seek to continually learn and grow. For example, a routine expert teacher might deliver lessons that are highly effective under typical conditions. However, when conditions change - a new curriculum, new standards, new assessments, new kinds of students - this teacher would falter. On the other hand, a more adaptive teacher would nimbly adjust and modify lessons appropriately for each new context.

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In this paper, we do not study expert teachers per se, but we use the framework of adaptive expertise to identify *adaptive practices* that teachers might adopt when thrown into the novel conditions of distance learning. Adaptive experts engage in three core adaptive practices. In this study, we looked for self-reported evidence of each of these three adaptive practices in K-8 teachers. First, adaptive experts can perceive new needs or *challenges* that call for adaptation (Lin et al., 2005). Without perception of a new need or challenge, there is no motivation to change. To assess this, we asked teachers to describe the key challenges they faced in designing instruction for distance learning. Second, adaptive experts modify or adjust current practices in response to new needs and challenges (Martin & Schwartz, 2009). We call these *reactive adaptations* because they occur in response to a perceived challenge. To assess this practice, we asked teachers to explain how they had changed their teaching during distance learning. Third, adaptive experts engage in *prospective adaptations* which are motivated by a desire to continually learn and improve their performance in the long-run, rather than in response to an immediate need (Martin & Schwartz, 2009). To assess prospective adaptations, we asked teachers what they planned to change about their teaching upon return to the in-person classroom.

How did teachers adapt to distance learning during COVID-related school closures?

A small body of emerging literature explores how teachers adapted their instruction during COVID-related school closures. We focus our review of this literature on evidence related to the three core practices of adaptive experts discussed above.

There is research suggesting that teachers faced several *challenges* during the transition to distance learning. Chief amongst them is lack of access to technology and/or internet connections (Francom, Lee & Pinkney, 2021; Simmons, 2020) and low familiarity with online learning tools and technology for both students and teachers (Anderson & Hira, 2020; Blagg & Luetmer, 2020; Doiron & Marsigliano, 2020; Herold, 2020; Mupinga, 2005; Saad & Sankaran, 2020). Studies also report high rates of absenteeism among students during the pandemic, particularly in less advantaged rural and urban populations (Anderson, 2020; Bintliff, 2020; Leech et al., 2020). One survey study suggested that teachers met with instructional challenges, such that 55% of teachers said that their lessons hadn't translated well to distance learning (Leech et al., 2020).

Most of the research documenting *reactive teacher adaptations* in response to COVID-related distance learning focuses on the adoption of new technological tools and their use. It is not surprising that teachers began using new technological tools, such as video conferencing platforms like Zoom and learning management systems such as Google Classroom to enable online mediums for previously in-person activities and functions. Teachers also adopted technologies for communication with parents, such as ClassDojo (Francom, Lee & Pinkney, 2021; Lieberman, 2020; Leech et al. 2020). There is also evidence that teachers engaged in new practices, such as pre-recording their lectures for students to watch on their own time (Pilkington & Hanif, 2021) or organizing virtual social gatherings to provide social and emotional support to students (Chamberlain et al., 2020).

Little research examines *prospective teacher adaptations* or planned future changes to teaching after the pandemic. One study found that teachers planned to continue using many of the technological tools discussed above to record their lectures, communicate with students more frequently, or even take students on virtual field trips, which suggests a positive outcome of COVID-19 (Francom et al., 2021). However, this study focused on technology adoption, not teacher practices.

A few patterns emerged from this literature review. The majority of the research on teacher adaptation during the pandemic was conducted in the context of higher education, used case study methods, or focused on technology. In contrast, our work examines K-8 teachers, uses survey methods, and focuses more broadly on teacher practices. Moreover, most research describes what teaching looked like during the pandemic, but very little work has explored how the pandemic could spur long-term changes to teacher practice upon a return to in-person instruction. Finally, we have not come across other papers that use the adaptive expertise framework to examine pandemic-related teacher change. We aim to fill these gaps with the current study.

The Current Study

In this study, we investigate teacher adaptation during the pandemic by surveying K-8 teachers about use of three adaptive teacher practices: (1) perception of **challenges** associated with distance learning, (2) **reactive adaptations** during distance learning (or adaptations made in response to new needs or challenges), (3) planned **prospective adaptations** for future in-person learning (or changes intended to be long-term improvements). This led us to examine the following research questions:

1. To what extent did teachers perceive challenges of distance learning, engage in reactive adaptations in response to the new conditions of distance learning, and plan to make prospective adaptations upon return to in-person learning?

2. What kinds of COVID-related challenges, reactive adaptations, and prospective adaptations did teachers experience?
3. To what extent did teachers plan to make prospective adaptations that were transformative to their teaching? What kinds of planned prospective adaptations were transformative in nature, signaling possible long-term changes in K-8 education?

During the sudden shift to distance learning, we expected that teachers would perceive many new challenges to teaching and respond by reactively adapting their teaching practices to meet at least some of these new challenges. Given the extremely novel conditions posed by distance learning, one could argue that teachers were essentially required to adapt their teaching to some extent, and we found some evidence of teacher adaptation during COVID-19 from our literature review. However, a more open question for us was whether the pandemic would spur teachers to plan prospective adaptations when they returned to in-person learning. While we found evidence that teachers may use newly learned technology after the pandemic (Francom et al., 2021), we were interested in better understanding the extent and types of planned changes to future teaching practices. In other words, would this experience of distance learning cause lasting changes to teachers' practices? Or would teachers simply go back to their old, routine ways of teaching once the pandemic ended?

Methods

Sample

In May and June of 2020, 71 K-8 school teachers completed the survey study. Teachers hailed from 8 public and 4 charter schools throughout New York and Connecticut. Overall, the sample contained teachers associated with a variety of different grades, subjects, experience levels, school types, and student SES levels. Our team contacted 103 principals across two states for whom contact information was publically available, inviting their school to participate in the study. About 23% of teachers who received the survey completed it.

Survey

While the survey included several demographic questions, this paper focuses on three open-ended survey questions about teaching both during and after the pandemic:

1. What key challenges have you faced in designing instruction for distance learning? Give one or two examples.
2. In which ways have you had to change your teaching practices to meet your students' needs during distance learning?
3. Is there anything you have learned from your experience with distance learning that will change how you teach once you are back in the classroom? If so, please describe.

Measures and Coding

Responses to questions 1-3 were coded for *types* of challenges, reactive adaptations, and prospective adaptations, respectively. Additionally, responses to the third question were coded for prospective adaptations that were *transformative*. We conducted primarily bottom-up, emergent coding of the types of challenges and adaptations, with some top-down coding based on our definition of adaptation (Chi, 1997). Each response was coded by two coders and acceptable interrater reliability was achieved ($\kappa > .7$).

Types of challenges & adaptations (reactive and prospective)

Nine types of challenges and adaptations emerged from the data. We coded for these in all three questions. Coding categories were not mutually exclusive. These categories were: (1) lessons and instructional design (*how* teaching happens), (2) curriculum, goals and expectations (*what* is taught), (3) engagement and motivation, (4) technology access and learning (as it relates both to teachers and students), (5) differentiation, (6) non-instructional teacher responsibilities (such as providing technology support to families), (7) assessment and feedback, (8) student autonomy, and (9) communication (with students and families).

Identifying prospective adaptations that transform the classroom

We looked more deeply into the prospective adaptations category to identify prospective adaptations that had the potential to transform a teacher's practice. We noticed that some prospective adaptations were improvements or variations on existing practices. Yet other prospective adaptations were more significant -- they represented a new teaching practice or a big change relative to the teacher's practice before the pandemic.

We call these **transformative adaptations**. For example, using a virtual platform to provide engaging visuals during a lesson is an improvement to an existing practice, as the tool enhances the lesson, but it does not create a significant change in the classroom. However, a new type of instructional design, such as a flipped classroom model, constituted a significantly new practice, potentially transforming the way students learn.

Results

Extent of reported challenges and adaptations

All teachers, save one, perceived challenges during distance learning (Table 1). Similarly, the vast majority of teachers (96%) reported reactively adapting their practices in some way during the pandemic to meet their students' needs. This was not surprising, given that distance learning created drastically new conditions requiring some level of adaptation. More surprisingly, 89% of teachers planned prospective adaptations to in-person teaching practices. The surprisingly high percent of teachers planning to change future practices suggests that post-pandemic classrooms may look different. These outcomes did not vary by teachers' characteristics, such as years of experience, subjects taught and grade.

Table 1
Percent of teachers who describe at least one challenge, reactive adaptation, and prospective adaptation.

Adaptive Practices	% Teachers
Challenges	99%
Reactive Adaptations	96%
Prospective Adaptations	89%

Types of challenges, reactive adaptations, and prospective adaptations

Figure 1 summarizes the prevalence of each type of challenge and reactive adaptation teachers experienced during distance learning, as well as planned prospective adaptations to future classroom practices. Bars represent the percent of teachers who mentioned each type of challenge, reactive adaptation, or prospective adaptation. Our description of these results will highlight the three most prevalent categories of each measure.

Challenges teachers perceived in Spring, 2020

The challenges teachers reported (Figure 1, blue bars) were broadly distributed across many categories, suggesting teachers perceived a range of challenges. The most frequently mentioned challenge was lessons and instructional design, mentioned by 44% of teachers, who often cited limitations in the modes of instruction and inability to incorporate hands-on materials, such as math manipulatives. Student engagement and motivation was the second largest category of challenges (37%), and included challenges related to poor participation, and difficulty keeping students motivated to learn. Technology was the third largest category (28%), with teachers reporting lack of student access and difficulty learning new technology.

Figure 1
Prevalence and types of reported challenges, reactive adaptations, and prospective adaptations

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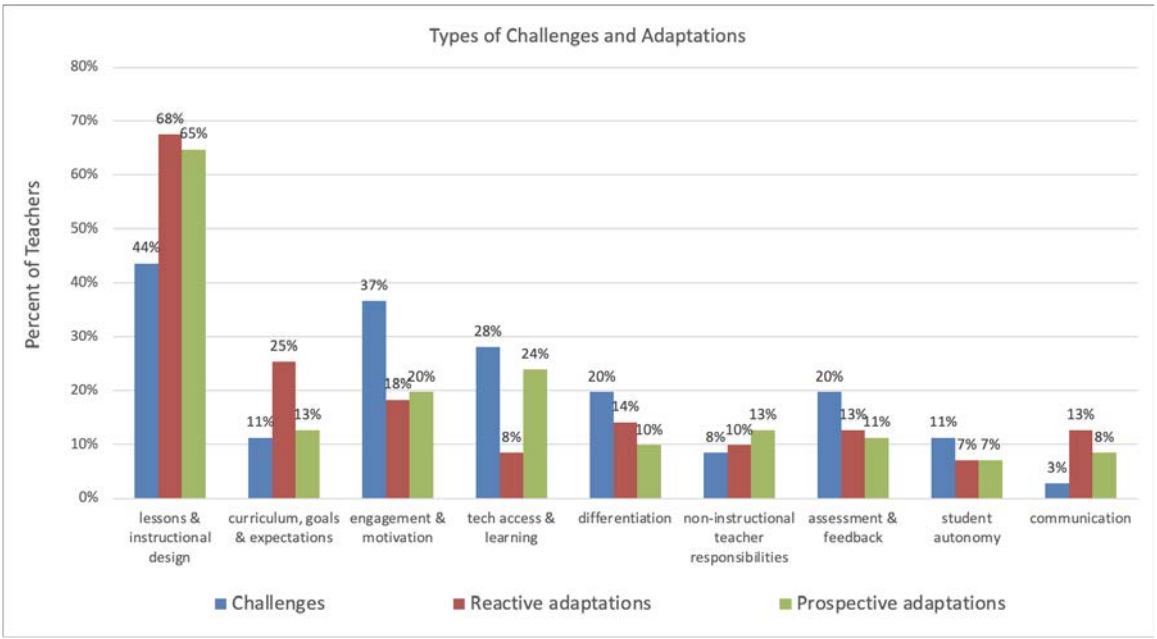

Reactive adaptations implemented in Spring, 2020

The majority of reactive adaptations (68%) were to lessons and instructional design (red bars in Figure 1). These included incorporating new technology, use of tutorial videos, shortening lessons and assignments, higher levels of direct instruction, reduction of discussion and group activities, use of drawing and visualizations in the absence of manipulatives, and use of culturally authentic resources, such as dialogues, videos, posters and flyers. Adaptations to curriculum, goals and expectations comprised the next largest category of adaptations (25%), and included reduction or re-prioritization of content, and reduced goals and expectations. Finally, adaptations aimed at engaging and motivating students were the third largest category (18%). Examples include giving short, simple tasks to increase engagement and showing greater patience with work completion and outside student challenges.

Prospective adaptations to future in-person instruction

65% of teachers planned to adapt in-person lessons and instructional design based on what they learned during the pandemic (green bars Figure 1). This includes providing clearer and more concise directions, creating more effective visual aids, reducing speaking time by focusing on key ideas, and allowing more time for student practice. 24% of teachers reported they would make changes involving technology access and learning, by incorporating newly learned technology into the classroom. 20% of teachers planned to improve student engagement in the future, by utilizing culturally relevant resources, allowing students to respond to teacher feedback using digital tools, and promoting online student-to-student discourse. In comparison to adaptations during distance learning, fewer teachers reported future changes to curriculum, goals and expectations, suggesting these types of changes may have been short-term responses to reduced instructional time during the pandemic.

Prospective adaptations that transform the classroom

30% of teachers reported planning to implement a practice that would transform their classroom after the pandemic. Four themes emerged in the types of significantly new practices teachers reported: expanding the learning environment, new instructional approaches, expanding the learning community, and a new focus on student needs. Examples of these transformative adaptations are provided in Table 2. These new practices can provide insight into the types of changes we might expect to see in post-pandemic classrooms.

Table 2
Emergent themes and examples of transformative adaptations

Theme	Examples of transformative adaptations
Expanding the learning environment (n = 12)	• Creating resources that students can review at home • Creating digital resources students can use to make up for absences • Pre-teaching concepts digitally before teaching them in class
New instructional approaches (n = 9)	• Providing online resources for students to use at their own pace in class • Implementing a flipped classroom model
Expanding the teaching community (n = 5)	• Sharing resources to help parents identify signs of learning loss • Providing families and other teachers visibility into tools such as Google Classroom to enable better support of students • Giving students and parents access to learning materials at home • Weekly family newsletters
New focus on student needs (n = 5)	• Intentionally creating moments for students to feel connected and happy • Designing opportunities for students to develop social relationships • A new focus on praising for effort • Advocating for more resources for students with disabilities

Discussion

During the COVID-19 pandemic, teachers were suddenly forced to teach remotely. This may have had the hidden benefit of provoking teacher adaptation. In fact, we found evidence that teachers engaged in three of the core practices of adaptive experts during the pandemic. First, all of the teachers we surveyed (save one) perceived key challenges that motivate the need for adaptation. Teachers faced challenges in adapting their in-person lessons to an online format, motivating and engaging their students, and supporting technology learning and access. Second, almost all teachers reactively adapted their practices in response to the new challenges. They modified instruction for an online format, re-prioritized content due to limited instructional time, and simplified or shortened tasks. While challenges were broadly distributed across categories, teachers most often reported adapting lessons and instructional design in response to those challenges. One possible explanation is that teachers have significant control over lessons and instructional design, and are most comfortable enacting changes in that area. Third, most teachers in our study planned to prospectively change future classroom practices by applying what they learned during the pandemic to future in-person teaching. Overall, our evidence suggests that the pandemic acted as a catalyst for teacher adaptation.

Even more promising is the finding that 30% of teachers planned to adapt their future practices in ways that could transform their classrooms. Teachers learned a great deal from the experience of remote teaching which may have motivated them to adopt entirely new practices. Given the many examples of failed uptake of reforms by teachers (Cuban, 2009; Duffy & Roebler, 1986; Hiebert & Stigler, 2000), we find this to be a particularly encouraging result. The instructional legacy of the pandemic may be that it provoked some teachers to make major changes to their practice.

Why was the experience of remote teaching during the pandemic so successful at promoting teacher adaptation? We did not collect data on this directly, so we can only speculate. However, we see a parallel between the conditions of remote teaching during the pandemic and learning activities that promote the development of adaptive expertise. One way to develop adaptive expertise is to provide learners with exploratory, inventive learning experiences (Kapur, 2008; Schwartz & Martin, 2004). The pandemic may have provided a similar sort of learning experience for teachers, where they freely experimented with new teaching methods under novel constraints. This is different from typical models for affecting teacher change, such as traditional professional development. Therefore, our work may carry implications for the design of teacher education. Future research should investigate whether professional development which allows teachers to explore the design of instruction under novel conditions might spur teacher adaptation and the development of teachers' adaptive expertise.

The emergent themes in teachers' transformative changes offer a possible silver lining of the pandemic. If the learning environment can be extended, students can access learning materials outside of the classroom and during absences. This may mitigate some of the negative effects of absences on academic performance

(Gottfried, 2011). Similarly, expanding the teaching community may allow greater family involvement in education which is important for academic performance (Weiss, Bouffard, Bridglall & Gordon, 2009). Specifically, keeping families informed and providing access to educational resources can facilitate out-of-school learning and support. New instructional approaches might allow for increasingly personalized learning, or other teaching models that offer benefits to students (Pane, Steiner, Baird & Hamilton, 2015). Finally, by focusing on student needs, teachers become more attuned to the challenges their students face, which may prepare teachers to better adapt to the needs of their students in the future. Additionally, the increased focus on social-emotional needs may motivate educators to adopt social-emotional learning interventions in the classroom, which can offer benefits for childrens' mental health and academic performance (Zins, 2004).

One limitation of this study is that the data are obtained from self-reports. Future research should aim to obtain additional evidence of teachers' adaptive teaching practices during the pandemic. Additionally, while we collected data on planned adaptations, we do not know which of these were subsequently implemented in the classroom. We are currently analyzing data from a follow-up interview study to investigate which types of adaptations are actually implemented and which conditions make those changes possible.

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International Society of the Learning Sciences

Combining Participatory Research with Responsible Research and Innovation to Develop Emerging Educational Technologies

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Abstract: The learning sciences have strong established practices of participatory research that encourage projects to be more relevant to today's educational issues. However, societal and personal considerations may also influence the relevance and impact of research. We propose using a Responsible Research and Innovation framework to build on participatory methods in the learning sciences and formalize a process for considering a project's broader context. Through a case study on neuroadaptive technologies for teaching and learning, we demonstrate a methodology for Responsible Research and Innovation that can support participatory methods by encouraging reflexivity from researchers and anticipation of a project's future use cases.

Introduction

The learning sciences have strong traditions of community-engaged participatory research. These research methods take the design of learning systems into real-world settings, centering stakeholder voices during the research process (DiSalvo & DiSalvo, 2014). Participatory methods range from contributory, where members of the public contribute data to a project designed by scientists, to collaborative projects with more public input into design, analysis, or research dissemination, to projects entirely co-created by scientists and community members (Bonney et al., 2009). Methods like Participatory Design and Participatory Action Research tend towards a co-created model, bringing communities into research as collaborators to define key issues and develop plans of action (Jacobs et al 2016). Other methods like co-design are more scientist-led but still engage deeply with members of the public in developing and evaluating solutions to educational needs (Roschelle et al. 2006). Participatory methods in the learning sciences often bring in students, teachers, and parents to create research that is more relevant and ideally provides benefits to the stakeholders involved in that research (Jacobs et al 2016).

However, societal and personal considerations beyond participation are necessary for the development of more responsible and relevant research agendas. A recent article by Selwyn (2021) brought to question the future of educational technology amidst a global landscape of recent disasters, including the COVID-19 pandemic. Selwyn argues that, while the field has made significant progress to improve learning and teaching, it has overlooked the potential of major disruptions and failed to anticipate the kinds of adaptations required by something like a global pandemic. Unintended consequences may also arise outside of global disasters, for instance out of a dominant trend in human-computer interaction to assume that race does not affect technological interactions. As Rankin & Henderson (2021) demonstrate, the common practice of ignoring race has led to erasing certain racial groups from the discussion, tokenizing Black children in participatory research, and a suite of other consequences. Following this line of thinking, public participation alone is not enough to anticipate major shifts and consequences in education; participation must be paired with an orientation to anticipate future societal contexts and with reflexivity from researchers to challenge their own biases and assumptions.

We propose that Responsible Research and Innovation (RRI) can extend the tradition of community-engaged research in the learning sciences to consider additional societal and personal factors. In other words, RRI is novel in contributing a broader iterative framework for responsible societal development of educational technologies. RRI ties the social and scientific together by emphasizing the need for **anticipation, inclusion, reflexivity,** and **responsiveness** (defined later in this article) in research and innovation approaches (Stilgoe et al., 2013; Stilgoe & Guston, 2017). Like Participatory Design and Participatory Action Research, RRI emphasizes researcher responsiveness to public input. However, RRI takes participatory methods a step further by highlighting the importance of researchers considering their pre-existing assumptions (reflexivity) and anticipating future technological landscapes. RRI can apply to future research landscapes globally or can pare down the scale to think about the future of a very specific technology (as we use it in this article).

Responsible Research and Innovation

Responsible Research and Innovation stems from the field of Science and Technology Studies, which acknowledges that science and culture are co-created and thus governance, innovation, and research must assess the socio-cultural systems that influence science and technology (van Atteveldt et al., 2019). There are multiple definitions of RRI but one of the most resonant from Stilgoe et al. (2013) defines RRI as a "means of taking care

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of the future through collective stewardship of science and innovation in the present." RRI contains four key components that call for (1) early **anticipation** of research consequences through (2) **reflexivity** (i.e., self-reflection and reassessment of pre-existing assumptions), (3) **inclusion** of the public in technological or research development, and (4) **responsiveness** of researchers and tech designers to components 1-3 (Stilgoe & Guston, 2017). One of the hallmarks of RRI is its reach to various sites of innovation; this means that RRI acknowledges that research projects alone are not charged with democratizing research and that every type of research stakeholder, including governments and funders, must consider the broader landscape of their work. The case study presented in this article decreases the scope of RRI to demonstrate how the framework can function on a researcher and single-stakeholder level that could then be integrated into a more system-level view.

In a review of RRI methodologies, Schuijiff & Dijkstra (2020) found that an RRI approach has been used most in the fields of nanotechnology and information communication technologies, with a few examples from other fields like synthetic biology. Schuijiff & Dijkstra (2020) found that researchers who incorporate RRI frameworks tend to focus on one of four methods in RRI: (1) Opening to stakeholders, (2) stimulating reflection from researchers and innovators, (3) anticipating ethical, legal, and socio-economic aspects, and (4) institutional-level responsibility. These RRI methods also include sub-methodologies. Opening to the public in RRI may involve creating narratives with multiple stakeholders, holding workshops, or other public engagement modes. Meanwhile, stimulating reflection can occur at different stages of research through facilitated workshops.

This project attempts to incorporate each component of Responsible Research and Innovation into the development of emerging educational technologies, specifically neuroadaptive learning tools. We primarily focus on methods to open up to stakeholders, encourage reflection, and anticipate context, excluding methods to encourage institutionalizing responsibility. Our case study incorporates each element of RRI into interviews with teachers and a workshop with researchers of a neuroadaptive learning technology project (see Table 1).

Table 1

Elements of Responsible Research and Innovation, their definition, and how they appear our case study

RRI Element	Definition	Implementation in Study
Anticipation	Exploring desired futures, alongside intended and unintended consequences of technologies before they are broadly disseminated	Teachers consider what their needs are in the classroom by discussing what superpowers they would like and reflect on the use of how neuroadaptive tools. Researchers consider how their project may be implemented in later stages of its development.
Reflexivity	Considering motivations, assumptions, biases, and worldviews driving innovation activities	Teachers reflect on choosing classroom technology, their views of tech in education, and their tech literacy. Researchers asked to explicitly state the assumptions they hold about the impact and use cases of their project.
Inclusion	Advancing deliberation amongst stakeholders to include perspectives on and knowledge of innovation	Teachers give feedback on the neuroadaptive learning tool and share cognitive states they'd find useful to know about their students. Researchers asked to think about how each part of the interviews can feed back into the project
Responsiveness	Translating the above practices into action as opportunities are identified	Researchers asked to define concrete steps to respond to teacher feedback.

Neuroadaptive Learning Technologies

In this paper, we extend the call for RRI to the development of emerging educational technologies, specifically neuroadaptive learning tools. Developments in portable brain imaging and machine learning have led to an increased interest in developing neuroadaptive technology and brain-computer interfaces (BCIs) for education that could assess a learner's cognitive state (e.g., frustrated, inattentive, etc.) and adapt in some way to that state (Wegemer et al. 2019; Liu et al., 2021). Our case study addressed an NSF-funded project that combines behavioral

data with non-invasive brain sensors from functional Near Infrared Spectroscopy (fNIRS) to capture a learner's cognitive state and adjust the learning experience appropriately in an Intelligent Tutoring System (ITS).

Neurotechnology research currently lacks a breadth of participatory research methods and would benefit from both a learning sciences perspective on participation and an RRI framing to contextualize research. Beyond a lack of participatory methods, research on neuroadaptive learning technologies seems misaligned with a broader educational context, potentially driven by technological novelty rather than social or educational issues. However, a lack of attending to social or educational issues does not mean that neuroadaptive learning technologies will not come to fruition. In a critical review of developments in educational neurotechnology, Williamson (2019) brings up emerging concerns such as invasion of student privacy and over-rewarding of specific cognitive skills. The review points out that studies of neuroimaging for education have led to inferences about quantifiable differences in brain function, for example differences resulting from socio-economic status, that could lead to tangible policy decisions. Even with some scientific skepticism about the accuracy of novel brain imaging devices, Williamson demonstrates that political support is emerging for commercial educational neurotech. The policy and social implications of such studies require that they be approached with attention to assumptions that are baked into the design and analysis of brain imaging, and with care for how findings are publicized.

In applying Responsible Research and Innovation to neuroadaptive educational technology, we aim to show how RRI can help reorient an exploratory educational technology to appropriate use cases that don't solely rely on technological novelty and consider potential downfalls. To the best of our knowledge, only one project to date has used an RRI framework in Mind, Brain, and Education research. van Atteveldt et al., (2019) conducted semi-structured interviews and focus groups with stakeholders to modify a neurofeedback intervention that aimed to improve learners' agency. They conclude that societal stakeholders are capable of deliberating on technical, social, and political constructs of innovation and that their viewpoints are necessary complements to researcher perspectives in the process of responsible research.

Building on the work of van Atteveldt et al., (2019) we are adding to evidence supporting the feasibility of RRI for emerging educational technologies, specifically brain-sensing learning tools. Actors in the educational neurotechnology space include researchers, educators, educational administrators, funders (private and public), companies, and policymakers (from local to federal), however, for the sake of feasibility in the case study, this research narrows in on the application of RRI between university researchers and teachers. We first gathered teacher feedback on the fNIRS project then conducted a workshop with the NSF project team to respond to feedback (as described further in the case study). By extending a Responsible Research and Innovation Framework to neuroadaptive educational technology research, we aim to:

1: Demonstrate a methodology for, and the merits of, integrating a Responsible Research and Innovation framework and participatory methods into emerging educational technology research.

2: Synthesize educator views on emerging educational neurotechnology and researcher responses to educator feedback. This synthesis is meant to inform and refine both the specific neuroadaptive tool in question (fNIRS for ITS) and future projects that aim to develop BCIs for education.

Case Study

We outline a case study that explored the feasibility of applying a Responsible Research and Innovation framework to neuroadaptive educational technology projects. We report on the project in question, then describe two initial pilot interviews, semi-structured interviews with teachers, and a workshop with the project team.

Project and Project Team

The NSF-funded educational neurotechnology project, initiated in 2018 with pilot research beginning 2-3 years earlier, aims to develop methods for using brain data in real-world educational environments by understanding changes in cognitive states during learning and broadly improving the design of an ITS. The project itself is focused on developmental math learning in college settings and singles out specific cognitive processes to study through brain sensing and behavior. The project examines frontal lobe activity using fNIRS during use of the e-learning system ASSISTments (Heffernan & Heffernan, 2014). The project team is composed of three co-PIs with expertise areas spanning fNIRS, human-computer interaction, machine learning, ITS, learning sciences, and cognitive neuroscience. The team also includes 3-4 PhD students, several undergraduates, and 2 teachers. Beyond participating in the workshop, the project team described here was not involved in designing, facilitating, or analyzing the case study in this article. Friedman had been an undergraduate research assistant on the project before beginning work on this case study, Kenner advised on all components of this case study, and Walker is a co-PI on the NSF project who advised on the framing and broader impacts of this case study after its completion. We acknowledge that two of the three authors on this article were very closely familiar with the NSF project.

Pilot Interviews

Methods

Pilot interviews were conducted prior to the beginning of the grant in early 2018 with two out of three co-PI's from the neuroadaptive learning project (one of whom was Walker prior to her involvement in this case study). These interviews asked the researchers about their backgrounds, the projects they're involved in, how they decide on collaborators in those projects, implementation or long-term goals for projects, and the funding landscape for educational and/or neurotechnology. Analysis of the pilot interviews then informed interviews with teachers.

Results

The primary finding from pilot interviews that influenced teacher interviews was that the two co-PI's were not clear on how they imagined the end use cases of the neuroadaptive technology project. When answering questions about end users, researchers instantly referenced use of brain-sensing devices in formal learning environments and then proceeded to question their assumption of formal learning applications. One researcher stated "we always talk about formal learning… [I] don't know why that's the case." On the other hand, both researchers talked about neurotechnology entering the market via gaming or self-directed learning. One researcher said it's possible that the technology could be used as a tool to teach students about technology without them ever actually using it.

Teacher Interviews

Teacher Recruitment and Demographics

Teachers were recruited for interviews through various venues including an NSF-funded Research Experience for Teachers (RET) at a northeastern university, a university research center, and personal connections. The RET program invites community college and/or high school teachers to spend three months working in a computing lab. Teachers received emails describing the interviews and asking if they knew others who may be interested in participating. Criteria for participation was simply that interviewees must be educators or teachers in high school/community college settings, could teach any discipline, and be in any phase of their career.

Teachers ranged widely in age (23-68) and number of years working as a teacher (ranging from one student teacher to 31 years of teaching). All the people interviewed taught STEM + Computing courses (computer science, chemistry, physics, digital media arts, biology, environmental science, math, astronomy, and makerspace directing) to grades 7-12, and 6 out of 11 teachers taught in private schools. The high proportion of private schools represented in our sample of teachers is a limitation in our study for the inclusion aspect of responsible research and innovation, however the demographics do not affect the ability to demonstrate an RRI methodology.

Teacher Recruitment and Demographics

Interviews with teachers were conducted in person and virtually from 2018-2019. Interviews aimed to understand teachers' experiences, gather feedback on the brain-sensing ITS, and fill in gaps that were identified in the pilot interviews. Questions were structured in five sections, two of which were tied to the anticipation and inclusion components of Responsible Research and Innovation:

1. *Teacher background:* inquired about current job, age groups taught, previous positions, teaching interests, and academic background.
2. *Information on technology use in the classroom (tied to reflexivity in RRI):* asked teachers to list the tools they use in the classroom daily or occasionally and probed about comfort with classroom technologies
3. *Speculation about future technology (tied to reflexivity and anticipation of future needs in RRI)*: teachers speculated about their current and future needs in the classroom by describing the superpowers they would like to have to help them do their job. This speculation was modelled after a study conducted by Holstein et al. (2017) that aimed to explore teacher's needs for real time analytics from Intelligent Tutors. In their study, the team used superpowers as a probe to investigate challenges that teachers face in the classroom. The question posed was "If you could have any superpowers you wanted, to help you do your job, what would they be?". The intention was to elicit classroom needs without technological limitations.
4. *Feedback on the neuroadaptive learning technology (tied to inclusion of public opinion in RRI)*: presented the neuroadaptive educational technology project to get feedback, asked about possible contexts of use (formal/informal learning, subject area), cognitive states of interest to teachers, and hesitations about using the technology.
5. *School technology policies:* Inquired about school policies that support or hinder implementation of new educational technologies. This interview section is not addressed in this case study.

Interviews were audio recorded and key quotes were later transcribed. Each interview was analyzed by a single researcher and commonalities were pulled out into a findings document to be presented to the research team. The focus of analyzing these interviews was to efficiently translate feedback and integrate it with the neuroadaptive educational project, therefore rigorous coding methodology was less of a concern.

Interview Results

Based on the background information collected in interviews, teachers' major goals in the classroom fell into three categories: (1) building community and collaborative learning experiences, (2) building critical skills and thought patterns, and (3) encouraging active learning. When it came to building critical skills, teachers emphasized general skills like self-confidence and communication. In addition to non-technological approaches, teachers described technologies that they use to address their classroom goals, including online visualization and lab tools, collaborative technologies that assist in individual learning, and technologies that easily transfer to homework (e.g., collaborative coding software or flipped classroom models where content is taught through homework).

In the section on reflexivity/speculation, teachers shared a series of superpowers that they would like to have to help them do their job. Teachers mentioned 9 superpowers, the top 4 of which are listed in Table 2.

Table 2

Describes the top superpowers that teachers mentioned when asked what would help them do their job.

Superpower	# Of Responses	Relevant Quotes
Knowing how to fashion material	4	*"To be able to perfectly come up with the… explanation that tunes into where they are with THEIR life and their understanding of things so that they get what I'm trying to explain to them"*
Give students perspective: situate them in an overview	3	*"A lot of students, they're young, they're in class, they've never known anything but school and how do you get them to stay engaged and move beyond the 'well I have to get through this step to get to that step'"- "[I want to] show them possible futures in a really concrete way"*
Confidence imbuer: show students their own superpower	3	*"Kids are smart in so many ways and … for lots of different reasons. Kids have ideas about what they can and can't do, and getting through that is a really huge part of the job."* *"It's easier to be creatively curious when you know that you have strengths that you bring in..."*
Teachers' time expander	3	

In providing feedback on the neurotechnology, teachers liked (1) the potential to individualize digital instruction to diverse learners, including helping students discover themselves, and (2) the possibility to help educators better understand their student's learning patterns at home. Teachers also shared a series of cognitive states they were most interested in knowing about their students (see Table 3). In parallel, teachers' primary concerns about brain-sensing learning tools included the possibility for automation to over-optimize or over-emphasize one learning style and leave little room for unstructured learning. There were also concerns about invasion of student personal information including the potential for student embarrassment, parental privacy concerns, and data privacy concerns.

Table 3

Top cognitive states teachers were interested in knowing about their students if given the chance

State	# Of Responses
Creatively Curious/Flow State	7
WHY not WHEN Zoning Out	3
Stress/Test Anxiety	3
Bored	2
Frustrated	2
Amount of Effort	1

Not Open to Learning	1
Distracted	1
Fast Mastery	1
Intimidated	1
Surrender	1
Reflective	1
Have a positive contribution	1

Researcher Workshop

Workshop Methods

In the second phase of the project, thematic findings from interviews were discussed in a workshop with the neuroadaptive learning team. There were 6 attendees at the workshop including the 3 co-PIs, 2 PhD students, and one masters student. Prior to the workshop, synthesized de-identified interview findings were sent to the project team. Throughout the workshop, researchers worked from a packet of questions to document their thoughts and shared the most important highlights on a whiteboard and with sticky notes. This workshop was conducted as part of a PI meeting at the start of the NSF grant period and included three phases:

1. *Thinking reflexively about self and project:* Speculation about superpowers for teachers, personal and team goals within the project, development of the project in the short and long term, discovering which parts of the projects are or are not amenable to feedback
2. *Presentation and step through findings:* Presentation of interview findings during which the team was asked to consider which feedback would apply to the project, to what degree feedback could be incorporated, and how many years into the project the feedback would apply.
3. *Finding actionable items:* A discussion about notable feedback, which feedback can feasibly be incorporated into the project, and at what point in the project

Workshop Results

In the reflexive thinking portion of the workshop, researchers aligned on individual goals and goals within the timeline of the project. Individually, each researcher was motivated to partake in the project to learn more about the other disciplines (i.e., psychology, human-computer interaction, learning sciences). On a project level, the team agreed on three goals: The 1-year goal was to align cognitive constructs between controlled psychological tasks to the Intelligent Tutoring System ASSISTments; the 3-year goals were to collect brain data with the fNIRS device and to work on automatic classification of cognitive states based on that data; the 5-10 year goal was to begin prototyping learning systems to create meaningful learning interventions. One of the research team's key takeaways from a reflexivity perspective was the necessity of spending more time aligning goals between each project team member and learning about each other's disciplines. Aligning goals in the beginning of the workshop also helped to assess teacher feedback to understand where it could be incorporated in the timeline of the project.

While stepping through the findings, researchers decided that the project's most clear use case was as a homework assistant tool; the team also realized that supporting in-class collaboration was a major point of interest but was not necessarily suitable for this project. The team also landed on three ways that findings from the interviews could have an impact on the project and when in the project timeline these could have an impact:

1. Writing broader impacts sections – immediate implications for the project (0+ years)
2. Thinking critically about the cognitive and learning constructs being studied in this and future grants – immediate (0+ years) and short-term (1-3 years) implications for the project
3. Measuring not only learning but also self-efficacy in learning – immediate (0+ years), short-term (1-3 years), and long-term (3+ years) implications for the project

While stepping through interview data, the project team became interested in reconsidering which cognitive states the project should assess and better mapping those states to goals in the current experiment. The project was initiated with an interest in assessing changes in attention, rule-learning, and proactive/reactive control. In hearing about the cognitive constructs that teachers were interested in, researchers had a rich discussion about how those constructs appear in psychology, HCI, and the learning sciences. For instance, the top cognitive state of interest for teachers (flow state) was discussed as potentially measurable through deep learning in the learning sciences and the ideas of proactive vs. reactive control in psychology. Proactive control, which is defined as more goal-driven behavior, is closely mapped with specific brain states and was discussed in the workshop as potentially related to more active learning. Other immediate implications for the project arose from teachers' thoughts about

brain-sensing as a tool to provide feedback to students on their own learning styles to help develop learning self-efficacy. In considering the possibility of a self-efficacy application, the research team concretely considered integrating self-report prompts into experiments with the fNIRS device to assess self-awareness in conjunction with the cognitive state of interest. Integrating self-report would be a very concrete way to adjust the project to address possible use cases early in the research of emerging technologies.

Discussion and Conclusion

One of the strengths of our approach to RRI is that each of the four dimensions were tied together across the entirety of the case study. In their review of methodological RRI papers, Schuijiff & Dijkstra (2020) concluded that most methods focus almost exclusively on one dimension of the framework. They speculate that focusing equally on all of the dimensions could overburden the research process. However, the case study described in this article demonstrates the possibility of integrating each element in a single RRI process.

The clearest benefits of using RRI in the neuroadaptive learning project were in the dimensions of reflexivity and anticipation. In the speculative portion of the interviews, asking teachers about which superpowers they would like instead of what technological support they need (as per the methods described by Holstein et al., 2017) helped move beyond the concept of what is or is not technologically possible. Asking teachers about their desired superpowers *prior* to getting feedback on the neurotechnology helped ensure that teachers, especially those who were skeptical of the tool, provided useful feedback. During the workshop, discussing teachers' needs in terms of superpowers also helped paint a fuller picture of what teachers struggle with in the classroom.

Despite being useful in their own way, the speculative questions in the interviews did not directly lead to anticipation in the workshop. Instead, anticipation of project use cases was enabled by exercises in reflexivity in the beginning of the workshop, which helped researchers keep personal and project goals in mind while reflecting on teacher feedback. One of the teachers' top classroom goals involved building collaborative communities, which led the research team to realize that facilitating collaboration was also a shared interest of theirs but was not a suitable goal for the grant's scope and for the type of brain sensing. Instead, the team decided that the best framing for the neuroadaptive tool was as a homework assistant tool. This decision was in direct response to teachers' feedback on the neuroadaptive tool, seeing it as most useful during solo work to provide personalized feedback to students on their learning and feedback to teachers on their assignments. The anticipatory component of RRI was made more concrete by starting with goal setting at 1, 3, and 5-10 years away and continuously revisiting that timeline to situate feedback in certain points of the project. Future work could involve analyzing policy and school contexts to weave that information into the reflexivity and anticipatory aspects of the case study. Our approach to reflexivity could also benefit from investigation into the pre-existing biases of the research team to draw attention to value systems at play in the design of emerging educational technologies.

The responsiveness and inclusion dimensions of RRI were baked into the methodology of the project through consideration of teacher interviews during the workshop. The study demonstrated the feasibility and usefulness of extending participatory methods into the development of emerging technology not yet feasible for use in educational settings. However, the inclusion dimension would be strengthened by direct exchanges between researchers and teachers, as well as input from additional stakeholders like parents and students. Furthermore, beyond the workshop, there was minimal uptake of results into the project. The responsiveness dimension of RRI would have benefited from revisiting and more deeply integrating feedback throughout the project lifecycle. In this way, RRI might pull in participatory methods from the learning sciences, aiming for participation that is not just contributory as in our case study and instead co-creates a project with members of the public through methods like Participatory Action Research, Participatory Design, and Co-Design (Bonney et al., 2009; Roschelle et al., 2006; DiSalvo & DiSalvo, 2014; Jacobs et al 2016). This may help ensure that the inclusion component of RRI benefits teachers, students, and parents, by directly addressing their needs in the classroom.

This research was done without value alignments within the practices of Responsible Research and Innovation. One substantive contention with RRI is an underlying assumption that "good" research practices will lead to "good" outcomes. In fact, the same might be said of participatory research methods (i.e., research is inherently better if it is participatory). We also acknowledge that RRI does not necessarily account for secondary factors that make inclusion more equitable, such as appropriate compensation and community agreements. For our own future work and other practitioners looking to integrate RRI, Foley et al. (2016) suggest combining RRI with other aspirations such as sustainability, social justice, gender/racial equity, etc. Researchers in the learning sciences have already begun approaching participatory methods with specific value systems; Participatory Action Research has been imbued with ideas from feminist inquiry that call for an examination of power relations in the research process (Jacobs, 2016), while lenses of racial identity and Black feminist epistemology have been applied to participatory design methods for creating conversational agents with Black youth (Rankin & Henderson, 2021). Combining value-based participatory approaches with anticipatory and reflexive practices from RRI may help

formalize a process and definition for responsible research, ensuring that all stakeholders are on the same page about what is responsible.

In this work, we propose expanding on typical participatory methodologies in the learning sciences by contextualizing them in a responsible research and innovation framework and applying this framework to emerging educational technologies, specifically neuroadaptive learning tools. We conclude that participatory methods and Responsible Research and Innovation complement each other in conducting relevant, responsible, and inclusive research. RRI contributes contextual, anticipatory, and reflexive thinking to creating educational technology, especially tools that are still emerging. Meanwhile, participatory methods in the learning sciences, especially those that consider certain values, strengthen the responsiveness and inclusion dimensions of RRI. Connecting researcher and educator perspectives through a lens of Responsible Research and Innovation can clarify immediate and long-term goals of a project, contextualize a project in a specific use case, and help define how emerging technologies may ultimately be relevant for education and not simply technologically novel.

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"A Tangled Moment": Unpacking Conflicting Frames by Examining Pedagogical Judgment

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Abstract: Ambitious and equitable pedagogies have been widely accepted as a way to address systemic inequities. Current research and professional development efforts overemphasize practice and fall short in unpacking the complexities of supporting teachers' uptake of reform-oriented instruction. These practice-based efforts often fail to adequately address dominant discourses in mathematics classrooms – of particular interest to this analysis is a *culture of exclusion*. This paper describes how exclusionary and inclusionary frames were evidenced in instructional practice and how those frames surfaced and shifted during sustained reflection on instruction. Attention to pedagogical judgment in the analysis lays bare taken-for-granted conceptions of ambitious mathematics instruction. This case is conceptualized as extreme, demonstrating the ease of invoking exclusionary frames, despite the teacher's commitment to broadening access to mathematics and supportive professional network. Findings illustrate how attending to the components of pedagogical judgment can support teacher sensemaking around navigating the intricacies of ambitious and equitable instruction.

This study explores a common and important contradiction in mathematics teaching by looking at one teacher, who I call Julie Woodman (all teacher and student names are pseudonyms). Julie was an experienced teacher, committed to her professional growth and to building positive relationships and mathematical experiences for her students. Even though she was deeply committed to ambitious and equitable math teaching and to broadening access to rich mathematical engagement, there were still ways that exclusion came out in classroom activity. To understand why that might be, I studied two different sites of teacher sensemaking — during a lesson and a video-based coaching debrief afterwards. My analysis of her sensemaking was guided by the three components of pedagogical judgment – action, responsibility, and reasoning – to describe (1) how inclusionary and exclusionary frames of mathematical activity and ability were evidenced in instructional practice and (2) how Julie was supported to surface and shift these frames. I see this as an extreme case (Yin, 2009) of a common phenomenon that occurs (namely, exclusionary experiences in mathematics classrooms), even with an experienced and committed teacher.

Ambitious and equitable mathematics pedagogies have been widely accepted as a way to address systemic inequities (Boaler, 2002; Sztajn et al., 2017). Ambitious teaching works to support students' conceptual and procedural understanding through meaningful mathematics engagement (Cobb et al., 2020) while equitable teaching serves to support *all* students' learning. These pedagogies aim to position students with mathematical authority and agency by redefining competence in more expansive ways, opening up participation structures to allow for and foster more diverse ways of being, belonging, and knowing (Cohen et al., 1999; Esmonde, 2012; Gresalfi et al., 2009). However, classrooms do not exist in a vacuum – they are situated within broader discourses and power dynamics that are (re)produced through classroom activity and interaction. A great deal of professional development efforts have been made to support such reform-oriented instructional practices, and despite the ubiquity of these ideas, there is dearth of research regarding the necessary resources to support teachers and their learning in enacting reform-oriented teaching (Horn & Garner, 2022; Louie, 2017a).

Theoretical Framework

To understand the complexity of inclusionary instructional practice and teacher sensemaking, I draw on three theories: the culture of exclusion (Louie, 2017b), frame analysis (Goffman, 1974), and pedagogical judgment (Horn, 2019). Broader power dynamics play out in classroom interactions in the stories or broad narratives that serve as resources for participants to interpret and organize activity (Hand et al., 2012). Of particular interest to this analysis is how exclusion is fostered in the mathematics classroom. Louie (2017b) has described a *culture of exclusion*. Traditionally narrow conceptions around mathematical activity and ability occur in tandem with the (re)production of marginalization (Chen & Horn, 2020) resulting in a dominant one-size-fits-few discourse that is persistent and invasive in mathematics classrooms (Louie, 2017b). Exclusion manifests in two ways: "(a) exclusion from meaningful engagement with disciplinary ideas and practices through narrow definitions of mathematical activity

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and (b) exclusion from positive identities as learners and doers of mathematics through narrow and hierarchical definitions of mathematical ability" (Louie, 2017b, p. 490). One way that exclusion is made salient is in how mathematical activity and ability are framed (summarized in Table 1). Frame analysis (Goffman, 1974) therefore lends itself as a framework in order to describe and make sense of classroom interactions and the lesson debrief.

Table 1
Exclusionary and Inclusionary Frames (Louie, 2017b)

Exclusionary Frames	Inclusionary Frames
Rote Practice Activity Frame ● Valorizes correctness ● Routine tasks ● Closed questions ● Discussion centers on answer-getting	**Sensemaking Activity Frame** ● Valorizes meaning-making and connections ● Open-ended, non-routine tasks **Multi-Dimensional Activity Frame** ● Valorizes collaboration, experimentation, argumentation ● Open-ended, non-routine tasks
Hierarchical Ability Frame ● Ability is unequally distributed ● Valorizes speed and correctness ● Positions some students as helpers or in need of help	**Multi-Dimensional Ability Frame** ● Everyone has both strengths and areas for growth ● Valorizes skills not traditionally considered mathematical ● Positions students as resources

I also build on previous work around teacher learning. Work in teacher education is dominated by practice-based approaches, focused on the practical applications of teaching (pedagogical action). This has led to a predominance of "ideal types" (Horn, 2019), presented as tidy, one-size-fits-all solutions that do not account for the inevitable challenges that arise for teachers as they enact these practices in their individual contexts. Horn's pedagogical judgment provides a framework to describe the interplay between a teacher's pedagogical action, responsibility, and reasoning. I draw on this framework as a way to ensure that my analysis addresses the complex and interconnectedness of Julie's classroom practice that is rooted in her commitments, obligations, and sensemaking. Analyzing one of Julie's lessons provides evidence of her pedagogical action, while the subsequent debrief provides an opportunity to explore her reasoning and responsibility Teacher conversations centered on problems of practice make possible opportunities for rich interactional professional learning and reflection (Horn & Little, 2010), and sustained conversations and reflections focused on problems of practice reveal teachers' pedagogical judgment (Horn, 2019). This makes the lesson debrief an appropriate place to explore her reasoning and responsibility. Furthermore, the pedagogical judgment framework makes it possible to bridge the classroom and teacher learning contexts in my analysis.

Methods and Data

This analysis comes from a larger ethnographic study, connecting research and practice to understand and support urban mathematics teachers' development and enactment of ambitious instruction (Horn & Garner, 2022). The research team developed a Video-based Formative Feedback (VFF) cycle to support and create opportunities for co-inquiry into practice. The VFF cycle consisted of five steps: (1) the focal teacher identified a question or goal of interest; (2) on the day of the lesson, the teacher selected four focal student groups (blue, purple, green, and orange groups) to audio record; (3) the class was documented using a whole-class tablet camera mounted on a Swivl tripod, audio recorders for the four student groups, and a GoPro point-of-view camera attached to the teacher; (4) the research team reviews and analyzes the video and audio and identifies clips that support co-inquiry; (5) the research team meets with the teacher and their school-based colleagues within two days of filming to view and discuss the clips in light of the teacher's question. The VFF debrief (step 5) is filmed with a wide angle view of the participants. I have analyzed two data sources in this analysis: the classroom and the debrief. The classroom video data includes a whole class video and audio recordings of four focal groups. The primary participants of the debrief were the focal

teacher, and two researchers who facilitated the session (Brette and Lani). There was another researcher present, taking fieldnotes and a partner teacher at the school, however their interactions during the debrief were relatively minimal. The focal teacher, Julie Woodman, was a high school teacher with over five years of experience. She was supported by a selective and well-resourced PD organization, and Julie was deeply committed to broadening access to mathematics. In interviews, Julie expressed a desire to foster students' understanding through mathematical discourse and prioritizing building relationships in her classroom.

Focal lesson

Julie's AP Statistics lesson introduced hypothesis testing through a card game. Julie called on student volunteers to draw a card: if they drew a black, they got an extra credit point, if they drew a red, they had to sweep the classroom. Six students drew cards with replacement, and all six drew the same color card. The underlying question at play was *If the deck is fair, how likely is it to get 6 red cards in a row?* Following the game, students worked in groups during three episodes of groupwork, each followed by a whole class discussion.

Data analysis

For the post-lesson debrief data, I applied methods of flexible coding (Deterding & Waters, 2021) – initially indexing the entire debrief and utilizing analytic memos to derive the "main stories" (p. 725). My unit of analysis was episodes of pedagogical reasoning (Horn, 2005). I partitioned the conversation into EPRs based on the central topic of the conversation, and using open, concept-driven coding, I coded for aspects of pedagogical judgment and inclusive and exclusionary framing. To code for pedagogical judgment, I attended to Julie's pedagogical actions (when she talked specifically about what she did during the lesson), pedagogical reasoning (when she described her thinking, e.g., "I was intending…" or shared other contextual details to describe her thinking), and responsibility (when she expressed a sense of commitment, e.g., "I go really freaking fast because I have to"). When coding for inclusionary and exclusionary frames, I attended to what or who Julie and the facilitators discussed and used the framework described by Louie (2017, p. 496). I also looked for challenges or resistance to a particular framing. I confirmed interpretations with fieldnotes, interviews from the broader study, and with the researcher facilitators.

For the classroom data, I created a side-by-side transcript for each focal group within each episode of groupwork and the following whole class episodes. The groupwork episodes served as my unit of analysis, coded according to the culture of exclusion framework to describe students' conversations and mathematical activity that followed from Julie's initial framings. Specifically, I attended to how much students were talking, what kind of mathematical activity came up, evidence for sensemaking, and how connected the conversations were (i.e., did students engage with one another's' ideas, taking them up and building off each others' thinking?).

Findings

I will describe how frames of mathematical activity and ability were co-constructed in the classroom video by describing Julie's verbal directives and the resulting student conversations. Turning to the debrief, I will explore how Julie made sense of the classroom activity and describe how the exclusion that came out in the classroom activity contradicted with her inclusionary commitments to teaching.

Conflicting Frames in Pedagogical Action

Groupwork episode 1: What could be going on here?

Julie launched the first episode by telling groups "I need you to talk to each other about two possible explanations for how [drawing six red cards in a row] happened." Julie's direction to students was open-ended and nonroutine. Furthermore, her launch elicited focused math talk (Manz, 2012) and rich sensemaking in students' conversations. The groups generated the following possible explanations: 1) all the cards are red; 2) students drew cards from the same location in the deck; 3) the cards weren't shuffled; and 4) six students drew red cards by chance or bad luck. Although the groups' resulting conversations were driven by answering Julie's question, students freely contributed multiple ideas.

For example, the purple group began their discussion declaring that all the cards must be red, eliciting laughter from the group. Chris then posed a question about the probability: "They were all red? Or there's a 50-50 chance though right?" The group took up Chris's question and engaged for several turns of talk. Alyssa confirmed

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his probability: “It should be if it's a standard deck of cards and she didn't rig them” and elaborated that cards were drawn with replacement, making the chances the same. She then proposed another explanation that could affect the probability – students were picking from the same place in the deck. Bethany disagreed until Chris suggested that Julie could have been making students pick the same card. He expressed doubt with this suggestion, but Bethany added on “Oh like if it was on the top or something?” The group’s dynamic was overall affirming of one another’s ideas, both in utterances to show agreeance as well as in the way they took up one another’s ideas and questions, giving them value and merit in the conversation. Chris’s question was especially compelling – despite no explicit mention of probability during the game, it came up in *all* of the focal groups’ conversations, intuitively and organically describing the probabilistic nature of the activity without any focus on calculations or procedures. Further evidencing this pattern, Danny, a member of another group, made a connection to statistical significance:

> Of course they're all red, uhh, so in regards to how we got it, it could have just been that she took all the black cards out of it, or…she reduced the amount significantly to the point where it would be statistically…it's uh statistically impossible for us to actually get a black card.

The openness of Julie’s launch invited varied participation, and students were not limited by procedures or formulas, making it possible for students to make connections to other mathematical ideas. Students’ discussions were indeed mathematical in nature as students made sense of Julie’s question and their symmetric experience in the card game. Taken together, her question and the resulting conversations invoked the *sensemaking frame of mathematical activity.* Furthermore, the episode described here points to a discourse of inclusion, in terms of who had access to meaningful mathematical activity and ways in which students could be perceived as competent.

Groupwork episode 2: What is the probability?

After settling on the two explanations, students are unlucky or the deck is not standard, Julie told students, “Assume I'm telling the truth. If I'm telling the truth, I need you to calculate a probability of actually drawing six red cards.” This was perhaps a shift away from sensemaking, evidenced by directing students to find “*the* probability.” Indeed, students’ talk centered on recalling the procedure to determine the probability. Unlike Julie’s previous question, students did not contribute as freely, nor did they take up one another's ideas. To illustrate, the blue group was only concerned with trying to calculate the probability. Although multiple students offered possible solutions, no one’s idea took root in their conversation:

Isabel:	Six divided by…
George:	No it’s one out of 52...to the sixth power.
Jacob:	One times [...] It’s a one in 64 chance I think. One in 64.
George:	How you know?
Jacob:	It’s a one in 64 …

George made a bid to engage with Jacob’s solution, however Jacob only repeated his answer instead of discussing it with his groupmates. Further constraining students’ sensemaking, many groups did not have enough time to reach a consensus, leaving students’ contributions and ideas disconnected and unresolved – valorizing speed and correctness. For example, the green group did not arrive at calculating a probability because they were trying to determine the number of cards in a deck:

Farah:	How many are red and how many are black?
Danny:	So we already know it's independent you know what I mean?
Elijah:	How many cards are in a deck? 32?
Danny:	50? 72? So like, fifty two cards? Four times 13 is what, 52? And two jokers. 54.
Farah:	But there’s still red and black.

The majority of turns of talk turns were trying to make sense of the composition of a deck of cards. The group surfaced everything they needed to reach an answer – the number of cards, the color composition of the cards, and identifying that the card draws were independent. The group was moving towards finding a probability; however their individual ideas did not come together. Overall, the focal groups’ conversations were answer-focused with little

to no sensemaking, explanation, or co-constructing of ideas. Considering the nature of students' conversations that Julie's prompt elicited coupled with the time constraint suggested that this episode invoked the *rote practice activity frame and the hierarchical ability frame*. Importantly, Julie's framing on the activity alone is not necessarily enough to be considered rote practice. This move will be further unpacked in a later section of this paper, but it could be conceptualized as sensemaking *if* students' conversations suggested this kind of mathematical activity. However, her framing of the question and the time constraint she imposed led to a shift in students' participation and the nature of their mathematical engagement towards routine, rote practice motivated by a singular correct answer. Students did not participate as inclusively as they had in the first episode, as some students were excluded from mathematical sensemaking and opportunities for competence if they did not draw on an algorithm or work quickly enough.

Groupwork episode 3: Is Ms. Woodman lying?

In the subsequent whole class discussion, a student shared how to calculate the probability: "It's like one half probability of getting a red. That times the sixth power. [...] One over…64" or 1.65%. Julie then prompted groups to discuss, "I want someone to use that 1.5% in a sentence to answer the question of whether you think Ms. Woodman is lying to you or not." Along the same lines as the second episode, this question alone doesn't necessarily point to a particular frame. However, students took up her question as a cue of using 'statistical significance' as students worked to recall a particular scripted answer: "Um:: we have like do you remember the 5% thing?" again suggesting basic recall rather than sensemaking." Students in the focal groups were focused on coming up with a specific explanation or conclusion in a noticeably different way than in the first episode. In this episode, students' conversations centered on trying to come up with a *correct* answer that filtered their sensemaking:

> Myles: I feel like she is lying because isn't it like a very small chance-
> Liam: -I thought statistically significant - it's less than 2.5%
> Nina: No it's less than 5%.

Myles made a bid that could have prompted the group towards sensemaking, however the following turns of talk immediately went to "the 5% thing." Illustrated by these examples, students engaged in closed and routine mathematical activity that centered correctness – pointing to the *rote practice activity frame*.

Considering all three episodes together, students took up Julie's directives in ways that undermined inclusionary discourse brought out in the initial episode. As the nature of students' conversations changed, the mathematical activity with which they engaged shifted from rich sensemaking to narrow answer-getting as students worked to recall algorithms and scripted answers. Importantly, in the second two episodes, students were excluded from mathematical activity and did not have a chance to show mathematical competence – what students needed to participate (and to feel successful in doing so) was speed and correctness. Julie and her students co-constructed frames of mathematical activity and ability that brought exclusion to the surface of classroom activity. It is important to note that I would not say that this exclusion cancels out or undoes the inclusionary discourse in the initial episode, nor does it necessarily work against the inclusionary culture that might exist in the classroom outside of this singular activity. What this suggests, however, is that the culture of exclusion makes these frames sensible choices in interaction, making exclusionary experiences a common phenomenon in mathematics classrooms. What is compelling about this lesson is that Julie's pedagogical judgment is rooted in inclusionary commitments, as I will unpack in the next sections of this paper.

Inclusionary pedagogical responsibilities

Before recording the classroom video, Julie asked the researchers to pay attention to student dynamics and selected the focal groups because she suspected they had "status issues":

> There's some really confident, super high math kids that have gone through AP computer science and AP calc BC [...] They have all the math badges and this is the last one to hit. Then I also have a large group of students that are coming from regular Algebra II and this is their first time feeling an honors math class. They've gone through this process of failing a lot of times, but improving, improving, improving, but those other kids have been acing every test. I'm just wondering how that dynamic looks like in a group.

Throughout the debrief, Julie elucidated two primary responsibilities that motivated her lesson design and instructional choices – one of them being to attend to issues of status. Julie described how she designed lessons with status in mind, saying "I try to take a lot of the theoretical math out of it, like the formula-based stuff, and I try to make it something graspable." Then, connecting to the card game task, "there was no math involved there. Maybe a little bit at the end, but every one of them could have contributed to that conversation." Julie's reflections made clear that her intentions were rooted in her pedagogical responsibility to status. The task was open-ended, something that "every one of them could have contributed to" and, indeed, students did not need to rely on routines or algorithms but their intuition and experience instead. Her planning and design of the task, grounded in this responsibility, invoked the *multidimensional frames of mathematical ability and activity*.

Julie also spoke of a second responsibility – one to the AP curriculum. She described an obligation to support students to make connections between important mathematical ideas. For example, she interpreted her second prompt as a connecting to another mathematical idea: "I thought it was kind of cool that you're finding a p-value using prior knowledge, which I thought was kind of a cool way to introduce it." As she narrated her rationale, grounded in this responsibility, Julie drew on the *sensemaking frame of mathematical activity*.

Rooting out exclusionary frames in pedagogical reasoning

As Julie reflected on the lesson and responded to the video record of the focal groups, she elaborated on her pedagogical reasoning, surfacing assumptions about what she thought students should be able to do. The first two clips highlighted two groups answering Julie's first prompt (groupwork episode 1). Clip 1 featured Jacob's correct probability with no reasoning or explanation, Julie diagnosed as an issue of conceptual understanding: "This concept, the multiplication rule for independent events, which we've already taught in regular stats, we go over that so many times. It's one of the hardest things for kids to just remember." Brette presented a second clip of the green group who didn't have time to come to a consensus about the probability. Julie was surprised that the group spent time discussing the number of cards, and she expressed that she expected that calculation to be very quick. Brette used this clip to challenge Julie's diagnosis and presented two potential barriers to students: a pacing issue and the contextual underpinning of the card game impacted students' sensemaking.

In this conversation, Julie connected her pedagogical reasoning to her actions. *Because* Julie had expected students to answer her question quickly, she did not provide enough time for students to reach an answer. Brette and Lani continued to challenge Julie's assumptions:

Brette:	Not all kids have that knowledge super ingrained. It seems like-
Julie:	-We play with cards **a lot**. I give them cards for seating charts every unit. And it's on the table, like it's half and half. You know what I mean? I guess I didn't think that was going to be something they needed to think about.
Lani:	Right. We were talking about yesterday, when we were thinking about all of the math of this, we were thinking about how cards on the one hand you can make up suits and think about colors. The color is just 50-50, but you have to have sort of an abstract understanding to see-
Julie:	-And we do in the probability unit. I let them look at a deck of cards and we come up with a summary. There's 13 of each suit. There's four of each number card. There's four of each face card.
Lani:	They did 13 times four really quick.
Julie:	They knew the numbers. That's interesting. I would never have thought that was something that group struggled with.

Julie added, "It wasn't about the calculation. It was about the percent being low I guess. I got the answer and then was like 1.5% and let's talk about that." As she shared her evolving reasoning around what happened, Julie expressed a conflict between her pedagogical action and the original intention and the framing of the activity – classroom activity was focused on the calculation, not conceptual development of hypothesis testing and sensemaking, and this surfaced exclusion. Brette explained, "It seemed to create a pattern where the higher status kids are getting the right answers and the lower status kids didn't have a chance to get there." Although Julie's intentions were grounded in her inclusionary reasoning and responsibility, as the lesson played out, her subsequent actions (the wording of her directive to the group and the lesson pacing) undermined her intentions and invited

exclusionary frames of mathematical activity and ability as the students took up and responded to her moves. Contemplating the facilitators' claims, Julie shared with the team:

> I think I wasn't expecting to use the 1.5 before the lesson so I think I was just kind of going past where I wanted to go with that. [...] That moment was so unplanned because what I said, the goal wasn't even for them to get, like going into the lesson, that 1.5% was not something I was going to go for at all. [...] Then I was like in the moment like this will look good. They know how to calculate this probability already. They can just do it real quick. It's less than five percent. They don't even need the whole normal curve thing.

Julie provided important context behind her move to have students calculate the probability – it was an unplanned, in-the-moment decision. In fact, Julie explained that she noticed a student calculating the probability and saw this as an opportunity for students to move towards hypothesis testing by connecting to their understanding of probability. In this narrativization, Julie interpreted her move to be inclusionary, drawing on the sensemaking activity frame. Julie was supported to consider a different interpretation of her pedagogical actions – that the activity was actually exclusionary, drawing on the rote practiced ability frame and rote practice activity frame – by confronting the video record and the facilitators' moves to press against her assumptions. Lani described these conflicting frames as a "tangled moment," sympathizing with the tension Julie had uncovered in the debrief. Julie went on to explain how she now understood the conflicting frames in the activity:

> The deck of cards was a great way for them to develop those two competing hypotheses without realizing it, but then when I went to finish it off and do the math and stuff like that, that was completely unplanned. I wasn't mentally prepared for how to wrap that up and transition.

As Julie engaged in sustained reflection, she laid bare her pedagogical reasoning, surfacing assumptions she had made during the lesson. The researchers challenged these assumptions, and using the video record, illustrated how students' conversations during the second two questions exacerbated status issues. In response, Julie articulated a conflict between her pedagogical actions and her pedagogical responsibilities: the actions she took that were rooted in her responsibility to the AP curriculum undermined and conflicted with her responsibility to status and equity.

Discussion

The theoretical contribution of this paper stems from drawing connections across the classroom and teacher conversation settings. It has been pointed out that current literature on teacher learning rarely draws empirical connections between multiple contexts (Lefstein et al., 2020). By attending to Julie's sensemaking in multiple contexts, I was able to describe not only how exclusion came out during classroom activity, but also how she understood her actions, both in the moment during the lesson and later in reflection during the debrief. To only consider what played out during the lesson would be to tell a story of how mathematical ability and activity frames can contribute to inclusionary and exclusionary practices. In fact, current research and related professional development efforts do not adequately address the complexities of classroom activity and teachers' sensemaking of ambitious and equitable mathematics instruction (Horn, 2019; Horn & Garner, 2022). An overemphasis on Julie's pedagogical actions furthers a dichotomous view of teaching (that is, a good versus bad binary).

Turning to the debrief as a context to study teacher learning, the debrief was designed to support her inquiry and to avoid evaluation and "best practices." In preparation, Brette and Lani wanted to draw Julie's attention to how status issues were exacerbated and students were excluded from meaningful mathematics engagement. However, the debrief was not facilitated to provide Julie with simplistic fixes like "ask more open questions" and "give students more time." Rather, the facilitators unearthed Julie's assumptions and used the video record to support Julie in connecting her pedagogical actions and reasoning to students' mathematical activity and engagement. Furthermore, the debrief provided Julie an opportunity for sustained reflection and a chance to revisit her lesson which illuminated a conflict between her pedagogical responsibilities. Evidenced in the literature, reformed oriented pedagogies and similar frameworks are presented as tidy solutions (Horn & Kane, 2019), however, this analysis suggests that this is not the case. Classroom activity is deeply complex that is not dictated solely by teachers' intentions and actions and requires time and careful attention to understand. For teachers to grow in their practice, it is necessary to support them with feedback that centers on their pedagogical judgment and space to explore and reflect on their teaching.

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Meta-Theoretic Competence Demonstrated by Students in the Patterns Class

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Abstract: Engaging students in theory building practices is an important focus of science education. This study aims to identify students' resources for engaging in scientific theory building. More specifically, it examines the resources 8th grade students brought to their engagement in theory building in a science elective course called the Patterns class. The Patterns class engaged students in a simplified version of theory building, which involved iterative cycles of articulation, evaluation, and refinement of pattern theories. Pattern theories were written descriptions of general patterns in behavior that could be found in examples across domains, such as threshold and equilibration. Approaching video data and student work through a microanalytic lens, resources were identified belonging to the articulation, evaluation, and refinement of pattern theories across dimensions of deeper structure, generality, domain of application, and causal relationships. In identifying theory building resources, the study introduces a new category of knowledge: meta-theoretic competence.

Introduction

In recent years, science education has shifted from teaching students the content and skills of science separately, to helping students learn both content and skills in an integrated way, through participation in science practices (Ford & Fordham, 2006). The construction of scientific theory is a central activity of science. Students should therefore have opportunities to engage in theory building in the science classroom and develop skills for participating in theory building practices. In alignment with this perspective, the U.S. Next Generation Science Standards include theory building practices such as modeling and explanation in their learning objectives for K-12 science education (NRC, 2012). Many research programs have investigated the impact of explanation- and model-based instruction on student science learning (Manz, 2012; Passmore & Stewart, 2002). A number of approaches have used explanation or modeling activities as a way of eliciting and building on students' ideas, in alignment with constructivist ideals (diSessa, 1995; Wilensky & Reisman, 2006). Studies to date have primarily focused on developing students' understanding of science concepts by refining their thinking through theory building activities. The present research is complementary to this work, having a long-term goal of designing theory building activities that engage and refine students' resources for theory building. A first step toward this goal is beginning to identify such resources.

There is a rich tradition of research examining the continuities that connect novices and experts, rather than the differences that divide them (Warren et al., 2001). Work within this paradigm has urged education researchers to take an anti-deficit perspective of learners and view them as bringing rich intuitive and culturally-learned funds of knowledge to their learning in and out of school (Adiredja, 2019; Moll, et al., 1992). Leaders in the field have challenged educators to find ways of honoring and leveraging the resources children bring to their learning, particularly with respect to children from non-dominant backgrounds, whose ways of knowing and making sense of the world have historically been marginalized by classroom instruction (Bang, et al., 2012). Research within this tradition has uncovered resources for understanding science topics from the elementary to the undergraduate level, as well as resources for productive engagement in scientific discourse (Hammer, 2000; Hudicourt-Barnes, 2003; Rosebery et al., 2010). The present work aims to make a contribution to this tradition of research by identifying resources students have for scientific theory building. In achieving this goal, it presents a new category of knowledge: meta-theoretic competence.

Theoretical Foundations

This work is motivated by an epistemological perspective called knowledge in pieces (KiP; diSessa, 1993). KiP grew out of Piagetian constructivism and shares with it a focus on the role of prior knowledge in learning. In addition to constructivism, KiP has roots in cognitive modeling, sharing with it the goal of building a theoretical framework for modeling knowledge and learning. With its attention to technical precision, KiP offers a detailed account of the conjecture that new knowledge is constructed by the learner through engaging their prior knowledge. KiP models an individual's knowledge as a complex system of a diverse array of knowledge elements. The knowledge system of the novice is characterized by loosely connected networks of elements. This means that networks of knowledge drawn on by the novice to explain a phenomenon shift from context to context, responding

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to context-specific features of the phenomenon. For example, a physics novice may draw on one set of knowledge elements to explain the orbit of the moon around the Earth and a different set to explain the arc of a tossed ball. The expert, by contrast, would draw on the same network of knowledge to explain both trajectories. KiP models the transition from novice to expert, or learning in general, as a process of reorganization and refinement of the knowledge system.

With this picture of learning, KiP views prior knowledge elements as resources for learning, rather than misconceptions that need to be replaced (McClosky, 1982). Instruction is therefore designed to help students engage and refine their existing ways of thinking and making sense of the world. Researchers working within the KiP paradigm have identified a number of resources that may be seeds for more sophisticated knowledge, practices, and epistemologies. The identification of productive ideas, moves, and perspectives demonstrated by students in both lab and classroom settings has led to the development of a number of new theoretical categories of knowledge.

For example, *phenomenological primitives* (p-prims) are intuitive knowledge elements that guide a learner's intuitive sense of mechanism (diSessa, 1993). *Coordination classes* are larger knowledge structures used in extracting information (like velocity or force) from observable data in the world (diSessa & Sherin, 1998). These categories of knowledge include resources for the development of conceptual understanding in science. Other categories of knowledge include resources for the development of skills for participation in scientific practices. For example, *meta-representational competence* (MRC) includes resources for constructing, critiquing, and making sense of representations (diSessa, 2004). Yet other categories of knowledge include resources for understanding the nature of science. For example, *epistemological resources* include resources for understanding the nature of knowledge and its origins, epistemological activities, and positions one might take towards knowledge (Hammer & Elby, 2002).

The present work uses meta-representational competence as a reference model for organizing resources for scientific theory building. To make the link to this model explicit, I call this category of knowledge *meta-theoretic competence* (MTC). Meta-representational competence features knowledge that transcends the production and use of representations (diSessa, 2004). It includes skills for the invention of new representations, for their critique, and for their explanation. Resources for representation invention include the ability to draw, and sensitivity to representational possibilities of visual elements (e.g., color, length, width). Resources for the critique of representations include criteria such as completeness, precision and parsimony. The resources belonging to MRC are assumed to be "gradually developed through cultural practices in and out of school" (diSessa, 2004, p.294). In the next section, I describe the empirical context for my work and my approach to analyzing data, which led to my development of meta-theoretic competence as a category of knowledge resources.

Methods

This work is situated in the context of a larger research project, which was aimed at the design of a middle school course on topics in the domain of dynamical systems theory. DST is a highly mathematical science, which uses differential and difference equations to model systems that change over time. The course guided students' development of descriptions of general patterns of change, which could be found in phenomena across domains. Such patterns include threshold, equilibration, exponential growth, and oscillation. Threshold, for example, can be seen in the tipping point of a tower of blocks and the limit of a person's patience. Many of the descriptions of these patterns, which the students wrote, were essentially conceptual versions of the mathematical equations DST uses to model phenomena. Our research team called students' written descriptions *pattern theories* and engaged students in an iterative process of pattern theory building and refinement. We called the course the Patterns class, because of its focus on exploring and describing patterns. The goal of the present work is to understand the productive resources students brought to their engagement in theory building in the context of the Patterns class.

The Patterns class was taught in a public middle school in an economically depressed neighborhood of a large city on the West coast of the United States. The school was selected based on the willingness of the 8th grade science teacher to share her elective period with the research team. She had traditionally used the elective as a science enrichment course for students who were proficient on tests of basic skills in English and math. The author taught the course, having been a high school science teacher for six years before transitioning to research. The class met on Monday, Tuesday, and Thursday mornings for 40 minutes, totaling 52 hours over the school year. Twenty-one 8th grade students (11 girls and 10 boys) participated in the course. Eighteen of the students had immigrated to the U.S. from Mexico and Central America. Two students identified as African American and one as Bosnian American. The majority of students attending the school were designated as English Language Learners and from low-income households. The students were selected on the basis of their availability and willingness to participate in the experimental curriculum.

Patterns class design

The course was designed to engage students in a simplified version of scientific theory building through an iterative process of theory articulation, evaluation, and refinement. Through this process, students constructed and refined theories for patterns including threshold, equilibration, exponential growth, and oscillation. Each unit opened with the exploration of two pattern examples, followed by students' articulation of their first draft pattern theories. The students then evaluated their theories against a third example and revised their thinking, producing second draft pattern theories. They generated additional examples and evaluated their theories against those, producing third and final draft pattern theories. In addition to mirroring a simplified scientific theory building process, the sequence was meant to help students articulate and iteratively refine their thinking and their theories. Below, I briefly unpack the first two pattern units, to give the reader a sense for the Patterns class and to provide a basic chronological reference for the narratives I provide to illustrate the elements of meta-theoretic competence.

Threshold unit

The threshold unit was designed with a pattern benchmark in mind. The threshold benchmark consisted of a *pre-phase*, *limit*, and *post-phase*. During the pre-phase, a system parameter is varied until it reaches a limit. When the parameter exceeds the limit, the system transitions to a post-phase, which is markedly different from the pre-phase.

The threshold unit began with the exploration of two examples: the addition of coins to a cup hung over a spaghetti bridge until the bridge broke, and the addition of drops of water to a coin until the water flowed onto the table. The students explored these examples in the context of small group team challenges, which were each allocated a single class period. Following their exploration of these examples, the students individually wrote their first draft pattern theories. Their theory building was guided by a prompt, which focused them on describing the pattern in behavior common to both examples: "Tell the story of both behaviors so that someone listening to your story would agree that you are talking about either one of the behaviors, but they wouldn't know for sure which one you were talking about." This activity was allocated about half a class period.

The students then evaluated their pattern theories against a third example: adding salt to a cup of water until a submerged egg floated to the surface. They explored this example in small groups in the context of an investigation, which was allocated a single class period. Students were asked to compare the egg example with the spaghetti bridge and drops-on-a-coin examples and record their thoughts in writing. The teacher collected their responses and presented the class with a representative sample of both their example comparisons and written pattern theories, facilitating a whole-class reflection during which students compared pattern theories with each other and with examples. The reflection discussion was given a single class period. The students were then invited to revise their pattern theories and write second drafts. This activity was allocated about 10 minutes and took place following the reflection discussion.

The students were then invited to generate examples from their own lives, which followed the pattern. Students worked alone to generate initial lists and then in small groups to create posters showcasing their favorite examples. They hung their posters around the classroom and participated in a gallery walk, considering their classmates' work. During the walk, they applied sticky notes to posters to identify examples they agreed with, disagreed with, or didn't understand. The teacher selected two contentious examples to feature in a whole-class debate (e.g., "bothering someone until they burst" and "getting a haircut"). Before the debate, she gave the students time both individually and in small groups to prepare arguments for why these examples did or did not follow the pattern. She then asked students to consider one example at a time, offering points to support or challenge the example. The students were invited to revise their pattern theories a final time and write third drafts. This activity was allocated about 10 minutes and took place following the debate.

Equilibration unit

The equilibration unit was designed with a pattern benchmark in mind. The equilibration benchmark was a pattern of *difference drives rate*. An equilibrating entity moves towards equilibrium at a rate proportional to the difference between its current state and its equilibrium state. A pattern of *difference drives rate* can be seen in both thermal equilibration and the calming of emotions over time.

The equilibration unit began with the exploration of two examples of thermal equilibration: the warming of cold milk to room temperature and the cooling of hot tea to room temperature. The students explored these examples in the context of small group investigations. The investigations took the form of traditional science labs and were each allocated a single class period. They were each preceded by activities in which the students created and presented hypotheses of how the temperature would change over time. They were each followed by activities guiding data interpretation and activities focused on the generation and discussion of potential causes for the fast-

then-slow temperature change. Following their exploration of these examples, the students were given half a class period to write their first draft pattern theories.

The students then evaluated their pattern theories against a third example: the diffusion of beans through a semi-partitioned box as they shook the box back and forth. They explored this example in small groups in the context of an investigation, which was allocated a single class period. They were asked to compare the bean example with the warming and cooling examples and record their thoughts in writing. The teacher collected their responses and presented the class with a representative sample of both their example comparisons and written pattern theories, facilitating a whole-class reflection during which students compared pattern theories and examples. The reflection discussion was given a single class period. The last 10 minutes of the period were reserved for the students to revise their pattern theories and write second drafts.

As in the threshold unit, the students were invited to generate examples from their own lives, which followed the pattern. They worked alone to generate ideas and then in small groups to create posters showcasing their examples. They hung the posters around the classroom and participated in a gallery walk, using sticky notes as they had in the threshold unit. The teacher selected a contentious example to feature in a whole-class debate (emotions calming). She gave the students time to prepare their thoughts on the example. During the debate, she asked students to either offer points in support of *emotions calming* as an example of the pattern, or points to challenge it. Following the debate, the students were invited to revise their pattern theories and write third and final drafts.

Data collection

Data were collected in the form of video footage, student work, and teacher reflections. Each class period was videotaped using two cameras. One camera was positioned at the front of the classroom and captured the students sitting at their tables in groups of 4. The other camera was positioned at the back of the classroom and captured the activity at the front board when the teacher or student presenters were speaking. When the class engaged in small group or individual work, this camera was repositioned to capture the work of one group. Student work was collected at the end of each class period. The work was scanned and returned to the students the next day to keep in their course portfolios. As the teacher, I recorded reflections at the end of each lesson, documenting things I had noticed in terms of student thinking and engagement, with respect to the course design.

Data analysis

The broader goal of the present study was to understand the nature of student theory building in the Patterns Class. I approached this goal through a KiP lens, expecting to find evidence of students' productive engagement in theory building. I analyzed student work using a microanalytic approach characteristic of knowledge analysis (diSessa, Sherin, & Levin, 2016). I examined students' written theory drafts for theory-like characteristics, and their notes from activities for evidence of their thinking between theory drafts. I reviewed the written teaching reflections, looking for class or small group discussions related to students' articulation and refinement of pattern theories. The teaching reflections helped me identify video footage to review, transcribe, and analyze. While watching the video footage, I noted on the transcript where I saw evidence of productive engagement in theory building, naming and briefly characterizing what looked like ideas, moves, and aesthetics that seemed productive with respect to students' theory building. I collected the elements I had named in a separate list.

It became apparent that the list of elements were student resources for theory building and the focus of my inquiry narrowed to identifying the productive resources students brought to their theory building in the Patterns class. The list was analogous to a collection of resources for engaging in another set of scientific practices, which already existed as a category of knowledge in the KiP literature. This category of knowledge was meta-representational competence (MRC; diSessa, 2004). My collection of resources for theory building was parallel to the collection of resources belonging to MRC, in several ways. Both are capacities for engaging in multiple dimensions of a realm of scientific practice (including generation and critique of scientific artifacts), and both include capacities gained from interactions with others in and out of school. Because of this analogy, I decided to use MRC as a reference model and named my category of resources *meta-theoretic competence* (MTC).

I reviewed the list, which I had thus far compiled, and combined resources that seemed similar and clarified distinctions between resources that seemed similar but were different in important ways. In sum, I engaged in an epistemic game of "list making" (Collins & Ferguson, 1993). I moved back and forth between my list and the data, refining the list so that it more accurately captured the productive things students were doing with respect to theory building. When I arrived at a final list, I described each resource and connected it with a particular example from the data. In working out the organization of the items on the list, it became apparent that there were two dimensions according to which the items on the list should be organized. These dimensions were stages of theory building (e.g., articulating, evaluating, and refining theories) and pattern-theory-specific elements

(e.g., deeper structure, generality, domain of application, and causal relationships). Because items on the list were connected with elements from both dimensions, I transferred my epistemic form from a list to a cross product or table (Collins & Ferguson, 1993).

Findings

My analysis of student engagement in the Patterns class produced a table of resources for meta-theoretic competence. The table outlines resources for three stages of theory building (articulating, evaluating, and refining pattern theories) across four characteristics of pattern theories (deeper structure, generality, domain of application, and causal relationships). Table 1, below, is meant to give the reader a sense for the larger ontology of meta-theoretic competence. Due to space limitations, I list only one resource per cell.

Table 1. Theory building resources demonstrated by students in the Patterns class

Stages/Pattern Characteristics	Deeper Structure	Generality	Domain of Application	Causal Relationships
Articulating	Articulating the pattern in behavior instantiated by examples	Using general language to describe a pattern in behavior	Generating examples from physical and psychosocial domains	Articulating intuitions about causal relationships underlying behavior
Evaluating	Comparing examples based on similarities and differences	Questioning the generality of the language used	Challenging and defending the fit between examples and pattern theories	Challenging and defending the logic of intuitions
Refining	Removing surface features from the pattern theory	Removing context-specific features to make the pattern theory applicable to more examples	*There was no opportunity in the course for students to demonstrate resources for this category	Responding to challenges by unpacking or modifying ideas

I unpack the list below, illustrating each category of resource with narrative from the class, drawing on either video transcript or student work. In the narrative, I highlight the particular resource using italics.

Deeper structure

An ability to look beyond a phenomenon's surface features and articulate its deeper structure is a hallmark of expertise in science and fundamental to the construction of scientific theories (Chi, Feltovich, & Glaser, 1981). Deeper structure can take different forms, from a mathematical relationship between system variables, to a mechanism driving system behavior. In the Patterns class, a theory attended to deeper structure if it described the *pattern in behavior* common to multiple examples, rather than their common surface features.

Articulating deeper structure

In the threshold unit, students were asked to individually write their first draft pattern theory after exploring two examples: adding coins to a spaghetti bridge until it snapped and adding drops of water to the surface of a coin until the water overflowed. Their theory building was guided by a prompt, which focused them on describing the *pattern in behavior* common to both examples: "*Tell the story of both behaviors* so that someone listening to your story would agree that you are talking about either one of the behaviors, but they wouldn't know for sure which one you were talking about." Some students produced pattern theories that focused on common surface features, for example: "Both involved household items, needed techniques in order to do both of these experiments, both took patience." Many of the students, however, *articulated patterns in behavior* common to both examples, for example: "Both of these patterns involve adding things to objects until they can't hold those objects anymore."

Evaluating deeper structure

Students were asked to evaluate their first draft pattern theory against a third example: adding salt to a cup of water until a submerged egg floated to its surface. Two examples of threshold were observed in this example by the students: the floating of the egg in response to the addition of salt, and the saturation of the water with salt. This led to two different conceptualizations of the pattern: one of threshold as *tipping point*, and one of threshold as *maximum capacity*. Following their exploration of the example, the students individually responded to prompts asking them to compare the new example with the initial two examples. Comparing the saturation of the water with the spaghetti bridge, Patricia *identified a similarity in behavior*, writing: "We had to see how many drops an object would hold." Another student, Selena, compared the floating egg with the spaghetti bridge. She *identified a similarity in behavior*, writing: "You added more objects in it." She also *identified a difference in behavior*, writing: "We were seeing if it floats and in the spaghetti bridge we were seeing how many pennies you could put before it breaks."

Refining deeper structure

Following the egg investigation, the teacher led the students in a discussion where they compared the examples they had thus far explored as well as their first theory drafts. The students were then invited to revise their thinking and write second draft pattern theories. Patricia's initial theory of the pattern had focused on the common material and social features of the spaghetti bridge and drops-on-a-coin examples: "Both used pennies, had to have a special technique." Her second theory draft characterized the pattern as: "They all involve adding something to get a *reaction* out of it. It mostly resulted in something overfilling up other objects." Notably, she refined her theory by *removing surface features* and focusing instead on the deeper pattern in behavior underlying examples.

Generality

The power of a scientific theory, in part, depends on its range of applicability, and therefore its level of generality (Atkins, 2010). In the Patterns class, a theory was considered general if it *used language that did not tie it to any particular example*.

Articulating a general theory

The students practiced tuning their theory's level of generality during each pattern unit when they responded to the prompt by telling "the story of both behaviors so that someone listening to your story would agree that you are *talking about either one of the behaviors, but they wouldn't know for sure which one you were talking about*." Students' pattern theories were considered general when they were written in language that did not tie them to a particular example. Their initial drafts in the threshold unit included theories that described the pattern in context of specific examples, for example: "We used pennies, we put the pennies in a container, we counted, we did it again." The students' later drafts tended to be context-free, *using general language to describe the pattern in behavior*, for example: "Adding something to something until it changes."

Evaluating the generality of a theory

Students were shown their peers' theory drafts before revising their theories. The teacher projected anonymous examples of students' work and asked the class to compare their theories. During this discussion, Alvaro problematized the name one group had given the pattern – "The Break" – saying: "Actually, not everything had to do with something breaking. Because you know the one where we squirted the drop of water onto the pennies? It didn't break, it spilled…" Alvaro pointed out the inadequacy of the word break, on the grounds that it didn't apply to all examples. In doing this, he demonstrated a resource for evaluating a theory's generality, specifically by *questioning the generality of the language used*.

Refining the generality of a theory

Students refined their pattern theories' level of generality. For example, in the threshold unit, one student's initial theory read: "We used pennies and with those pennies only a certain amount of weight had to be held before it interrupted the experiment." The pattern is described in the context of the spaghetti bridge investigation and is therefore not general. For their second draft of the pattern theory, the same student wrote: "You need to add something on an object until it breaks or you can't fit any more." The student *removed context-specific features* from their theory, making it applicable to a broad range of phenomena.

Domain of application

A scientific theory is applicable to a bounded regime (Suppe, 1972). In the Patterns class, students specified their theory's domain of application by *listing examples* that followed the pattern.

Articulating the domain of application

Once students had written their second draft pattern theories, they were invited to generate a list of their own examples. For the threshold unit, students *generated psychosocial examples* such as "adding more sadness until you cry," and "bothering someone until they burst." They *generated physical examples* such as "filling up a water balloon," "pulling gum until it snaps," and "getting a haircut."

Evaluating the domain of application

From the examples the students generated, the teacher identified two to feature in a whole-class debate: "bothering someone until they burst," and "getting a haircut." During the debate, students *challenged the fit between examples and theories* by attending to mappings between the two. For example, Martin challenged the example of bothering someone until they burst, saying: "There's not really a maximum, like you could keep annoying them... 'cause after they get burst you could still keep annoying them, it isn't, it won't, it's not going to get fulled up on anything." Martin viewed the pattern as maximum capacity, and for him, there was no maximum limit to bothering someone.

Causal relationships

A chief application of scientific theory is the explanation of observed phenomena (Hempel & Oppenheim, 1948). In the Patterns class, a theory was seen as articulating causal relationships if it moved beyond describing the pattern in behavior to *include a causal explanation* for it.

Articulating causal relationships

The students were encouraged to think about the causal driver underlying a pattern in the second unit of the course, which focused on equilibration. They participated in a whole-class discussion with the aim of developing a causal explanation for an example where a glass of cold milk warmed to room temperature fast-then-slow. Before the discussion, the teacher asked the students to write down their initial explanations. She then seeded the discussion by reading the students' explanations aloud, leaving them anonymous. The explanations included ideas about the milk slowing down to reach room temperature, the physical apparatus used to conduct the experiment, and the milk adjusting to room temperature. In generating these causal explanations, students demonstrated resources for articulating causal explanations in the form of *intuitions about causal relationships*.

Evaluating causal relationships

Having read all of the ideas, the teacher focused the students on one idea in particular: "Because it was getting to room temperature at the end, so it was slowing down. It's like a race, when you're getting to the destination you start to slow down." The students debated the idea, demonstrating resources for challenging and defending its logic.

> Leo: Why would you slow down when you're about to finish a race? It doesn't make sense.
>
> Alvaro: Say there's a wall. Are you going to run straight into it, Leo?
>
> Leo: Well, I'm not gonna go slower though, because then I'll lose.
>
> Alvaro: Like no-no-no-no-no! Like, say you're winning 'cause you're going as fast as you can, then when you're gonna reach the wall, don't you start to like kinda? [stomps feet on ground slowly]

Leo *challenged the explanation on the grounds of its logic*: who slows down at the end of a race? Alvaro *defended the explanation by modifying the race analogy* to make it logical, turning the general scenario of a race into a race that specifically ended at a wall, which he subsequently identified with room temperature.

Refining causal relationships

Through their discussion, the students refined a combination of several ideas to produce an explanation that was conceptually similar to Newton's law of heating: "That it has lots to cover so it just does it fast and then it starts slowing down because it needs to reach, it's almost reaching its max." The explanation was developed through students' modification of ideas in response to problems pointed out by their peers. In this way, students demonstrated resources for refining causal explanations, such as *addressing challenges by modifying ideas*.

Discussion

This paper presented a collection of resources for theory building, which were demonstrated by the 8th grade students who participated in the Patterns class. The collection of resources is only preliminary. It is assumed that other students participating in the same course would demonstrate different resources, and that different kinds of theory-building activities (e.g., computational modeling) would elicit different resources. Despite its limited scope, the list of resources for theory building makes an empirical contribution to literature concerned with identifying the productive knowledge students bring to their learning, responding to the call to education researchers to view students from an asset-based perspective. More broadly, the category of knowledge to which the theory-building resources belong is a theoretical contribution to the KiP research program, as an ontological innovation.

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Restorying Toward Justice and Anti-Racism in ELA Classrooms

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Abstract: Storytelling has been used as a vehicle to center diverse perspectives in classrooms; however, in the U.S., the most prevalent stories in schools continue to be those that reflect narratives of white supremacist systems. As educators search new ways to implement culturally sustaining pedagogies, storytelling can become a vehicle to allow students to voice their own funds of knowledge and act as experts on their own experiences. This participatory-design study examined ways that storytelling in 9th grade ELA classrooms supported students in restorying their classrooms and communities. Using jazz as a set of methodological tools, this study was codesigned with a U.S. mountain-west English teacher and her students as a digital storytelling project to disrupt dominant narratives in a rural school. Findings demonstrate the potential for historically marginalized youth to identify as agents of change when offered opportunities to restorying in historically white spaces.

Introduction

Sociocultural perspectives in education have long suggested that learning is deeply intertwined with the lived experiences that contribute to individual and collective identities and the practices and tools found in communities (e.g., Holland et al., 1998; Wertsch, 1991). For decades, the research community has agreed that there should be more space for learners to bring their identities and cultures—their stories—into learning environments (e.g., Dutro, 2009; González, Moll, & Amanti, 2005; Thomas & Stornaiuolo, 2016). However, recommendations for how educators can include learners' home practices, tools, and knowledges vary greatly. While critical scholars argue that learners, educators, and researchers should treat stories as legitimate forms of knowledge, understandings of how to design spaces that account for learner stories, and the success or failure of communities in enacting liberatory pedagogies around stories, continue to be needed (e.g., González et al., 2005; Kumashiro, 2000).

This participatory-design study used jazz tools (e.g., improvisation, trading fours, and harmonic substitution) to examine ways that storytelling in 9th grade English Language Arts (ELA) classrooms supported students in a process of disrupting dominant narratives by (re)storying (Stornaiuolo & Thomas, 2018) and critically reinventing (Morel et al., 2019) their classrooms and communities. The study took place in collaboration with Elizabeth Murray (all names are pseudonyms) and her 9th grade students during the 2018-2019 school year in a rural, mostly white community. Elizabeth and I co-designed and implemented a year-long curriculum based upon the *Throughlines* digital storytelling project (www.thethroughlinesproject.com) to support her 9th grade ELA students in understanding the ways their personal narratives intersected with or were missing from the dominant narratives of their communities. In this study, we sought to acknowledge the ways that whiteness has shaped institutional spaces and examine the ways that privilege might be leveraged and disrupted to shift educational spaces. While this study included students from a number of backgrounds, in this paper, I focus on the ways that students who self-identified as coming from historically marginalized backgrounds—for example, as people of color, LGBTQIIA+, neurodivergent, differently abled, and/or from lower socioeconomic classes—in order to explore the ways that these students described their experiences of restorying in a predominantly white space. Given the ongoing violence perpetuated against historically marginalized communities by white supremacist systems, there continues to be need for youth from these communities to have opportunities to see themselves as powerful and agentic historical actors (Gutierrez et al., 2019).

While jazz has previously been used as a metaphor for education, this study explored the ways that jazz tools can support researchers in better understanding the classroom as a dialogic third space (Gutiérrez, 2008). As a discipline, jazz has a rich history of disrupting white supremacy to restory the ways musicians and audiences interpret music. By drawing from these tools as part of my conceptual framework, I follow calls for engaging with new tools in learning sciences research to re-envision how researchers and teachers might work together to better understand how whiteness shapes classrooms, and what we can do to disrupt those systems and create space for students as epistemic agents. To do this, I explored the following questions: 1) How do storytelling projects in classrooms support students to practice restorying in their ELA classrooms? and 2) How can jazz tools support the ways researchers observe and understand students' and teachers moves toward restorying in classrooms?

Background

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Jazz as Conceptual Framework

Jazz music bridges Western harmonies with African rhythms. Like the interactions in classrooms, the music moves between structure and improvisation, which has long been associated with storytelling. Jazz offers a rich history and tools through which to make sense of the complexity of learning and identity building that can take place when young people are given opportunities to examine their own stories. For example, as musicians improvise to come up with new melodies to compliment a composed song, they simultaneously recall the ideas put forth by the players who have come before and recreate the genre by engaging with new ideas from the world around them (Berliner, 1994). Miles Davis (1962), the jazz trumpet player, said that every time he played he had something to say, but it was up to the audience to be listening. Classroom interactions hold similar improvisations (e.g., Philip, 2019; Sawyer, 2004). Schooling, like jazz music, is steeped in structures defined by whiteness and connected to the oppression of historically marginalized people. However, amidst these structures exists a wealth of counterstories that allow us to speculate toward future worlds.

Jazz could be a tenuous framework for a study that takes place in a mostly white, rural school by white researchers and teachers. However, as a discipline, jazz is built upon a rich history of disrupting interactions, educational spaces, and practices that were historically defined or usurped by whiteness. As a learning scientist, I see jazz as an essential blending of cultural tools and practices to reimagine the world (Solis, 2009). Jazz in the U.S. was initially created by Black musicians as an assertion of agency, dismantling the chordal patterns and melodic phrasing of Western classical music (for an example of early 20th century jazz, hear Armstrong's (1962) "Mack the Knife"). The discipline, and its musicians, have continued to dismantle structures of whiteness in music by continuing to posit reconceptualizations of harmony and rhythm, playing within a group, and improvising outside the confines of traditional song structure (Gioia, 2011).

As a musician, I see jazz as an entry point into new ways of disrupting white supremacy in myself and in my work. North American jazz music grew out of acts of restorying, melding multiple cultures in the decades after slavery was abolished. Drawing from African call-and-response, improvisation, and polyrhythm, as well as Western harmonies and dance-based compositions, the music carries multiple stories to diverse audiences simultaneously (Gioia, 2011). Jazz offers us a set of tools for analyzing the ways that cultural stories are leveraged, engaged, and restoried in classrooms and a way to think about students and teachers as improvisers within the constraints of traditional schooling. In Elizabeth's classroom, jazz emerged as a set of tools through which I could better understand students' interactions. As I listened to Elizabeth's students assert their stories, I was reminded of the ways that jazz musicians trade themes, improvise new ideas and perspectives, and reimagine the world.

Restorying

Restorying has deep roots in traditions of storytelling, particularly as a practice of counter-storying through which individuals with historically marginalized identities can speak back to systems and structures of power. In education, counter-stories can serve to question the deficit perspectives and assumptions of what counts as knowledge found in traditional classrooms (Thomas & Stornaiuolo, 2016). Recent scholarship on "(re)storying" has emerged as a digital storytelling practice. "[A] process by which young people reshape narratives to reflect perspectives and experiences that have been routinely marginalized or silenced" (Stornaiuolo & Thomas, 2018, p. 346). Stornaiuolo and Thomas (2018) theorized restorying as "a way young people use digital tools to write themselves into existence, first narrating and analyzing their lived experiences and then synthesizing and recontextualizing those stories to represent a diversity of perspectives and reshape dominant narratives." These authors have pointed to the potential of restorying with youth to "reconfigure school spaces" (p. 346). They suggested that when youth are offered opportunities to "re-author themselves and the institutional spaces they encounter," they are also supported in historicizing the self, particularly with regard to "intersectional forms of systemic inequity and oppression" (p. 346). This form of restorying with students becomes a practice of supporting students in "selfmaking" and suggests that restorying with students holds potential as a rich practice to shift toward justice-oriented pedagogies and perspectives within classrooms.

Jazz as Tools for Restorying

Jazz as a dialogic music (Santi & Zorzi, 2016) offers a means through which to understand dialogue in education as part of the inherent structure of learning to communicate together (Bakhtin, 1981). Scroggins (2019) and Philip (2019) have each written about the potential of critical improvisation to inform teacher's justice-oriented practices. Though they draw primarily from improvisatory theatre, these scholars add critical lenses to jazz-oriented perspectives that improvisation within teaching leads to more creative support of students by attending to the positionality of the classroom participants (Solis, 2009). In improvisation, each participants' ideas hold possibility; the history and structure of the artform dictates how these ideas either act productively or antithetically within the collaborative whole. Structures can be changed, but must be done so with purpose (Berliner, 1994). As

Philip (2019) acknowledges, in education, improvisation must be "purposefully oriented toward justice" to "renegotiate power" toward more humanizing perspectives (p. 4-5).

In classrooms, youth often draw on improvisatory moves—trading and extending each other's ideas through theme and variation—to establish third spaces (Gutiérrez, 2008) that honor their own funds of knowledge and agency as historical actors (Gutiérrez et al., 2019). The multivoicedness of these educational environments can be theorized as forms of polyphony and polyrhythm, what Kuby and Christ (2018) describe as "the ways that a number of ideas and perspectives compose, harmonize, and play simultaneously without loss" (p. 294). In this paper, I take up these tools from jazz to better understand the process that young people engage in when they assert ideas about themselves and their communities with one another, using dialogue to build shared knowledge (Kinloch & San Pedro, 2014). As Gutiérrez et al. (2019) describe, this dialogic process is incomplete without engaging in acts of historicizing that support young people in seeing themselves as historical actors whose actions and interactions are part of a broader historical landscape. Building on a foundation of historicizing, Thomas and Stornaiuolo (2016) examined the ways that young people can "write themselves into existence" (p. 346) through acts of restorying that offer opportunities to reimagine how their stories are inscribed in communities. In this study, restorying appeared as an act of resistance for young people from historically marginalized communities as they engaged with the world around them and reasserted their own perspectives into dominant narratives.

Methods

This study took place at Williams High, a high school in the mountain west United States, over the course of the 2018-2019 school year across three 9th grade English language arts classrooms. Elizabeth Murray, who identified as white and female, had been teaching for 14 years at the beginning of our study. Williams High served nearly 1,500 students, 20% of whom identified as people of color and 30% of whom were identified as qualifying for free and reduced lunch. The 58 students who participated in this study resembled the demographics of the school. This study was surrounded by violent political rhetoric leading up to the 2020 U.S. presidential election. More than once, I entered the building to hear small groups of students discussing the benefits of a border wall. In the years after Trump was elected, Elizabeth reported responding to increased bullying and worried about how to offer her students a safe school environment.

Elizabeth and I drew from participatory design research and feminist ethnography because of their explicit attention to power, caring, and emotionality. Elizabeth and I designed curriculum and also shared meals, folded laundry, and weeded her garden. I see these interactions as part of our improvisations together as we designed our study. In her classroom, Elizabeth led students to engage with a number of writing experiences that we called the *Throughlines* project. Students read excerpts from Freire and other critical scholars, engaged with their own choice texts, analyzed social and news media pieces developed in their community, and wrote about their own experiences and the experiences of their communities. Throughout these experiences we asked students to consider "what stories are missing from the narratives you see every day in your school and community?" Students were then tasked with developing digital narratives that would begin to fill the gaps they noted in the stories they encountered every day.

Using ethnographic methods of data collection and analysis, we looked for patterns in her classroom. I collected classroom and design artifacts, 67.5 hours of observation recordings, fieldnotes, reflective memos, and at least two interviews with a sample of 22 students and Elizabeth. Following jazz as method, I also wrote short pieces of fiction as part of my analysis. I treated these pieces as improvisations, giving myself room to understand my data without immediately pinning my analysis to the people within this study. After this improvisatory exercise, I returned to the data and looked for counterpoints to deepen my understanding of the students' and Elizabeth's experiences.

I began my data analysis in concert with examining jazz as an emerging framework. I reviewed weekly audio recordings and fieldnotes, looking for examples of jazz tools being used by students in the classroom. This process began by analyzing student interactions that resembled *trading*, a dialogic practice of improvisation that constrains musicians to developing new ideas in a limited time frame. Discussions with Elizabeth about the ways her students' "off-topic" conversations might instead be framed as improvisatory moves shifted the ways that we designed daily lessons. Other tools such as *theme and variation*, *polyphony and polyrhythm*, and *swing* became codes that both emerged inductively that I applied deductively to guide me to jazz and restorying as a framework. Together, Elizabeth and I worked to hear the stories students told and the ways their restorying resembled jazz.

Findings and Discussion

The students included in this paper are examples of the ways that many of the students with identities that had been "shattered by persistent structural inequality" (Stornaiuolo & Thomas, 2018, p. 352) restoried themselves as powerful agents able to disrupt injustice. The following focuses on the experiences of three students who identified

as having non-dominant identities and whose individual experiences both represent the ways we used jazz tools to understand the actions and engagements of students in classrooms and the ways that students restoried the dominant narratives to see themselves represented.

Theme and Variation: Playing until you find what to say

Players restory in jazz by identifying musical motifs within a composition and then using improvisation to play variations on those themes. Elizabeth's students also restoried around themes throughout the year. While identifying thematic ideas is a practice of ELA, in Elizabeth's classroom, we not only asked students to identify themes they read in literature, but how they might take up those themes and shift them for their own purposes. Students identified themes as they read and wrote, and then worked together to create variations on those themes, some of which included stories of trauma, creativity, family, and justice.

Leaf, a student who identified as Transgender (capitalized in accordance with Leaf's preferences) and part of the LGBTQIIA+ community, drew upon his gender identity and the bullying he had faced as the theme around which he improvised across his projects. This began with a profile he wrote about himself at the beginning of the year, where he described a "complicated' relationship with his father, which he explained was because his father "struggled to accept me." In his profile, Leaf also discussed his respect for Justin Blake, the Transgender YouTube star who had spoken out about his own mental health and coping with bullying when he was in school. "I respect Justin Blake a lot. He's gotten so much crap and gotten discriminated against, but he still continues to put out so much positivity. That's really hard to do." In a reflection on his first project, Leaf wrote, "I want to raise awareness about Bullying. Yeah, there's signs saying no bullying or whatever but when it happens no one does anything. I hate that because I know how it feels and words hurt when they build up."

In his narrative project, Leaf again drew from his own experiences being bullied because of his gender identity. He wrote an essay entitled "Mental Health Awareness," in which he described interviewing his friends to ask, "Is mental health talked about enough?" Leaf reported his findings expertly, weaving quotes from interviews into his prose, offering examples of his own experiences, and calling for increased awareness in the community. However, he also chose to have his story password protected, explaining "I only want those I give the password to see it." Although Leaf repeatedly wrote in reflections about the importance of creating awareness about the connections between mental health, identity, and bullying, he was not yet ready to present that message to his peers beyond a small group he selected. In an interview he explained, "I kind of have a support network, you could say, but not really, my family doesn't really understand me…I don't really have anybody now, I guess you could say." Leaf explained that he felt isolated because "there aren't really people like me here." He also emphasized how important it was to him to feel like he was giving to others and noted, "Bonding with new people feels amazing" and that he really wanted to find ways to talk to people about the bullying he had experienced.

Throughout the year, we observed that as Leaf shared his narratives with small groups of peers, he appeared to grow more confident. When Leaf began a new project in which students were prompted to identify "what it means to be human," he also began to vary his theme of mental health to include perspectives on diversity as a benefit to society. In this iteration of his theme and variation, he also began to articulate excitement about being able to create a message that he could present "especially to teachers and counselors here [at Williams and at Dover Middle School], I think they really need to know more about diversity." In a shift from previous projects, Leaf actively sought feedback on his messaging from his teacher and new groups of peers. As he refined his presentation, he began naming gender identity as part of the diversity that defined humanity. He created a digital presentation to use as a resource for his classmates and the school's counselors.

While he was creating his presentation, protests against a Drag Queen Story Hour at the local library began. While Elizabeth and I were concerned about the ways Leaf might feel his story was being placed in public view, in a final interview he acknowledged the protests and then explained that he knew people "were closed minded" but focused on the fact that nearly 300 people had also joined the counterprotest. In his final project, Leaf affirmed his own identities, acknowledging that his feelings of difference and diversity were exactly what made him valuable and necessary. In it he wrote, "Being different is a way to spread that difference. Transfer your experiences with others so that they can learn and maybe feel more valid and accepted." By improvising around themes of identity, mental health, and diversity, he found a variation in messaging that allowed him to restory himself into the narratives in his community.

Stornaiuolo and Thomas (2018) "theorized restorying as a way young people use digital tools to write themselves into existence, first narrating and analyzing their lived experiences and then synthesizing and recontextualizing those stories to represent a diversity of perspectives and restory dominant narratives." They also explore the ways acts of restorying can "reconfigure school spaces" (p. 346). For Leaf, this reconfiguring took place over the year as he examined and improvised to find the ways that his own identities could be part of the dominant narratives he heard each day in Dover. Leaf shifted from explaining the importance of talking about

diversity and mental health to just a few of his trusted peers, to speaking about his own experiences and advocating for others like him by sharing his experiences and stories. In an interview at the end of the year, I asked how he decided to speak about his own diversity and identity. He said,

> [This year] I started changing and understanding myself better. It's kind of like, well, I've been in that spot before, depression and everything, and so I'll do everything I can, no matter if it's a person I hate, I don't want anybody to go through that because it's a lot to go through. Not a lot of people pay attention…it's just really important to me.

For Leaf, talking about his identities became a form of activism, a way to help others by restorying the narratives around him to acknowledge differences and be more inclusive. Like a jazz musician, exploring variations on a theme, it took Leaf time to recognize his own story and then to find the ways that he would feel empowered to share that story and assert his own humanity.

Polyphony & Polyrhythm: Centering family as counterstory

In jazz, polyphony and polyrhythm refer to many sounds and rhythms simultaneously. Jazz theorists often use these terms to describe the layering of instruments that creates unique textures and voicings within a piece of music (Berliner, 1994). Together, these layered sounds allow for dialogue between musicians, a kind of musical heteroglossia (Bakhtin, 1981; Wertsch, 1991), where multiple voices emerge using different discourses over different time frames. In Elizabeth's classroom, polyphony and polyrhythm acted as tools to observe the multiple discourses and timeframes that young people used as they added to narratives in their communities.

For example, some students restoried through a number of separate counterstories across the year to disrupt dominant narratives in her family, school, and community. Jazmine (who identified as Latina), for example, appeared to restory slowly and differently across each project, writing her way into the perspectives she wanted to share. On the other hand, Truc (who identified as South Asian and male) appeared to know immediately what kind of story was missing from the community. Truc seemed a popular student, friendly with nearly everyone in Elizabeth's second hour classroom. Although he was quiet in class, he articulated his ideas clearly; on a survey that he saw himself as capable, even if he "didn't always like English." When Elizabeth and I presented the narrative project, most students had questions about what it meant to identify the dominant narratives they engaged with each day. Truc, however, immediately began to write, sitting in the back of the classroom, ignoring most of the interactions of his peers. In my fieldnotes, I recorded a moment in the middle of the project where I was concerned that Truc was lost because he had been so quiet. I approached him and asked how it was going. "Good." He said, staring at his screen. Not wanting to disrupt him, I walked behind him, expecting to see a game many of the peers he sat with had downloaded. Truc had pages of writing and images already chosen for his webpage.

Truc's story was about his family, a memory that he described in his reflection as "ordinary," though he acknowledged that it was "really different than anything that would happen here." In his story, Truc described visiting Chicago's Chinatown with his parents and members of his extended family. His writing was extremely descriptive, with "streaks of shallow brightness" and "doors clanging continuously," as well as the smells of "perfume and plastic," "black coffee and green tea" making his experience "even more nostalgic." Truc described his disappointment with what he had ordered, writing, "I requested whatever my mom had, so I was given a bowl of rice, no more than two handfuls, and a piece of bread on the side." He described his disgust at the bread, alluding to how much he had wished to have tried some of the other foods that made this "one of the most saturated memories I have." Elizabeth and I both celebrated Truc's writing. In his audio reflection, he explained that he told this story because although his family made him move to Dover from a larger city, "family is of course important. Family is one of the main factors in molding the person you are." For Truc, this story seemed to be a way to assert his heritage and one of his identities as a person who really valued his family.

He later reflected that he missed the diversity of the city, and that diversity was something he was trying to portray with his story. Similarly, in his interview at the end of the year, Truc continued to elaborate, explaining,

> I really liked the story project. I could write about it and keep going as long as I wanted…I chose this moment because I just remembered it really well. I moved to [this state] because there were better jobs for my family, but Dover is just really different from there. Just how people talk, the attitude of people. I don't know how to explain it, there's less diversity, it's fine, I guess, I just feel like I wrote it for myself.

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Truc's immediate engagement in the project, and his acknowledgement that he missed the kind of diversity that had been present in the bigger city from which he had moved, suggested that he wanted to add a narrative to Dover that allowed for the small moments in his family to feel like they fit into his community.
At the end of the year, Elizabeth and I talked about how much easier it seemed to be for her students to add new narratives when they had lived somewhere other than Dover. Truc was able to quickly add a narrative to those he observed because he had so many experiences of what it felt like to live in a place with more diversity. Unlike many of his peers, who needed to craft their restorying across the year, Truc was immediately able to identify the difference in his story and know that, though it might disrupt the dominant narratives in Dover, it was fully accepted as part of the fabric of the culture in other places and in his family. Like a musician who draws on personal and ancestral histories to invoke polyrhythmic polyphony, Truc drew from his past and his family to add his story to the largely white narratives that emphasized different values and experiences from his own in Dover. In doing so, he also recognized himself as the most important audience for his restorying.

Improvising and Extending: Restorying as choice

As jazz performers grow in expertise, they also build new ways to extend improvisations, sometimes even playing outside of the written chord changes to reimagine a composed piece into something entirely new (Gioia, 2011). For Stornaiuolo and Thomas (2018), this kind of creative innovation is central to restorying, particularly with historically marginalized youth. In Elizabeth's classroom, we saw several students make moves to question the dominant narratives they were observing by improvising around the structures we offered for telling their stories throughout the year. In some instances, these improvisations became full of extensions of the projects. For example, Levi and Brandon (who both identified as white and male), shifted their project on the second amendment to hosting gun safety classes when they realized the correlation between accidental death and gun ownership. While these actions were still aligned with the project goals, they went much farther than Elizabeth had required and created meaningful possibilities for learning.

Bailey was another student who took up the projects that Elizabeth presented and adapted them, restorying her English class assignment by assignment to meet her own aims. Bailey (who identified as white, female, and physically disabled) was an extremely quiet student who spent the entire year in Elizabeth's fourth period class. She had been born with a congenital limb difference and in my fieldnotes, I noted that she carried the same denim coat nearly every day and would pull the jacket over her right arm if other students glanced in her direction. While I never recorded bullying, Bailey emerged as someone I paid attention to, first to ensure her safety, and then as I noted the ways she had reframed the projects to fit her own ideas throughout the year.

In her survey at the beginning of the year, Bailey noted that she had "never been in an English class before." However, this seemed to refer to "high school English class," as she had attended middle school with a number of the other students in her class. She also identified herself as "very creative" and "a writer," and noted that she felt she "mattered a tremendous amount" and "completely belonged" in Elizabeth's classroom. Throughout much of the year, she sat at the front of the classroom, often with two other students who also identified as white, female, and neurodivergent. Throughout the projects, Bailey voiced her commitment to being creative and adapted nearly every assignment to work on fantasy and fan-fiction narratives in which she reimagined the world as a place of "magic and adventure" as well as "sometimes a really bad place." Although Bailey's writing did not, at first glance, critique the structures of society, her commitment to writing what she wanted seemed to be a way of restorying her ELA class and each of the stories she constructed focused on a character who had a physical difference from their peers and families. For example, in "Pies," these differences were punished until the character discovered a way to escape or change the situation in which they found themselves. (In this story, the main character is locked in a basement because of her ability to do magic, escaping only when she learns to use her powers.) In others, such as the fan-fiction piece she wrote entitled "The Legend of Zelda Day and Night," the main character's differences are mentioned in the opening, but do not seem to impact the character as they move throughout the story. Although Bailey did not reference these characteristics in her analyses of her writing, she did explain that she felt it was important to "have a lot of people represented."

When asked in an interview how she had approached the class, Bailey answered, "I was creative…I wrote what I wanted to write." As she evaluated her work using the standards Elizabeth had asked her students to meet, Bailey also explained that she thought she could meet all of them through her fiction, so she had chosen to work in that genre. For Bailey, restorying was an act of questioning the ways that English language arts class was set up and then refusing that structure to engage in the kinds of writing that would further her own goals.

Jazz moves forward and expands because of the innovations of musicians who improvise outside of the boundaries and traditions of the music; however, this only occurs when they know the rules they're breaking. Like jazz musicians in their genre, Bailey was still working within the genre of ELA, she reframed the boundaries of Elizabeth's assignments and projects, adding her own "sound" and to get what she wanted from the class. As she

explained, "The most important thing to me is creativity. Being original. Like, making your own things and sometimes they can be inspired by other people, their creativity can inspire your creativity." While Bailey's stories did not directly critique the structures of schooling as did the stories of some of her peers, I saw her commitment to her own development as a writer as an act of restorying because she asserted a different set of values into a school system that had defined learning as a pursuit of the standards. Thomas and Stornaiuolo (2016) described restorying as "a participatory textual practice" (p. 313) that becomes a dialogue between two ways of being. For Bailey, restorying ELA participation meant disrupting power structures of the classroom to define her experience.

Across Elizabeth's classes, students like Leaf, Truc, and Bailey "write themselves into existence" (Stornaiuolo & Thomas, 2018, p. 345) by restorying the narratives that they were allowed to claim within their families, classrooms, and communities. For students like Leaf, restorying took place over the course of the entire year, as he solidified the ways he wanted to claim his own stories and then decided upon the variations that would most honor his identities. Other students knew the stories they wanted to add to their community almost immediately. Students like Truc restoried quickly, adding his own stories to Dover's narratives to assert that families like his deserved representation, even outside of the "big city." Then there were students like Bailey, who not only decided to write fanfiction to make her own story visible in her favorite games, but also decided that the entire ELA classroom needed to be restoried in order to meet her needs.

Significance

Jazz is deeply intertwined with justice. It has been the soundtrack of protests and the continuing fight for civil rights. As a music, its very existence is dependent on the restorying of white supremacist narratives to illustrate the multiplicity of stories and voices that have existed throughout the United States' history. As these narratives are perpetuated insidiously in this country, jazz too continues to evolve, its artists extending the music into new forms, adding new variations to compositions and playing outside the changes, catching their audience off-guard while pushing the music forward. In Elizabeth's classroom, the students we observed restorying were mostly those whose identities had been historically marginalized, whether in terms of race, culture, socioeconomic status, gender identity, or ability. Restorying for these students was an act of justice, claiming their right to tell their stories told in the spaces where they lived. As these students became more confident in the themes of their stories and the variations they wanted to tell, they also began to push the boundaries of their classroom, taking up new ways of interacting and producing content in order to honor their own ways of knowing. As Elizabeth said at the end of the year, isn't that what we want for our students?

As Elizabeth's students were supported to tell their stories, we also saw them make moves toward epistemic agency. I think of epistemic agency as the power to map one's stories onto the learning that takes place in school. In the push for inclusive and culturally sustaining schooling, *teachers* have often been tasked with determining how to include students' cultural knowledge in the classroom. However, in this study, we aimed to support students in determining how their own cultural knowledge could shift classroom learning. When students are supported with justice-oriented practices, they have the potential to reconsider the world and the ways that they move through it. For students from historically marginalized backgrounds this is often an act of restorying. For students from dominant backgrounds, it is often an act of questioning, beginning to discuss the histories of their privilege in order to shift perspectives. In an era characterized by a constant questioning of truth, it is more pivotal than ever that English teachers work to support their students in developing the skills to read the world and see themselves as powerful with potential to assert more humanizing forms of knowledge.

Jazz as Methodological Toolkit

Design research results not only in empirical findings, but also in the development of methods and theory. By structuring this study around jazz, I found that jazz became not only a metaphor, but a set of methodological tools through which I could make sense of the moves that students and Elizabeth made. Questions of structure and agency are enduring in education and anthropology; jazz as a tool kit provides a way to look at these questions from new perspectives in relation to human learning. For me, jazz is about joy. White supremacy lands heavily on all of us, even those of us whom it offers privilege. Music is ultimately about joy, and jazz is a direct expression of Black joy in the United States. Even in a mostly white, rural setting, and perhaps specifically because of this context, tools that speak to creativity and joy and triumph are exactly the counterpoint necessary to reimagine what learning can look like in these spaces. As we continue to encounter violence against Black people, while allowing education in highly segregated spaces, then we will continue to see white supremacy proliferate. Students need support to question their own histories and narratives. In our current reality—where police killings of Black men and boys perpetuate, where the COVID-19 pandemic continues to take the lives of people of color and people living in poverty at alarming rates, and where systemic oppression means that many people in the U.S. do not have enough to eat—helping students to reflect on their stories to disrupt inequity carries specific urgency.

Taking up new ideologies and ways of knowing in education has the potential to disrupt this cycle. Especially when we draw from tools that have successfully disrupted these perspectives in other genres and disciplines. Jazz tools offer a means of observing classrooms as holistic ecologies where every move has ramifications and improvisations can be traced. These tools also offer a way toward refusal (Tuck & Yang, 2014)— a means of reframing the world and refusing the framework of white supremacy. These tools offer researchers and educators new possibilities for "world making" (Solis, 2009), not only as a set of analytic tools, but also in the future as a toolkit for design, a way to listen deeply to the stories of our participants as we build new kinds of learning environments. In studies that claim criticality, making space for these new worlds based on the stories of teachers and students should be our top priority.

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Perspectives on the Process of Design from Education and the Design Fields: Toward Transformative Design

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Abstract: This synthetic review explores traditional approaches to educational design that have predominated education for the past century, considers the limitations of these approaches for fostering transformative second-order changes in schools in ways that can counter normative hegemonic arrangements, and contemplates the possibilities of approaches to design from design fields and research on participatory design. The review closes with an exploration of potential approaches for educational design going forward to pursue changes that introduce new goals, structures, and roles to transform education in service of more equitable futures.

Introduction

A significant body of research suggests that the cultural configurations of schools, including their governance structures, organization, and teachers' approaches to curriculum and instruction, have not substantially changed in North America over the last century (Cuban, 1988, 2020; Tyack & Cuban, 1995; Hess, 2011; Payne, 2008). Acclaimed historian Cuban (1988) ascribes this reification to a traditional focus in education on first-order, as opposed to second-order changes. As Cuban (1988) explains, "first-order changes try to make what already exists more efficient and more effective, without disturbing the basic organizational features, without substantially altering the ways in which adults and children perform their roles" while "second-order changes seek to alter the fundamental ways in which organizations are put together" (p. 72). The ongoing COVID-19 pandemic, intensification of the global climate crisis, growing economic inequality, proliferation of fake news, increased global migration, calls for justice from minoritized groups, and demands for reconciliation and decolonization from Indigenous peoples have highlighted the need for new approaches to education involving second-order changes that can address issues central to larger shifting patterns of privilege and marginalization. There is a need in this regard to think creatively and explicitly about the assumptions and preconceptions of how we think about and enact education, not just at the macro level of how schools are organized, but at the everyday level of how teachers teach, how they organize activities for their students, and how students engage in these activities.

Questions remain, however, around how, and the extent to which, prominent and still emerging ways to conceptualize and carry out educational design can work to foster the kinds of second-order changes that might address the immense challenges and inequity present in the world today. Seeking to lend insight into this question, this review examines the limitations and affordances of various approaches to educational design for fostering second-order changes in schools that might advance more preferable educational futures.

We begin by defining what we mean by design processes and distinguishing between design processes and the more typical focus on design principles. Next, we review the traditional approach to design processes that persistently informs design in pre-service teacher programs, school districts/jurisdiction, and learning environments. We then discuss two alternative perspectives on educational design and research that are increasingly gaining traction in the field of education: (a) perspectives on design thinking arising out of design fields and (b) perspectives on participatory design. Each of these perspectives, we argue, offers opportunities for transformative design of learning environments through fostering second-order changes beyond what is usually possible through the traditional design processes. We conclude the review with a discussion outlining possible fusions and intersections of these various design perspectives that could better serve all students and address issues residing within the complex and diverse social and cultural worlds in which we live.

Defining Design Process: Design Processes Versus Design Principles

Before discussing design processes in education, it is important to first distinguish between what we mean by *design processes* in comparison to the more typical focus on *design principles*. In defining the nature of design principles, Kali (2006) explains that design fields commonly "gather and abstract designers' experiences and research by creating collections of design principles or design patterns that synthesize design knowledge and can be used to guide new designs" (p. 188). This dynamic can be seen in the field of education where researchers commonly articulate the implications of their work in the form of abstracted design principles (whether or not the researchers use this specific term) to highlight the design characteristics of productive learning environments.

By comparison, a focus on *design processes* defines characteristics of the processes through which desirable learning environments might be designed rather than defining the characteristics of the learning

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environments themselves. Specifically, by the term design process we mean both the articulation of the process of design as well as articulation of the mindsets that contribute to and support productive design. In so doing, we purposefully combine what McKenny et al. (2015) refer to as "technical" and "phenomenological" perspectives in terms of the activity flow of the design process as well as the productive mindsets of designers that facilitate the design process.

Certainly, designers might focus on design process as well as design principles, but in education much research is focused on design principles with less explicit articulation, particularly in the scholarly literature, of the design processes themselves. While design principles can serve as powerful heuristics to guide design of educational environments, without also attending explicitly to the processes by which educators design, educators miss a powerful opportunity to more fully realize transformative second-order changes because design principles tend to already assume or dictate a frame for the design rather than supporting or prioritizing consideration and exploration of new frames, which is an explicit goal of newer design thinking and participatory design processes. By frames, we refer here to the differing vantage points, perspective, and conceptual lenses by which "we name the things to which we will attend and frame the context in which we will attend to them" (Schön, 1984, p. 40).

Traditional Industrial Perspectives on Design Process in Education

While attending to the design process offers possibilities for transformative second-order changes, traditional design processes in education have historically focused on technical rational ways of thinking rooted in the "backward design" method first developed by Bobbitt (1918) and then fully articulated and popularized by Tyler (1949) three decades later. This design tradition continued in education with design processes and procedures associated with task analysis as articulated by Gagné (1965). Borrowing heavily from behaviourism, these process-based frameworks start with a learning objective and then work backward to plan for instruction. Within Gagne's proposed design process, for example, task analysis is conducted to decompose higher order skills and goals into subordinate constituent elements. Instructional design then focuses on sequential instruction of subordinate elements. The most popular approach to design taught in almost all teacher education programs in North America today, Understanding by Design (Wiggins & McTighe, 2005), continues to reflect this backward design process focussing on a sequence of (a) identifying the targeted outcomes in terms of big ideas and skills, (b) determining how those outcomes will be assessed, and (c) choosing learning activities that will support the targeted outcomes as measured by the assessments.

The ongoing prominence of these traditional approaches for conceptualizing design processes in the field of education may explain, at least in part, why education as practiced in K-12 classrooms has changed so little in North America over the last century (Cuban, 2020; Payne, 2008). These approaches to design are emblematic of a focus on first-order changes in educational environments, as opposed to second-order changes that seek to fundamentally alter the ways education is understood and organized (Tyack & Cuban, 1995). The reason for this focus on first-order changes can be largely attributed to the ways these processes reflect a technical rational stance towards design. By "technical rational," we refer to perspectives and approaches that view "practitioners as 'instrumental problem solvers' applying well-defined solutions to well-defined problems" (Anderson & Coleman, 2015, p. 270). Through these lenses, educational design is framed as an act of instrumental problem solving emphasizing correct solutions proceeding from a pre-set goal or aim, with little or no emphasis placed on deeply exploring the nature of the problem or the ends to be achieved (e.g., Schön, 1983; Strong et al. 2016). If designers seek to advance more equitable futures in our schools and society, attention needs to consider not only the discrete learning outcomes found in subject specific programmes of study but also the nature of educational problems and the frame within the designer might work (Clark, 2021).

One example of the importance of attending to the frame of design is highlighted by Dwayne Donald (2010) in relation to low graduation rates and academic success among Indigenous students in Canada. As Donald explains, much discussion around this issue tends to be framed in terms of how to raise graduation rates and academic outcomes of Indigenous students in ways that imply a cultural deficit wherein culture becomes a code word for race and problematic difference. Donald clarifies that such a framing fails to consider the ways the lack of success seen in Indigenous students is directly connected to the historic and current state of the relationship among Indigenous and settler populations in Canada. Donald discusses a more productive frame that focuses on the relationship itself as an educational priority, not just for Indigenous students but for all students and society writ large, equal to what we are talking about in terms of Indigenous student success. These insights highlight the importance, as we discuss below, of approaching the design process more in line with design fields that focus on problem finding and the lived experiences and perspectives of stakeholders to reframe educational challenges.

Perspectives on Design Thinking from the Design Fields

The linear, instrumental, and technical rational tradition of design in education stands in contrast to the ways

design is conceptualized and understood in design fields. While design fields focused heavily on the proposition that design could be a highly rational and scientific process through the middle and late middle portions of the 20th century (e.g., Simon, 1969), the field underwent significant paradigmatic shifts starting in the 1970s when design began to be understood more holistically in terms of the complexity and "wicked" nature of important design challenges that preclude, defy, and negate such technical rational approaches to problem solving (e.g., Buchanan, 1995; Norman, 1998; Rittel & Webber, 1973; Schön, 1984). This more human-centered approach to design — often termed a designerly stance towards design — includes: (a) deeply exploring the perspectives, experiences, needs, and goals of stakeholders in relation to wicked problems, (b) "reframing" design challenges by stepping back and reconsidering the vantage points, perspectives, and metaphors being used to define the actual nature of the challenges, and (c) engaging in ongoing cycles of ideation and iteration of possible responses through multiple rounds of feedback from stakeholders (Buchanan, 1992; Dorst, 2011; Norman, 2013; Schön, 1984).

Particularly over the last decade, there have been increased calls to integrate these more human-centered perspectives on design into education (e.g., Kirschner, 2015; Koh, Chai, Wong, & Hong, 2015; Razzouk & Shute, 2012). The most prominent approach to human-centered design in education, and across many other fields as well, involves the notion of design thinking as articulated and promoted by IDEO and the Stanford Design School (e.g., Brown, 2008; IDEO, 2012). Design thinking so conceptualized articulates stages of the design process that are referred to with various names but generally involve four key moments: (a) *discovery* (where the designer or team comes to understand the nature of the challenge, does background research, and often works to develop empathy with stakeholders), (b) *interpretation* (where the designer or team works to synthesize what is been learned in a way to frame or reframe the opportunities for design and the specific question that the design process seeks to address), (c) *ideation* (where the designer or team generates and refines a range of possible ideas to pursue to address the design question identified in the interpretation phase), and (d) *experimentation* (where the designer or team begins iteratively prototyping, gathering feedback, and refining the approach) (e.g., IDEO, 2012). The IDEO/Stanford perspectives on design also heavily emphasize that design thinking mindsets, such as embracing ambiguity, as well as the need for empathy and radical collaboration, are also central to the design process.

In terms of the affordances of design thinking for fostering second-order changes as compared to traditional backward design, there is an emphasis on the importance of: (a) divergent thinking in addition to the primarily convergent thinking of the backward design approaches; (b) coming to understand the needs and perspectives of stakeholders; (c) exploring the problem before framing or reframing the specific articulation of the design question to be explored rather than jumping in with assumptions of the questions to be design for as foregone conclusions; and (d) collecting feedback throughout the design process rather than completing the design process before seeking out feedback. This structuring thus has substantial affordances compared to traditional backward design approaches in terms of moving beyond "first-order changes [that] try to make what already exists more efficient and more effective, without disturbing the basic organizational features, without substantially altering the ways in which adults and children perform their roles" (Cuban, 1988, p. 72). By creating an opening to rethink the opportunities and questions to explore, design thinking can create the possibility of exploring "second-order changes [that] introduce new goals, structures and roles that transform familiar ways of doing things into new ways of solving persistent problems" (Cuban, 1988, p. 72).

Other research from design fields suggest, however, that design thinking thus conceptualized does not fully constitute a designerly stance that focuses on second-order changes in service of transforming the cultural configurations within schools. While basic design thinking approaches create openings to rethink educational challenges, issues, and problems related to equity, diversity, and inclusion that might foster second-order changes, research in design fields emphasize the importance of focusing the design process on what are known as "wicked problems" (Rittel & Webber, 1973; Buchanan, 1992). Wicked problems are problems that are difficult or impossible to solve, have multiple possible explanations depending on the worldview and perspective of the observer, are often symptoms of deeper structural problems, have no single solution, involve complex interactions of stakeholders with differing needs and values, and resist easy solutions because of complex interdependencies that result in or reveal new challenges when the problem is explored (Rittel & Webber, 1973; Buchanan, 1992). While research has explicitly focused on wicked or ill-formed problems in the context of design thinking with both preservice teachers (O'Byrne et al., 2018; Harth & Panke, 2019) and in-service teachers (Hubbard & Datnow, 2020; Marin et al., 2013; Retna, 2016; Sheehan et al., 2018), the IDEO and the Stanford Design School (Brown, 2008; IDEO, 2012) models of design thinking do not explicitly foreground or frame design challenges in terms of wicked problems. For example, the IDEO (2012) design thinking models encourage designers to frame problems in terms of 'How might we…' (HMW) questions, which can foster a tendency to place clear boundaries and constraints around problems whereby problems are viewed as relatively "tame," rather than dynamic, complex, ill-defined, and confusing (i.e., wicked) (Buchanon, 1992, p. 15).

Notably the implementations in education of IDEO and the Stanford design thinking models, paralleling

the situation in the field of business management, often don't engage with, or reference, other literature in design fields (Johansson-Sköldberg et al., 2013; Sosa, 2015). Reflective of this disconnect, design thinking as taken up in educational practice often does not deeply consider key elements inherent to a designerly stance towards inquiry such as the notion of "reframing" or "positioning" a design problem (Buchanan, 1992; Dorst, 2011; Gulari, 2015; Schon, 1984). While educators employing a technical rational stance towards design would be largely unconscious of how they are framing a problematic situation, those adopting a more designerly stance would work to reframe or reposition a problem by stepping back and considering it through differing vantage points, perspectives, and metaphors (Dorst, 2011). Working against the tendency of interpreting issues or challenges in education through traditional discourses, a designerly stance to framing challenges educators to view problems through non-dominant and often overlooked discourses in education (e.g., feminist, ecological, critical). Through this process, educators would then be able to reframe a challenge in ways that might better advance second-order changes that can counter status quo hegemonic arrangements in education.

The limitations of how human-centered design is most often taken up in educational contexts can also be seen in how stakeholders are positioned in the design process. While IDEO (2012), for example, emphasizes the ways design thinking is a "deeply human approach," it also asserts that it "relies on your ability to be intuitive, to interpret what you observe and to develop ideas that are emotionally meaningful to those you are designing for" (p. 14). Theorists in design fields, including Sanders and Stappers (2008), have criticized this designer-centered stance for the ways it promotes an "expert mindset" built on "hierarchy and control" (p. 9) that assumes the designer can determine what is best for those implicated in a problem. Additionally, while perspectives on design as promoted by IDEO and the Stanford Design School heavily emphasize that the process is not linear, and that there will be substantial iteration and recursion back and forth between stages of the process, the design thinking process is articulated from a procedural perspective. Reflective of a procedural stance towards design, there is often a focus in the educational literature on the relatively straightforward implementation of IDEO/Stanford conceptions of design thinking for preservice teachers (e.g., Henriksen et al., 2020; Shively & Palilonis, 2018) or inservice teachers (e.g., Spoon et al., 2020; Hennessey and Mueller, 2020; Scheer et al., 2012).

Recent research in the field of education, however, is moving beyond IDEO/Stanford conceptualization of design thinking, by incorporating expanded perspectives from design fields to address wicked problems (e.g., Norman, 2013; Schön, 1984) while working with both preservice teachers (e.g., Jordan, 2016) and in-service teachers (e.g., Goldman et al., 2020; Svihla & Reeve, 2016; Svihla et al., 2016; Koh, Chai, Benjamin, & Hong, 2015; Jordan et al., 2014). Within this body of literature, there is a particular focus on framing and reframing design challenges in terms of larger complex structural, social, cultural, historical, and political systems that are implicated in learning environments and students' opportunities to learn. While the IDEO/Stanford conceptualization certainly brings strengths in terms of how concrete and accessible it is to new designers, the broadening of conceptualizations of design thinking that are beginning to enter the field of education create many more opportunities for deep consideration of the framing and reframing process whereby challenges might be reconsidered from novel perspectives that have the possibility of generating second-order changes that account for greater equity in our schools and society.

Perspectives on Participatory Design in Education

Echoing the concerns discussed above, other researchers propose that the approaches to design thinking outlined in the previous section have substantial potential to sustain and extend neoliberal perspectives furthering the loss of already marginalized identities, perspectives, cultures, and value systems (Gram, 2019; CBC, 2019; Taboada et al., 2020). Essentially, while many design thinking approaches emphasize understanding stakeholder needs, gathering feedback from stakeholders, and even a focus on radical collaboration to include multiple perspectives on the design team, most perspectives on design thinking still envision the designer or the design team as designing "for" stakeholders rather than designing "with" stakeholders, which runs the risk of recreating or perpetuating inequitable power structures and barriers. This dynamic can be seen, for example, in the ways people with differing abilities can be seen as recipients design rather than participants in the design process itself. Liz Jackson, a disability advocate and design strategist, outlines how this designer-centric perspective can lead to "disability dongles" involving an "elegant and well-intended, but ultimately useless solution to a problem people with disabilities never knew they had" (CBC Radio, 2019, para. 2). Reflective of insights like this, approaches to participatory design (Björgvinsson, Ehn, & Hillgren, 2012; Ehn, 1988; Luck, 2018) and decolonial design (Taboada et al., 2020) have evolved in design fields resulting in approaches to collaborative design that are more just, equitable, and counter-hegemonic.

Building on these ideas, similar approaches to participatory design have been explored in education (e.g., Gutiérrez & Jurow, 2016; Bang et al., 2012; Penuel & Gallagher, 2009). In this section, we outline some of the major currents of participatory design in educational research and conceptualize them according to their potential

to enact second-order changes in schools by designing with, instead of for, stakeholders. That is to say, we seek to demonstrate how several recent participatory approaches to design in education may provide avenues to "introduce new goals, structures and roles that transform familiar ways of doing things into new ways of solving persistent problems" (Cuban, 1988, p. 72) in educational settings. In particular, the following paragraphs consider Participatory Design Research (PDR), Design Based Implementation Research (DBIR), and Cultural Historical Activity Theory (CHAT) approaches to participatory design.

Participatory Design Research. PDR can be defined as a form of inquiry designed to "create more culturally-relevant and reusable learning artifacts *for, with and by those* who will use them" (Chew et al., 2021, p. 541, italicized in original). Notably, as Jurow et al. (2016) explain, PDR "allows for the inclusion of diverse perspectives on what kind of learning matters, why, when, where, and for whom" and also "requires careful consideration and ongoing negotiation about what participation means and how it can be best enacted throughout the processes of design and research" (p. 219). PDR differs from traditional approaches to educational design and research in that it challenges assumptions about "normative hierarchically powered decision-making structures" (Bang & Vossoughi, 2016, p. 174). As a consequence, there are a number of putative advantages to PDR approaches over traditionally hierarchical educational research methods that may lend themselves to realizing second-order change in schools. For instance, PDR methods can function as a means of what Booker et al. (2016) regard as 'systematic repair' that supports "three related components of repair work: visibility, agency, and power" (p. 232) by promoting claims of *epistemic authority* among participants, which they describe as "exercising the right or the power to know" (p. 223). According to Booker and colleagues, such systematic repair can be enacted through PDR by (a) maintaining open conversations about phenomenon to be studied, (b) re-mediating the roles of all stakeholders, including the researchers, as both learners and as authorities in the process of knowing, (c) enacting multiple rounds of collaborative data analysis and design that can expand what counts as data (i.e., the collaborative and methodological processes themselves), and (d) eschewing deficit-based conceptions of the problem that can serve "to diminish participation" (p. 234). Ultimately, PDR, through its commitments to co-design, encourages researchers and educational designers to ask "who does the design and why" (Engeström, 2011, p. 600) and to also pay "attention to the positionality of researchers or their social identities in the unfolding of work" (Bang & Vossoughi, 2016, p. 174).

Design-Based Implementation Research. DBIR can be broadly defined as a collaborative mode of educational design and research that features elements of design thinking (Penuel et al., 2011). The main objective of DBIR is "to facilitate the design of educational interventions that are effective, sustainable, and scalable" (Fishman et al., 2013, p. 136). DBIR projects build upon four core principles as outlined by Penuel and colleagues (2011): (a) a focus on persistent problems of practice from multiple stakeholders' perspectives; (b) a commitment to iterative, collaborative design; (c) a concern with developing theory related to both classroom learning and implementation through systematic inquiry; (d) and an emphasis on developing capacity for sustaining change in systems (p. 332). DBIR explicitly emphasizes second-order changes by focusing on what Fishman and Penuel (2013) term infrastructuring, which is the "process of creating and sustaining new cultural practices and supportive technological mechanisms" (p. 393). Fishman and Penuel (2018) explain that DBIR's emphasis on how educational innovations are designed expands upon traditional educational research methods that often narrowly focus only on the potentially fleeting efficacy of educational innovations. Accordingly, DBIR is seen as an extension of educational design research that can assist researchers in creating "improvements to educational systems that last" (Penuel, 2018, p. 659).

Cultural-Historical Activity Theory Approaches. CHAT approaches to educational design vary in scope and name (e.g., Cole & Packer, 2016; Gutiérrez & Jurow, 2016; Sannino et al., 2016). Nevertheless, these approaches, when taken as a whole, focus on participatory design perspectives that "emphasize the cultural and institutional organization of human action in various forms, in a wide variety of social settings ranging from classrooms in schools to community settings and workplaces" (Penuel et al., 2016, p. 490). Of particular interest, CHAT research has articulated a particular approach to participatory design known as "Change Laboratories" (Engeström et al., 1996). The Change lab approach focuses on second-order change as a goal, which CHAT researchers articulate in terms of "expansive learning" (Engeström & Sannino, 2010). Essentially, a Change Lab brings together working practitioners and managers of a unit or group (which might be located in a school or other workplace) along with a small number of facilitators, interventionists, and/or researchers to support the group in their processes. Clients, students, and other stakeholders may also be represented in the group. The group conducts a series of five to ten Change Lab sessions. Sometimes these Change Labs are also conducted as boundary crossing laboratories with representatives from two or more groups engaged in collaboration or partnership. The Change Lab sessions are based on a "double stimulus" approach (Vygotsky, 1987, 1997). The first stimulus involves critical incidents, troubles, or problems from the workplace as recorded at the workplace that motivate the group to consider alternative approaches to their practice and organization. The group analyzes these first stimulus

events through the lens of a second stimulus that takes the form of conceptual tools (such as the iconic triangular models of the CHAT approach). These second stimulus models are often replaced or combined with mediating conceptualizations or models formulated by the participants through their work. Essentially, the participants explore second-order change by leveraging the mediating second stimulus in the design of a new concept for the activity they are trying to transform (Engeström & Sannino, 2010; Sannino, Engeström, & Lemos, 2016) through an *expansive learning* process (e.g., Engeström, 2015) that is "a creative type of learning in which learners join their forces to literally create something novel, essentially learning something that does not yet exist" (Sannino et al., 2016, p. 603).

Potential for Synthesis and Refinement Across Perspectives on Design

Rather than incommensurable, these perspectives on design offer opportunities for synergistic integration in support of second-order changes to create more equitable learning opportunities for all students and a more equitable world. Each perspective brings affordances and limitations. Traditional backward design perspectives, for example, emphasize integration, coherence, and alignment with end goals throughout the design process, but backward design perspectives are limited by their lack of emphasis on (a) reconsidering and exploring deeply the actual challenges and framings to focus upon and (b) the actual experiences, goals, strengths, needs, and perspectives of the stakeholders. Essentially, traditional backward design perspectives highlight convergent thinking but place less emphasis on articulating divergent thinking and stakeholder centrality. Design principle similarly can focus on first-order changes by already assuming or dictating a goal for the design. For example, within the UDL framework (Rose 2000; Hall et al., 2006), the curricular content and discrete learning outcomes that students are meant to learn is taken as a given. Design thinking perspectives, on the other hand, emphasize the cycles of divergent and convergent thinking much more explicitly, and in some cases focus deeply on the role of framing and reframing the nature of the challenge upon which to focus (Dorst, 2011; Buchanan, 1992), which creates the opportunity for second-order rather than first-order change. Design thinking perspectives, however, still can be limited by an emphasis on designing "for" stakeholders rather than "with" stakeholders, and design thinking may not bring the focus on alignment that can be emphasized by backward design perspectives. Participatory design perspectives, in turn, center stakeholders and stakeholders' understanding of their lived experiences, goals, strengths, and needs. Participatory design perspectives, however, could benefit from (a) design thinking perspectives in terms of the articulation of process to support deliberate attention to the potential of divergent thinking and reframing that could support transformational reconceptualization around those foci and (b) the potential of backward design to focus on the alignment between goals and means.

Thus, rather than incommensurable, these different perspectives offer substantial opportunities for synergistic integration. At the heart of the matter from the perspective of supporting fundamental second-order changes around equity are the dual needs for: (a) incorporating the voices of stakeholders, particularly those marginalized by the current social, cultural, political, and historical systems and (b) consciously and explicitly analyzing the frames through which the systems and challenges have been viewed to date as well as the potential affordances of other existing or new framings that could support fundamental second-order changes in light of those social, cultural, political, and historical systems.

Participatory design perspectives are obviously especially well suited to the former (i.e., incorporating the voices of stakeholders) while design thinking approaches are well suited to the latter (i.e., consciously and explicitly analyzing frames and considering new frames), but neither is necessarily sufficient on its own. Alone, both perspectives are capable of reproducing only first-order changes that may improve the efficiency or efficacy of stakeholder experiences without fundamentally transforming or contesting the status quo. Stakeholders in participatory design, like everyone else, may not immediately consider the arbitrariness of the figured worlds in which they live (Holland et al., 2001). Designers on design thinking teams may not bring the lived experiences that would allow powerful frames to be considered or even recognized as needed. Integrating participatory design and design thinking perspectives, however, would appear to provide great opportunity for synergy.

Perspectives on participatory design growing out of Cultural Historical Activity Theory (CHAT) (e.g., Engeström & Sannino, 2010; Sannino, Engeström, & Lemos, 2016) provide one possible foundation for such integration. We propose that the Change Lab approach with its double stimulus structure (described in the previous section) creates an excellent opportunity for synergizing participatory design approaches with perspectives from design thinking. In particular, design thinking ideas could help provide additional scaffolding to focus the design processes across Change Lab sessions (which have minimal articulation beyond the double stimulus structure), and design thinking models could be included as part of the second stimulus materials to help the group attend to and realize the opportunities for divergent thinking and fundamental reframing of the goals at the heart of the group's activity system. Such an integration would provide greater scaffolding to the actual processes of the group. This proposed synthesis would integrate strengths from participatory design as well as design thinking in a way

that could prove more reliably productive in terms of pursuing second-order rather than first-order change. Furthermore, the integration of the design thinking ideas and models might reduce (but not eliminate) the reliance of the Change Lab approach on highly skilled interventionists and researchers, which is currently an element of the Change Laboratory approach that prohibits broad scaling.

A synthesis of Change Laboratory and design thinking approaches is just one possible example of synergies that might be pursued, but it illustrates the opportunities that might be leveraged. Similar synergies are already being explored in models of Design-Based Implementation Research (as outlined in the previous section), which emphasize the integration of participatory design with elements of design thinking (e.g., Penuel et al., 2011) to pursue second-order change in the form of "infrastructuring" to create and sustain new cultural practices and mechanisms to transform education (Fishman & Penuel; 2013).

Another point of synergy and educational literature more broadly would involve more active leveraging of models from critical theory perspectives as explicit foci for reframing in design thinking and as second stimuli in Change Laboratory approaches or other participatory design approaches. A danger across all design teams is that the design team will not consider alternatives to the figured worlds in which they already operate. As Dorst (2011) makes clear, the distinction between successful and less successful designers often hinges on how frames are considered and created. A novice designer or team may default to simply adopting the existing frame without even questioning it. More sophisticated designers or teams may be able to consider a range of other frames provided by others. The most transformative design teams create or discover or identify frames that have not been considered previously in terms of the challenge they are attempting to address. Explicit consideration of critical perspectives may thus prompt possibilities for reframing challenges in ways that have not yet been considered.

Ultimately, the goals of design should move beyond first-order refinements of efficiency and effectiveness. These first-order refinements of efficiency and effectiveness most likely only replicate or reinforce existing inequitable neoliberal structures and figured worlds in education (and society more broadly). In order to move beyond these first-order refinements of efficiency and effectiveness, education needs to move beyond its reliance on backward design processes alone to guide design. Integrating and synergizing perspectives on design thinking and participatory design, particularly if guided by insights from critical analyses of the power structures and figured worlds that currently organize our activity systems, provide opportunities to pursue second-order changes that introduce new goals, structures, and roles to transform education in service of a more equitable future.

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Using Reference Models as a Springboard for Ontological Innovation: Analyzing a Central Theory Building Move in the Learning Sciences

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Abstract: The development of learning theory is of core importance to the learning sciences. Despite its importance, little is understood about our own theory building processes. This paper analyzes one case of theory development to better understand a particular theory building move associated with design-based research: ontological innovation. The case features the invention of a new category of knowledge and therefore exemplifies ontological innovation. Conducting a retrospective analysis, we identify seven steps, which were critical to the development of the new category of knowledge (meta-theoretic competence) in response to an existing reference model (meta-representational competence). These steps suggest the coupled nature of data and theory, and the importance of the researcher's own knowledge, which they bring to bear on their theory building practice.

Introduction

The development of learning theory is of core importance to the learning sciences (diSessa, 1991; Roschelle, 2021; Sandoval, 2014). In the last thirty years there have been many exciting developments in the field that have fundamentally shaped how we view the very nature of knowledge and learning processes, including a turn towards recognizing how learning is embodied in nature and socially and culturally organized (Abrahamson et al., 2020; Nasir et al, 2021; Nathan, 2021). Many of our most impactful advances have come via the strong commitment to interdisciplinarity in the learning sciences: building upon advances in cultural studies, sociology, anthropology, and educational neuroscience, to name a few. Together with these perspectives, the field has developed ethnographic and design-based methodologies that provide sources of insight into real-time learning processes (Bakker, 2018; Brown, 1992; Cobb, et al, 2003; diSessa, Sherin & Levin, 2016; Hall & Stevens, 2016). One of the hallmarks of theory building in the learning sciences is that theories that are developed in the context of real-world learning and performance data can generate novel theoretical ideas of wide scope. diSessa and Cobb named these novel theoretical ideas *ontological innovations* — "theoretical constructs that empower us to see order, pattern, and regularity in the complex settings in which we conduct design experiments" (diSessa & Cobb, 2004, p. 84). Ontological innovation can also be viewed as a theoretical move involving the recognition of new theoretically-relevant categories based on observations in data.

While it is widely agreed that the development of learning theory is an important goal, processes of theory development in the learning sciences are still not well understood. By its nature, theory building in the learning sciences has a strong commitment to being accountable to the moment by moment details of learning processes. Given this commitment to theorizing involving emergent categories based on empirical data, many moment-by-moment analyses of learning interactions describe the process of building theory as being informed by Grounded Theory (Glaser & Strauss, 2017/1967). However, while Grounded Theory shares with learning sciences researchers the commitment to extracting categories for research from empirical data, the description of the theory-building process is not well-tuned to modeling moment-by-moment learning processes (Parnafes & diSessa, 2013). Previous descriptions of theory building within the learning sciences have resulted in descriptions of general processes, such as researchers engaging in *observe*, *schematize* & *systematize* cycles (diSessa, in Parnafes et al., 2008; diSessa & Levin, 2021) in the case of generating new theoretical constructs, and general phases of theory building, such as *incubation*, *theory negotiation*, and *theory appropriation* phases (described in Parnafes & diSessa, 2013) in the case of analyses that extend and elaborate an existing theoretical construct. While these case observations offer helpful heuristics, the details of how these cycles and phases function require more elaboration, and exemplification in a broader set of instances. Our aim in this paper is thus to offer a case analysis of a theory building process, focusing in particular on the way existing theoretical constructs can serve as reference models that then lead to ontological innovations. The case we present comes from an analysis of the theory building process of the first author.

Theoretical foundations

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We begin by describing the theoretical framework that guided the theory building work featured in the case study: knowledge in pieces (diSessa, 1993). We then describe the theoretical framework that we use to characterize the theory building process: epistemic forms and games (Collins & Ferguson, 1993).

Knowledge in pieces

Knowledge in pieces (KiP) is a name for a broad class of theoretical models of knowledge—models in which knowledge is seen as consisting of a *complex system of elements of diverse types*. This broad epistemological perspective grew out of studies of individuals reasoning about the physical world. DiSessa showed that the way individuals thought about physical phenomena was well-modeled by a large number of knowledge elements that were often inarticulate and applied in a manner that depended sensitively on the context at hand (diSessa, 1993). This formulation of the organization of knowledge has strong implications for instruction: instead of replacing "misconceptions" about how the world works, instruction in formal physics needed to engage individuals' intuitive knowledge and re-contextualize it more appropriately for given contexts.

Knowledge in pieces has influenced studies in many other domains beyond intuitive physics, including algebra (Izsák, 2000; Levin, 2018), multiplication (Izsák, 2005), proportional reasoning (Izsák, Beckmann & Stark, 2021), calculus and linear algebra (Adiredja, 2014; Adiredja & Zandieh, 2020), geology (Barth-Cohen & Braden, 2021), and computer science (Lewis, 2012). As well, the framework has influenced the study of naive epistemology (Hammer & Elby, 2002), the role of emotions in cognition (Gupta, Elby, & Danielak, 2018), and ideologies about race and racism (Philip, 2011). Common themes across this body of work are that (a) intuitive knowledge based on experience in a domain provides a rich source of resources for learning, (b) the recognition and use of such knowledge resources are not necessarily articulate and that (c) the activation and use of knowledge resources depends sensitively on context. More extensive lists of principles and counter-principles for studying knowledge in a way that is consistent with knowledge in pieces is given in diSessa, Sherin & Levin (2016).

Ontological innovations may occur at the system level or at the element level, and sometimes both. A number of novel knowledge categories have been proposed over the years, including *phenomenological primitives* (p-prims; diSessa, 1993), *explanatory primitives* (e-prims; Kapon & diSessa, 2012), *naturalized axioms* (Philip, 2011), and *symbolic forms* (Sherin, 2001). More extensive knowledge systems such as *coordination classes* (diSessa & Sherin, 1998; diSessa & Wagner, 2005, Levin & diSessa, 2016) have been generated to explain how individuals obtain measurable information from the world and *strategy systems* (diSessa & Levin, 2021; Levin, 2018) have been used to explain how individuals coordinate knowledge in problem solving processes. In this paper, we show how an existing knowledge category (meta-representational competence; diSessa, 2004) is used as a springboard for ontological innovation.

Epistemic forms and games

Collins and Ferguson (1993) characterized the theory building work of scientists using a framework they called epistemic forms and games. Epistemic forms are abstract structures or templates, which scientists fill out in answering a particular research question. A form guides the game that is played to fill it out, in the same way that the cross-hatch structure of tic-tac-toe imposes certain constraints on how the game can be played. The completed form embodies theoretical knowledge, the form and game are therefore connected with knowledge and knowledge building. Collins and Ferguson present three kinds of epistemic games: structural analyses, functional analyses, and process analyses. They describe examples of typical forms produced by games within each category (e.g., lists, stage models, system-dynamics models), and unpack some of the moves in the associated games. For example, a scientist might play the list-building game to produce a list when their research question is something like "what is the nature of x?" and x can be decomposed into a smaller set of elements (e.g., a list of material substances found in the world). If the items on their list can be characterized in terms of multiple dimensions, the scientist might transfer to a cross-product or table game (e.g., the periodic table of the elements). In our analysis, we use the framework of epistemic forms and games to schematize the moves made by the first author in her theory building trajectory.

Methods

In order to understand the smaller steps involved in ontological innovation, we conducted retrospective analyses of our own theory building processes as case studies. In this paper, we report on the findings from the analysis of one case study. The case study was conducted by the first author; the Analytic Process and Findings sections are therefore written in first person. The case study examined the development of a knowledge category called meta-theoretic competence (MTC), which was developed to characterize 8th grade students' productive engagement in theory building, in the context of a science elective course (Swanson, 2022).

Context of research on student theory building

Data were collected in the context of a class designed for 8th grade students – the "Patterns" class – that met three mornings a week for forty minutes, both fall and spring semesters. The Patterns class was designed to engage students in the construction and refinement of a unique kind of theoretical artifact: a pattern theory. Pattern theories were essentially written descriptions of patterns in behavior underlying phenomena across domains. For example, a pattern of threshold can be seen in both the tipping point of a tower of blocks and the testing of a person's patience. Pattern theories were meant to serve as conceptual footholds for moving towards more mathematical, aggregate-level understandings of phenomena through the lens of dynamical systems theory. Twenty-one students participated in the course (11 girls, 10 boys). The teacher was also the researcher. Data were collected in the form of video footage and student work.

The course included units on patterns of threshold, equilibration, exponential growth, and oscillation. Each unit followed the same general sequence, meant to embody a simplified process of theory building and refinement. Students began by exploring two phenomena that exemplified the focal pattern. They were then invited to individually write descriptions of the pattern in behavior the two examples had in common (these were their first theory drafts). They evaluated their pattern theories against a third example and then revised their pattern theories to either clearly include or exclude the example. They then generated lists of examples that followed the pattern and discussed those examples in the context of a whole class debate. They were then invited to revise their thinking and write third and final pattern theory drafts.

For example, in the threshold unit, the students explored phenomena that exemplified the pattern of threshold (adding coins to a spaghetti bridge until it broke; adding drops of water to the surface of a coin until it overflowed) and then wrote descriptions of the pattern in behavior demonstrated by both examples. They then compared their pattern theory with another example (adding scoops of salt to a cup of water until a submerged egg floated) and refined their theory to more clearly include or exclude the example. They generated a list of additional examples that followed the pattern (e.g., "bothering someone till they burst," "getting a haircut") and argued about the fit of those examples with their classmates in the context of a whole class debate. By the end of the unit, they had refined their pattern theories (e.g., "adding something to something until it changes").

Analytic process for the case study of researcher theory building

The aim of the research described above was to characterize students' theory building in the context of the Patterns class. My KiP orientation made me interested in characterizing their theory building at a microanalytic scale and in understanding how their engagement in the activities I'd designed could be seen as seeds of scientific theory building. This orientation also placed the goal of modeling naive knowledge in my awareness, though it was not initially foregrounded in my thinking.

In order to understand my own process of theory development, I conducted a retrospective analysis of several sources of data. The first was a document containing reflections, which I had written throughout the course of my analysis of student work and video transcript. The second source consisted of the notes I had written on student work and video transcripts of class activities. I used the reflection document to reconstruct a narrative of my process at a level of detail that captured milestones in the development of my theoretical artifact (e.g., initial characterizations of the data, identifying a reference model). I used my notes on student work and transcripts to illustrate my narrative with specific examples. I read through the narrative of my process and partitioned it into seven steps, to capture what appeared to be key moves in the development of my theory. I present the narrative of my theory building process below, unpacking each of the seven steps in chronological order.

Findings

In this section, I describe the theory building process that emerged as I worked with the data. I partition my process into seven steps. The first step maps with Parnafes and diSessa's *incubation* stage. The second step maps with their *theory negotiation* stage. The third through seventh steps align roughly with their *theory appropriation* stage and offer a closer look at how a reference model can act as a springboard to ontological innovation.

Step 1: Examining data and assigning initial characterizations

The initial goal of my inquiry was broad: to understand the nature of student engagement in theory building in the Patterns class. I began by looking through the data and characterizing, at no particular grain size, elements of student work and activity, which seemed relevant to elements of theoretical science. In this way, my work during this step aligns with both Parnafes and diSessa's *incubation* stage, and diSessa's *observe* and *schematize* stages. As in the *incubation* stage, I began by looking across the data without hunting for evidence of existing theoretical constructs. However, in contrast with the *incubation* stage, my initial look wasn't purely open. Instead, my initial

interaction with the data resembled a combination of the *observe* and *schematize* stages. I viewed my data with the expectation that students would be doing productive things related to theory building, and I loosely schematized the productive things I saw the students doing.

For example, to students' pattern theories, I added notes such as "general language" and "pattern in behavior." To the margins of the video transcript, I added notes such as "offered intuitive causal explanation" or "challenged explanation on grounds of logic." In reviewing my notes, it became clear that many of my characterizations of student theory building could be categorized as *theory building moves* and those that were not (e.g., "general language") could be recast as moves (e.g., "used general language"). I conceptualized these theory building moves as *resources* for theory building. Though it seemed advantageous to characterize the resources as moves where possible, I felt using the term "resource" had an advantage over "move," in that it was less constrained and could involve a wider range of seeds for theory building, such as general aesthetics and intuitive explanations, which I also saw in the data. This move in my own theory building process is related to diSessa's *systematize* stage. My shift in schematization of the data inspired a clarification of my research aim and my question became more focused: "What resources do the students bring to their productive engagement in theory building in the Patterns class?"

Step 2: Identifying a reference model

I recognized that answering this question would yield a collection of resources students had for the construction of pattern theories. This cued to memory a collection of resources for engaging in another set of scientific practices, which already existed as a category of knowledge in the KiP framework. This category of knowledge was meta-representational competence (MRC; diSessa, 2004). MRC supports work with representations, which transcends their mere production and use. It includes skills for the invention and design of new representations, for their critique, for understanding the purposes of representations (both in general and in specific contexts), for explaining representations, and for learning new representations quickly with little intervention. MRC includes resources that are "gradually developed through cultural practices in and out of school." It is therefore concerned with naive knowledge that extends beyond the realm of intuition.

DiSessa and colleagues documented resources for the invention and design of new representations, such as the ability to draw and sensitivity to representational possibilities of visual elements (e.g., color, length, width). Resources for the critique of representations include criteria such as completeness, precision, and parsimony. It seemed sensible to use MRC as a reference model for organizing a class of resources for scientific theory building. Both models are concerned with a broad range of resources on which students can draw to engage in scientific practices, and both are concerned with elements of naive knowledge, which may have their origins in social interaction and schooling. To make the connection between my work and this reference model explicit, I decided to call this new category of knowledge "meta-theoretic competence."

Step 3: Abstracting the epistemic form underlying the reference model

Meta-theoretic competence (MTC) is a new category of knowledge. It is therefore an ontological innovation. To develop MTC, I drew inspiration from an existing ontology: MRC. In order to understand how my ontological innovation was seeded by a reference model, it is helpful to view my theory building activity through the lens of epistemic forms and games. My theory building was an epistemic game, the moves of which were driven by the epistemic form I was trying to produce. My target form was inspired by MRC, but MRC itself was not my target form. My target form was the *general structure underlying MRC*, which is a list of resources for productive engagement in a particular activity. Whereas MRC is concerned with students' engagement with representations, my concern was theory building.

The form I sought to produce was therefore a list of resources for productive engagement in different aspects of theory building. It is worth calling attention to the fact that I sought the general form underlying MRC and used that as the template to guide my theory building work. This move is likely idiosyncratic and reflective of my own interest in the nature of scientific theory building and my attention to schematizations of theory building that have previously been described in the literature, including epistemic forms and games.

Step 4: Organizing initial characterizations according to the epistemic form

Having determined the epistemic form I would need to fill out to answer my research question, I turned to organizing the initial resources I had identified in my data in the form of a list. Because MRC partitions resources according to aspects of work with representations such as invention, critique, etc., I anticipated that I would ultimately partition the elements on my list according to parallel aspects of theory building. However, at this point

in time, I didn't know what those categories should be, so I merely wrote the list in an order that matched my notes in the data.

Step 5: Refining the emerging model by creating categories

Looking across the resources, I thought of categories of theory building activities that could be used to organize my list. The categories that initially emerged were: theory articulation, evaluation, and refinement, and specification of a theory's domain of application. This move also connects with diSessa's *systematize* stage. To see how this worked, I organized the elements on the list according to these four activities.

Step 6: Going back to the data and reanalyzing it in terms of the model

With my revised template, I went back to the data and in addition to checking the appropriateness of my existing list of resources, I looked carefully for other examples in the data that might be resources for articulating, evaluating, or refining theories, or for specifying a theory's domain of application. I added resources to the list, filling out the template more fully. The activity of this step corresponds again with diSessa's *observe* and *schematize* stages.

At this point, I created two copies of the list. The first copy presented the resources simply in their categories as a partitioned list. For the second copy, I expanded the list by describing each resource in detail and illustrating it with student work or segments of transcript from the Patterns class.

Step 7: Further refining the model by changing the epistemic form

Working more closely with the data and explaining how it illustrated each resource on the list surfaced a pattern I hadn't previously noticed. What the examples revealed was that there was another dimension along which the theory building resources could be organized. This was a dimension of characteristics that were particular to Pattern theories. These dimensions included deeper structure, generality, and causal relationships. I tried reorganizing the list of theory building resources according to these aspects. The result was unsatisfying because, while it highlighted which aspect of pattern theories a resource could be used for, it obscured which theory building activity it corresponded with. As I rearranged the examples from my illustrated list, it became clear that the resources I had found were accountable to both dimensions (aspects of pattern theories and theory building activity). For example, in some of the data, students were demonstrating resources for *articulating causal relationships*, while in other examples, they were demonstrating resources for *evaluating a theory's level of generality*.

This led me to wonder if a cross-product form might be used to organize the theory building resources. I constructed a table to see what it would look like to have theory building activities in rows and pattern theory characteristics in columns. In my data, I found examples of resources for the articulation, evaluation, and refinement of pattern theories along the dimensions of deeper structure, causal relationships, and generality. It didn't make sense to cross the specification of the domain of application (essentially naming examples of things that followed the pattern) with characteristics of pattern theories. The product of this with deeper structure, for example, didn't mean anything. I struggled with what to do with "specifying the domain of application." It was a key component of the pattern theory building process and resources for it would need to be included in my ultimate model of MTC demonstrated by students in the Patterns class.

Because "specifying the domain of application" was so particular to pattern theory building, I decided to try moving it from the dimension of "theory building activity" to the dimension of "aspects of pattern theories." This shift required a refinement in the names of the two dimensions, as the table now consisted of a dimension of stages of theory building (articulating, evaluating, and refining - in rows), crossed with pattern-theory-specific elements (deeper structure, generality, domain of application, and causal relationships - in columns). A reduced version of the table is shown below (Table 1), to give the reader a sense of the kinds of resources that were included in the category, and to illustrate how they were organized in tabular format.

Table 1. Resources for theory building, which belong to the category of meta-theoretic competence

Stages/Pattern Characteristics	Deeper Structure	Generality	Domain of Application	Causal Relationships
Articulating	Articulating the pattern in behavior	Using general language to describe a pattern in behavior	Generating examples from physical and psychosocial domains	Articulating intuitions about

	instantiated by examples			causal relationships underlying behavior
Evaluating	Comparing examples based on similarities and differences	Questioning the generality of the language used	Challenging and defending the fit between examples and pattern theories	Challenging and defending the logic of intuitions
Refining	Removing surface features from the pattern theory	Removing context-specific features to make the pattern theory applicable to more examples	*There was no opportunity in the course for students to demonstrate resources for this category	Responding to challenges by unpacking or modifying ideas

In the language of epistemic forms and games, my shift from a list form to a table form is an example of a "transfer" from one epistemic form to another. This is an appropriate move in playing an epistemic game, if it becomes apparent that the original form is insufficient. Because it is focused on the larger organization of the elements, the activity of this step corresponds with diSessa's *systematize* stage.

High-level sketch of the theory building process

The theory building process described above consisted of seven steps: 1) examining the data and assigning initial characterizations, 2) identifying a reference model, 3) abstracting the epistemic form underlying the reference model, 4) organizing initial characterizations according to the epistemic form, 5) refining the emerging model by creating categories, 6) going back to the data and reanalyzing it in terms of the model, and 7) further refining the model by transferring to a new epistemic form. Figure 1, below, illustrates the seven steps of the researcher's theory-building trajectory.

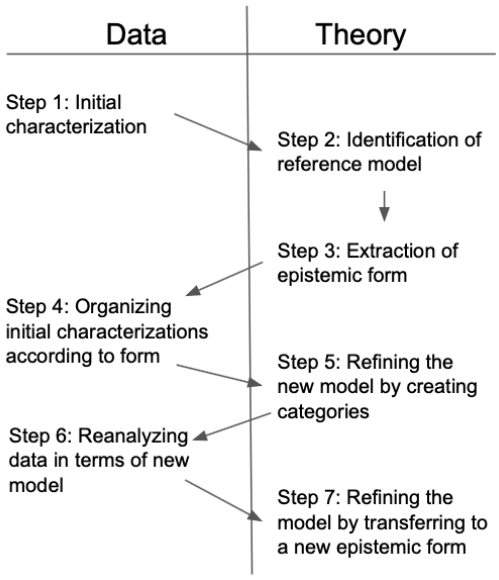

Figure 1. High-level sketch of the researcher's theory building trajectory.

Looking across these seven steps gives us a general sense for how the reference model acted as a springboard for ontological innovation in the examined case. There was a general pattern in which the researcher moved back and forth between data and theory, but the two were never quite separate. When the researcher gave the data an initial look, for example, she was looking at the data through the lens of her theoretical orientation with the expectation that the students would be doing productive things with respect to theory building. She therefore saw characteristics of artifacts and activities that might be productive resources for theory building and lifted those

out of the data by schematizing them as moves, for example. When she looked across the list of resources she had identified, she cued to memory a potential reference model, based on perceived similarities in structure and function. She drew this model from a network of familiar models. Because she had read the work of Collins and Ferguson and viewed her own scientific inquiry through the lens of epistemic forms and games, she was motivated to extract the epistemic form of a list from the reference model. She then used the form as a template for organizing her initial characterizations (or in the words of diSessa, she used the template to systematize her initial schematizations). Because she valued the construction of theory grounded in data, she continuously tested her model against the data and refined it so that there was a close fit.

The sequence illuminates a general pattern of moving back and forth between the data and the form, where the researcher keeps the one in mind, while looking at the other. It also shines a light on the importance of the knowledge the researcher brought to her theory building, or the role of her own meta-theoretic competence. Her theory-building knowledge included her epistemological orientation, which, typical of a KiP perspective, viewed naive knowledge as potentially productive and likely containing seeds for scientific theory building. Her theory-building knowledge also included a network of existing KiP models, which provided a number of possible reference models. Her theory-building knowledge also included an epistemological stance on the nature of scientific theory building, which was that scientists played epistemic games to fill out epistemic forms, which were general structures underlying particular models. She therefore thought to draw the deeper form out of the reference model and use it as a template for driving her epistemic game. Finally, her theory-building knowledge included an aesthetic for building theory grounded in data. All of these elements of her theory-building knowledge came together in her attempt to make more formal sense of her students' engagement in theory building in the Patterns class. It was their synergy that led her to use the reference model as a springboard for ontological innovation.

Conclusion

In this paper, we sketched the theoretical genesis of the ontological innovation of meta-theoretic competence (MTC). In particular, a seven-step trajectory from the initial look at the data to theory-in-progress captures one learning scientist's process of theory building, focusing particularly on unpacking the process of using reference models in the process of ontological innovation. We hope that our work in elaborating how a particular theoretical move functioned will help other researchers in the learning sciences recognize similar moves in their work, and to unpack processes of theorizing, for both newcomers and oldtimers in the field.

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Kites in the wind: Response cries as evidence of listening

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Abstract: Ingold (2007) argues that we hear in sound just as we see in light. The immersive media of sound and activities of everyday listening have largely been neglected in the field of the learning sciences. Reflecting on Ingold's metaphor of a kite in the sky, I discuss the importance of Goffman's (1978) concept of response cry in beginning to show us listening in learning. This paper describes three qualitative studies that all center sound as the primary medium for meaning-making. Findings demonstrate the ways in which response cries constitute evidence of listening and the tension of doing the complex work that is being a listener, particularly in the setting of listening together.

Centering sound

Sound is all around us, within us, moving through us. Ingold (2007) argues that we hear in sound, just as we see in light. It is like breath, like air. Despite the similar immersiveness of these media, our world has been dominated by the hegemony of the visual, as well documented by media scholars (Levin, 1993; Cox, 2011). Still, academic and everyday pursuits alike are hesitant to take listening seriously. This is epitomized in the legitimacy of "eyewitness" and its dismissible counterpart, "hearsay". While the field of learning sciences has dedicated resources to investigating the process of seeing as a way of knowing (e.g. Stevens & Hall, 1998; Christidou & Diamantopoulou, 2016), the immersive context of hearing and listening is an aspect of the sense-making process that rarely takes center stage in learning sciences research.

I have a personal stake in making this claim, as I believe worthwhile research should be personally meaningful: I am a life-long musician and someone who has spent hours being formally trained to listen (as many of us have with our current school systems). I have been struck by how beautifully complex listening is both in my own experience as a listener and in my study of it as a researcher. I believe we have an incredible opportunity to better understand how listening is constructed as a social practice. In this way, the phrase "active listening" is redundant.

Listening in the literature

Listening, which is distinct from hearing in that it is a conscious process of meaning-making rather than a physiological one (Low and Sonntag, 2013), is notoriously complex to understand, accounting for its neglect (Rowley-Jolivet, 2002). Certainly, the complexities of listening became apparent and even visceral in the COVID19 pandemic and the shift in modalities of hearing and listening from classroom co-presence to digital and long-distance. Historically, findings describe listening is the primary communicative activity of students, accounting for much more time than writing, reading, or speaking (Barker, Gladney, Edwards, Holley, and Gaines, 1980; Emanuel, Baker, Daufin, Ellington, Fitts, Himsel, Holladay and Okeowo, 2008). Overwhelmingly, early research praises the teachability of listening as demonstrated through comprehension exams, in which students who were instructed to summarize, draw inferences, and recall facts accurately and in order (Devine, 1978). This, however, reduces the nuances of sonic communication to a version of spoken text, a reduction that colors most of the past century's work on listening and leaves students to "prove" their listening by the rote regurgitation of information that plagues reading comprehension. While both listening and reading involve internalized, interpretive thinking, they are two very different activities (Bostrom, 2011).

Other research has theorized listening by comparing it to mathematical communication via signals and noise (Shannon and Weaver, 1949), to computers via information processing (Brown, Anderson, Shadbolt, & Lynch, 1985), and to the evolution of language via hunters and gatherers (Barsalou, 1999). Some have even offered theories of listening that are one-way as opposed to two-way, proposing that listening to an instructor 'transmit' knowledge is a mono-directional transaction (Lynch and Mendelsohn, 2010). Even in the case of diminished or lost hearing, embodiment of hearable interaction like the movement of lips, singing, facial expression is an essential mode of communication (Friedner & Helmreich, 2012).

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Much of the interactive process of both formal and informal learning environments relies on listening: lecturing, discussion, conversation, music, ambient sound, as well as environments that leverage audio performances that are subject-specific (Shapiro, Hall & Owens, 2017; Hall & SLaM, 2020; Silvis, Taylor & Stevens, 2018). If we did not assume both the power and potential of listening, we would not have the study of rhetoric, discourse analysis, conversation analysis, and communication studies. Since making and attending to sound is an interpretive, meaning-making process, we as a research community must seriously examine experiences of listening, including song and story.

Yet how do we know that someone is listening? This is a problem in daily life, in education broadly, and in research on the processes of listening. What is hearable is wider than what is heard, and what is heard is wider than what we might have listened to. We know there are certain performances associated with listening: making eye contact with a speaker, nodding our head, or repeating a certain phrase that was just heard. These, however, do not constitute sufficient evidence that what was said (the hearable) was actually processed and understood (listened to). How do we study listening, then?

Theoretical approach

This paper examines three studies which are linked by the centrality of auditory media to make an argument for the value of examining listening in learning. Here, listening is defined as a complex, meaning-making activity that leverages sound and the perceptual apparatuses of hearing. Listening provides similar opportunities as looking in the sense that there are ways of attuning one's perception. Listening *to* something is similar to looking *at* something, a stance of observation. Listening *for* something, however, is akin to looking *for* something, a stance of searching. The negotiation between these two modes of listening constitutes the experience of listening that Ingold describes when he writes against soundscape (2007):

> If sound is like the wind, then it will not stay put, nor does it put persons or things in their place. Sound flows, as wind blows, along irregular, winding paths, and the places it describes are like eddies, formed by a circular movement around rather than a fixed location *within.* To follow sound, that is to listen, is to wander the same paths. Attentive listening, as opposed to passive hearing, surely entails the very opposite of emplacement. We may, in practice, be anchored to the ground, but it is not sound that provides the anchor. Again, the analogy with flying a kite is apposite. Though the flyer's feet may be firmly planted on the spot, it is not the wind that keeps them there. Likewise, the sweep of sound continually endeavors to tear listeners away, causing them to surrender to its movement. It requires an effort to stay in place. And this effort pulls against sound rather than harmonizing with it. Place confinement, in short, is a form of deafness. (p.2)

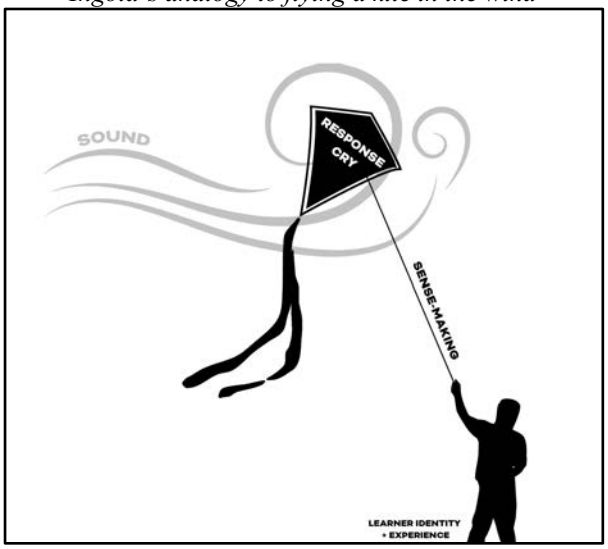
While I disagree with some of Ingold's other arguments around soundscape conceptually, his identification of the inherent movement of sound and his analogy to a kite are useful. Flying kites, proverbially, also allows us to learn something about both the construction of the kite and the wind with which it interacts. While the wind, like sound, is invisible, it is made evident through its interactions with other objects. So too is listening to sound made visible through interaction. This visibility is key since listening is uniquely a private sense-making experience: we cannot listen precisely like anyone else yet listening happens in social contexts.

Here, Goffman's work on response cries (1978) becomes helpful in understanding the internalization of a social other: we move throughout public life with an awareness that others might see or hear us. In Goffman's example, to trip on a sidewalk while sober and of sound mind often produces an utterance like, "They really ought to fix that sidewalk" not because there is a direct recipient of the utterance, but because the tripper lives in a world where clarifying to any onlookers that he is sober and of sound mind is socially valuable. Response cries demonstrate a figured world (Holland et al, 2001) of public perception which Goffman calls "response presence"; importantly, the winds of sound are an ever-present part of this world, its weather. It is in this world, then, that we might design activities to better understand listening's role in learning.

The *kite* is the response cry that we toss up in the air to twist in the wind, be upheld by it, and demonstrate the wind's very existence. The string between the kite and the person flying it is sense-making, the activity of staying in attuned connection with the motions and qualities of the wind, being in productive tension with time and place. It is our own tugging on the string and the wind's tugging back that co-produces a felt concept of "windiness". This tension is felt against the ground where we stand, our existing identities and experiences we as learners bring to the act of listening. The *wind* is that which is hearable all around us and, in the case of the studies in this paper, the eddies that we designed to represent place and time. The entire process of flying a kite constitutes *listening* (Figure 1).

Figure 1. Listening

Ingold's analogy to flying a kite in the wind



Does a listener stay grounded or is there re-positioning, new footing required to keep with the kite? What kinds of kites might be on display? What kinds of strings might connect listeners to the abstraction of sound?

In this paper, all of the designs for listening are such that no one is listening *alone*. While listening is an internal and private experience, it is always socially contextualized and most often happens amongst people as a part of communication. Using Hall & Ma's lens of ensemble learning (2018), I posit that ensemble listening—listening that we do together—is a different animal than solo listening. In short, there are things that we can learn when we listen together that perhaps are unavailable when we are listening alone: there are no solo kite-flyers in these studies.

Designing for listening

Three Studies

Let me orient us to the three studies in this analysis. These studies come to us as a part of ongoing design-based research (Barab & Squire, 2004) by the Space, Learning and Mobility (SLaM) lab. The content in the first case is quite different from the other two in that a single song is the focus of the session. In the latter two studies, a collection of digitized songs and oral histories is embedded along a mapped route. In all three, however, the idea of controversial or contested narratives arises. While separate analysis has been conducted for each study with its respective set of research questions and findings, this paper presents an analysis of the studies' shared interest in centering listening and presents findings that cross-cut all three.

Context for study 1: listening session

In the summer of 2015, sixteen high school students enrolled in a summer course at an elite Southern university program for rising high schoolers nominated controversial songs for analysis by the whole class. One nomination that was selected by facilitators was the song "Blurred Lines" by Robin Thicke and Pharrell. Since its publication, the song has garnered appropriate critique of its lyrics and themes regarding consent in sexual encounters and the gendered power dynamics of inter-personal relationship. In short, the singer comes across as someone who does not respect women. Using two cameras set on tripods and four microphones distributed across the four-person table groups, a record was compiled to show how students responded to listening to the song together.

Context for studies 2 and 3: listening on the move

The SLaM lab has been engaged in a long-term partnership with a community-based music museum wherein efforts have focused on preserving under-told stories about Black history in the area. Since music and oral history is at the core of our projects together, we had begun to ask questions about how students made sense of the recordings in relationship to the places about which the music and historians talked.

Through design-based research, we built a series of activities related to learning on the move (Marin, Taylor, Shapiro, & Hall, 2020) where students would encounter a qualitatively themed map with digital archival material of songs and oral histories while walking along a path of points of interest on the street where the museum is

located. A majority of the students participating in these walks were white, middle class, and had characteristics of identity and experience which were disparate from those that were represented in the DSSLs. The tension that Ingold identifies can be leveraged in design to amplify the experience of palimpsest, of being simultaneously here and *then* (Hall, R. & Space, Learning and Mobility Lab, 2020) which was of interest to our research team.

In the spring of 2019, thirteen master's students in followed two modes of a digital spatial storyline (DSSL) (Hall, R. & Space, Learning and Mobility Lab, 2020). DSSLs are a form of qualitative thematic mapping that attach multimedia sources to points in space as a way of telling (hi)stories about place. The master's course was oriented around the goal of developing a deep understanding of designing experiences for social studies learning. Our lab's interaction was positioned as an opportunity for students to be participants in a design-based research study in order to gain insight into how they might conduct their own future studies.

The DSSL contents were identical: both involved digital media of oral histories by local experts, songs related to themes from the neighborhood's history, and a map which coordinated real time GPS data and the view of the corridor. The first version of the DSSL involved a web app designed by our lab, called Storyliner, which serves up map-located media that requires users to opt-in by clicking on a map icon. The second version of the DSSL is in an app called Echoes, which uses the media from Storyliner but involves geofenced circles that automatically play the sonic content.

The design of this particular study called for the students to be paired up, with half of the pairs using Storyliner on the first part of the walk and the other half using Echoes. Both DSSLs were used while students were walking down a historic Black music and civil rights corridor in the South. We later coordinated the chest-mounted GoPros that students wore with some iPhone and iPad screen captures in order to examine how students connected their interaction with the media with the interaction within the pair.

In the third study, during the summer of 2019, two high school SLaM interns participated in a new iteration of the second study (see Figure 3) with an ear toward what they could glean from the design of the story walk in terms of strategies to make their own story walks. As a pair, they used a shared iPad and connecting their headphones through a splitter so that our record captured what they heard and what they said in perfect sync.

Data Analysis

For all three studies, I collaborated with colleague researchers, advisors, lab members, and participants to conduct interaction analysis (Jordan & Henderson, 1995) of the rich audio-video records through our standing Interaction Analysis Lab. Following the theoretical basis of response cries, we identified 'hot spots' in the record, paying close attention to how listening was being made evidence through gesture and utterance (Hall & Stevens, 2015). Additionally, we analyzed the video record through the lens of a question: "what resources do students leveraging in making sense of contentious or counter-story audio media?" In the case of both the 2019 studies, member checking was performed with participants to ensure that our analytical understanding of their experience was true to their memory and their own understandings.

Findings

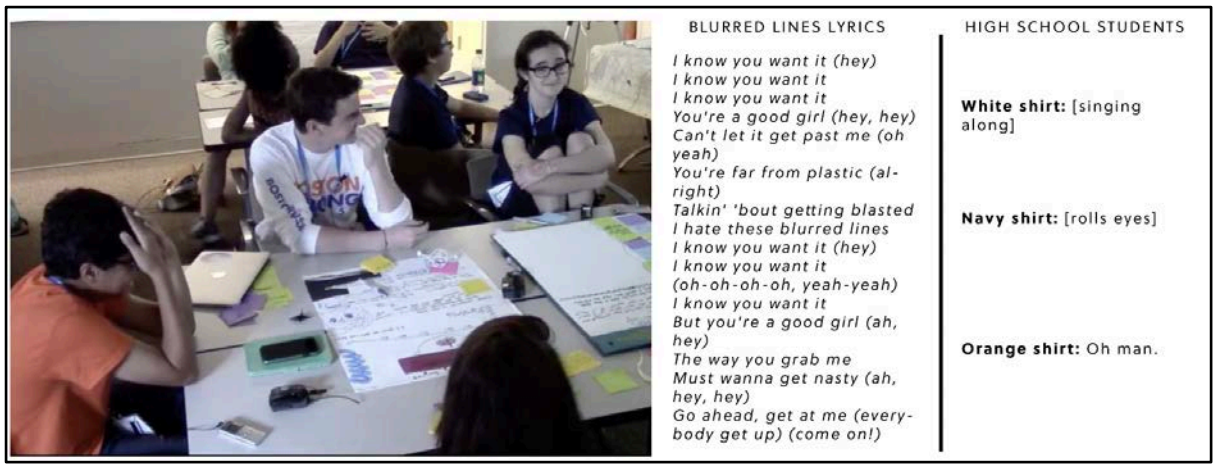
Kites

Students across all three studies used utterance, embodiment, and other methods to perform their private listening experience of song or story to those within their response presence, constituting response cries. We noticed *kites* or response cries of two main kinds related to the stances of listening as observation or listening as searching.

Listening To

One set of response cries can be grouped as more moment-to-moment reactionary and demonstrated a broad attendance to the sound. This connects with the observational stance of listening: listening *to* something. In the case of the high school students, the recording of 'Blurred Lines' sustained a tension between the students' existing social positions and their presence with one another while the song was playing. Alignment against the singers of 'Blurred Lines' became visible as students responded to hearing lyrics which they disagreed by shaking their heads, raising eyebrows, and hugging their knees to their chests (see Figure 3).

Figure 2. High schoolers produce response cries
Students are visibly reacting to that which they are listening to.

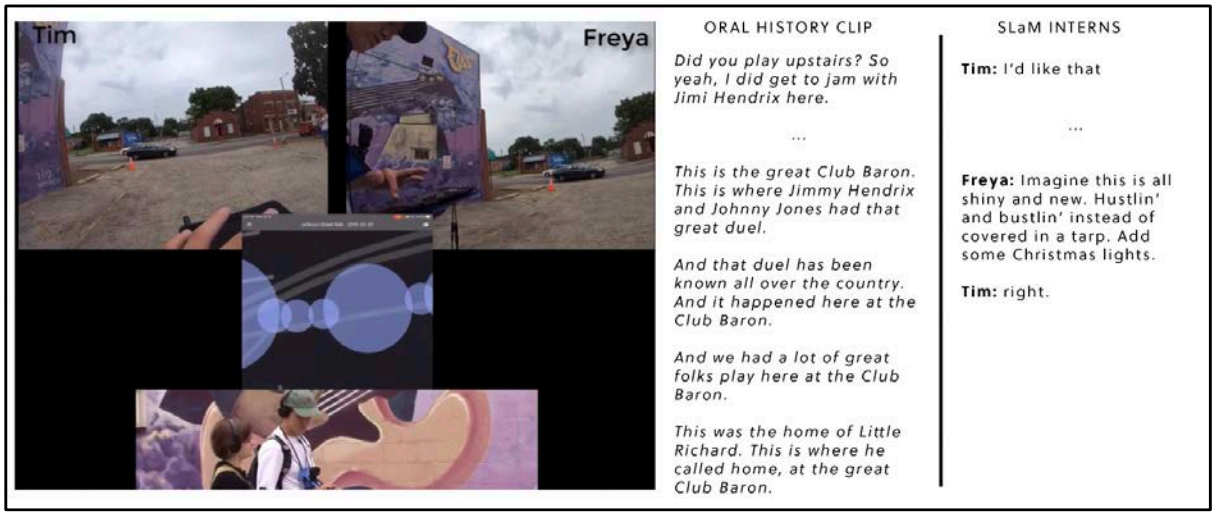


Realization of what may have been an alignment with the was evident as some students started by singing along but dwindled in their singing as the content of the lyrics became apparent. Response cries often precipitated each other, with one student exclaiming "oh man!" and making eye contact with a peer who then said "yikes" to the same lyric. Masters' students performed their private experience of listening into the response presence by walking in time to the beat of a song or consulting with their partner, asking, "Did you hear that about the interstate?" referring to an oral history clip.

Listening For

The other category of response cries relates to the searching stance of listening: listening *for* something. In the masters' class, a student returned to an audio clip to listen *for* the interstate story that her partner mentioned. For the summer interns, the idea of listening *for* the future emerged in their utterances about what a historic club must have been like overlapping with ideas of what it could be like "with some Christmas lights" and a band with Tim.

Figure 3. Summer interns use Echoes, a DSSL



The shift between these two modes of listening is obscured when it is not the explicit framing of the activity, but is evident in how learners are able to filter out audio information irrelevant to their pursuit (e.g. for the pair of masters' students, content not related to the Interstate was ignored).

In identifying these two modes and their accompanying response cries, the categories fall short of accounting for the ways in which each person has a different approach to listening, which likely includes some predispositions for certain types of listening *for* in a first listen (or a listening *to*) stance. Someone with a musical background may naturally gravitate toward noticing the instrumentation of a song; someone with a background in politics may

hear the story about the interstate through that particular lens. This is where strings come in to represent the connections between individual listeners and their response cries.

Strings

Students drew on a range of resources to connect where they current were (both literally in space and time and conceptually in their own positionality) to what they were listening to. The quality and texture of these strings is likely innumerable. Some brought in personal stories tied to themes in the music and others brought in original sources related to the sonic content like court records and news articles. One masters' student related a colorfully muraled overpass to a similar site she had visited in New Orleans despite the vast difference between the communities' respective use of these two spaces. Another student drew on a story a classmate had told her about the neighborhood to make sense of the oral history clip about the neighborhood's once-vibrant music scene. These connections create and sustain tension between the performance of listening and the personal history of the listener.

Discussion and Implications

Being moved by sound

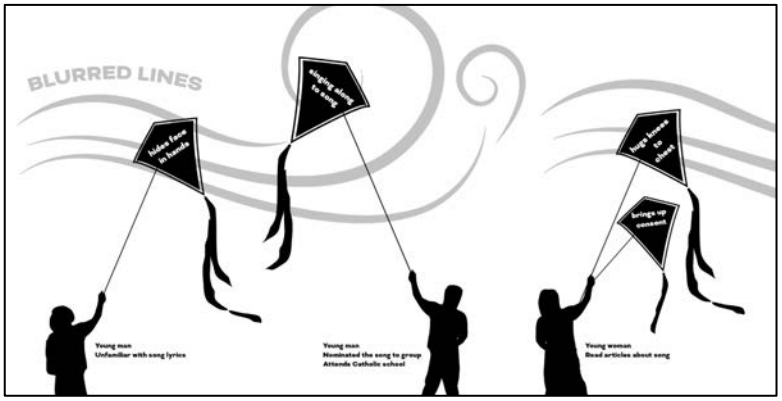
Earlier, Ingold described the possibility being swept up by sound, noting the effort it requires to stay in place when pulled by the sonic wind. Now, we can consider the difference between where we started when we unspooled our thread and launched our kite to where we stand as the wind whips it around. It is unlikely, though not impossible, to stay still. Ingold decries standing still: you might as well not have heard the sound to begin with.

Then a change in position must reflect being moved by the sound. Listening produces learning in this way. We are not where we found ourselves before we listened and responded. This movement and tension shapes us as learners, strengthening us and bringing us to new places. Listening is both the means and product of constructing new information in conversation. Doing this work of listening, however, might lead to entrenchment if we are only listening to that which already aligns with our personal experiences and understandings: we will see slack in the line and feel no windiness. It is essential to have a critical perspective of listening that honors the undeniable socio- and geo-politics of listening. Songs, counter stories, erased or undertold stories, public histories, personal narratives specifically of women (as 'Blurred Lines' goes to show) and Black people in the U.S. (as seen in DSSLs), and other forms of historically undervalued information must be revisited with the new commitment.

Listening together

Embedded in these findings are three clear methodological, epistemological, and ontological implications for what it means to listen *together*. Firstly, that kites *do* fly (so to speak) is a phenomenal thing. Because of response presence, listening inscribes itself in the record through interaction. Methodologically, this means that while noticing or proving listening as an activity is difficult, examining listening from an ensemble learning perspective makes visible the otherwise invisible personal experience of listening. It also provides the opportunity for understandings of sound to be expanded and challenged by co-listeners. For the high school students, it was pivotal that their utterances and accompanying takes on the song's meaning were so contrasted (see Figure 4).

Figure 4. Different kites, same sky



Since listening is inscribed in interaction, so too are the two main modes of listening to (or, observing) and listening for (or, searching). While it will take future work to better untangle the transitions between these modes and what prompts them, epistemologically, this opens the door for future investigation of how these modes constitute ways of knowing within the medium of sound.

Lastly, the context of listening *together* means that students draw on many resources to make sense of a song or story's meaning. It is a context where narrative and counter-narrative, personal experience and evidentiary documentation sit side-by-side as legitimate interpretations. This togetherness foregrounds the diverse ontologies, building intersubjectivity and co-constructing a meaning that otherwise—having listened alone, as is often our practice—would be less rich. Initial understandings of the song or story's meaning were complicated and made rich by the context of listening with others. Toward the end of each record, students express an idea of what was learned through listening that is specific to the context in which they listened, namely the meaning constructed between their own listening and the listening of their peers collectively.

A sky full of kites

I am reminded of a county-wide festival that was held near my hometown each year called Art and Wind. Beyond the regular festival offerings of snacks and folk art, the central feature of the day was collective kite flying. Nearly every person at the event had one or more kites: a purple octopus, a rainbow, a classic yellow quadrilateral. Flying a kite was its most fun when yours was one of thousands dotting the sky with fantastic color, all of them sweeping about like dancers in the air. The visual impact of seeing the kites together was the main attraction for Art and Wind Fest. With listening, I believe the same may be possible. Listening is a practice that stretches us outside of ourselves, to attune our hearing to the sound around us and make meaningful connections to what we hear. The main event could very well turn out to be how powerful it is when we reflect on our experiences of listening in a social context, when we listen together.

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Modeling Chance Processes in A Classroom's Ecological Investigation

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Abstract: The work of ecologists entails structuring variability by parsing random and directed variability. Middle-grade students are often introduced to ideas about probability and statistics in mathematics, but these ideas are rarely employed in science investigations. This paper reports on a design study in one 7th-grade science classroom that participated in a citizen-science project investigating changes in invasive crab populations. Students surveyed crab abundance at one field site, contributing observations to a citizen-science database. Finding an unexpected ratio between male and female crabs in their sample, students compared the ratio obtained in the field to a simulated sampling distribution of ratios in light of an equiprobable assumption. Finding that their sample's sex ratio was improbable yet consistent with samples in the larger database instigated a search for ecological mechanism. Evidence of student thinking in classroom conversations point to seeds of distinguishing random from directed variability.

One fundamental task in ecological investigations is to understand the abundance and distribution of organisms across space and time. Abundance and distribution of organisms is not uniform across space and time as species vary, individuals within a species vary, and environmental gradients vary. Distribution-generating processes include random (e.g., genetic recombination or small fluctuations in temperature) and causal mechanisms (e.g., organism-environment interactions, organism-organism interactions, seasonal variation in temperature). Additionally, ecological sampling inevitably introduces chance variability: repeated samples vary just by chance. Sampling is key in ecological investigations as ecological processes occur across multiple spatial and temporal scales, making a census approach impractical. Teasing apart variability due to chance and variability due to other underlying patterns and processes is a messy but critical activity in ecological investigations (Albert et al, 2010). This critical activity is often hidden from students' view. Conceptual underpinnings for understanding variability and changes in ecology and evolution take time and coherent forms of support to develop. Students from younger ages need repeated opportunities to encounter and build on these foundational ideas (Lehrer & Schauble, 2012). This research addresses ways of supporting the development of foundational ideas about variability and change in ecosystems by positioning students as participants in classroom approximations of professional ecological practices, particularly those of visualizing, measuring and modeling variability in ecological investigations.

Research Context & Design

The work reported here takes place within a larger, multi-year design-based research study investigating how students' conceptions of and practices for representing variability inform their construction and revision of models of ecosystems, and how students come to view the function and utility of the ecosystem models they have constructed, as well as relations between different models. The context of this work is a statewide middle school citizen science curriculum focused on monitoring and mapping species of interest in the Gulf of Maine intertidal ecosystem with the particular goal of understanding how the relative abundance and distribution of native and invasive species of crabs is changing due to climate-driven factors. In addition to classroom work, students survey native and invasive crab abundance at local field sites and contribute their collected data to a larger database of survey data collected by students up and down the coast of Maine. In this paper we report on the first implementation of a data modeling trajectory co-designed with two middle-school science teachers. Our design focused on cultivating an appreciation of the role of chance in sampling so that as students collected and analyzed samples during their citizen science investigations, they had the means to account for uncertainty due to chance in their observed samples, and in this light, to anticipate when sample variability indicated a need to search for an ecological mechanism.

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Instructional design

This instructional design builds on a data modeling perspective (Lehrer & Romberg, 1996). This perspective positions students as participants in approximations of statistical practices in professional science, especially those of visualizing, measuring, and modeling variability (Jones et al., 2017; Wild & Pfannkuch, 1999). Conceptual and representational cornerstones of these practices include mathematical descriptions of distribution and mathematical models of chance. These cornerstones in turn support model-based inference in light of uncertainty due to chance variability.

School curricula often allocate topics in probability and statistics to mathematics. Ideally, students come to science classrooms equipped with mathematical tools that they can utilize in science investigations. However, probability and statistics are often treated separately, and students may not meaningfully connect them in a way that this otherwise connected network of concepts and practices can readily be employed in service of scientific inquiry (Konold & Kazak, 2008; Moore, 1990). In this work, our instructional sequence aimed at both supporting students to develop mathematical means for visualizing, measuring and modeling variability while simultaneously advancing their scientific investigations (Lehrer, Schauble & Wisittanawat, 2020).

Prior instructional sequence: Visualizing and measuring variability

Prior to the instructional sequence that is the focus of this paper, we first supported students in developing ways of visualizing and measuring variability by challenging them to invent displays of data that they had generated. Students as novices to visualizing and analyzing data tend to focus on individual cases (e.g., the biggest crab or the crab they personally found) rather than on the aggregate (Konold et al., 2015). To support students to extend the view of data as mere cases to also encompass the view of data as an aggregate of distributed cases, we asked students to invent data displays that highlight characteristics (e.g., center and spread) of the data aggregate. Constructing data displays provided students opportunities to consider how to order, group and organize data, leading to structuring data as a distribution.

We searched for a candidate task (Lehrer & Schauble, 2021) in the invasive-crab investigation. That is, we searched for a task that provided opportunities to capitalize on children's conceptual resources in ways that would potentially support both the development of statistical practices and students' current scientific investigation. In this citizen-science investigation, students would record data of sizes of crabs found during their field survey. Prior to the field visit, students practiced measuring the size of a classroom's crab in residence (from their classroom's saltwater tanks). We posed the question: *How big is this green crab?* Each student measured the same crab and recorded their measurement. We then combined class measurements and provided groups of students with a copy of the class's batch of data. We asked students to develop displays of their class's measurement data to help other people quickly see what the crab's size really was. Consistent with prior work (e.g., Lehrer, Kim & Schauble, 2007), students generated different types of displays. The displays differed in how cases were grouped (e.g., no groupings, groups of same/similar values, groups of same size), how cases or groups of cases were ordered (e.g., by value or by frequency) and how cases were organized in relation to each other (e.g., on a consistent scale or not).

Next, we supported students to invent or use measures of center by posing the question: *What is our best guess of the crab's size given our class's data?* Students had already learned different measures of center, namely mean, median and mode, and they made use of these measures as estimates of the actual crab's size. To support students to invent or use measures of spread, we posed the question: *How precise were our class's measurements?* Here, students used range and interquartile range (and other similar invented measures that described the size of the middle or the biggest clump). Students also measured the same crab a second time, this time following a standard measurement protocol for measuring crab sizes—measuring the widest part of the carapace. This second data set invited comparisons between two data distributions and provided a situation for a test for robustness of measures of center and spread (e.g., whether changes in measures reflected changes in distributions). In this instructional sequence, students first invented both data displays and measures on paper, and we later introduced a digital tool, the Common Online Data Analysis Platform (CODAP), to facilitate future work with data.

Focal instructional sequence: Modeling sampling variability

The remainder of the paper focuses on this next phase of instruction. In this section we describe the tasks, tools, and rationale comprising the anticipated instructional sequence. In the Findings & Analysis section, we describe the enacted instructional sequence.

With ways to visualize and measure variability in hand, we aimed to extend students' conception of variability to include the role of chance. Again, we searched for a candidate task that served as an entrée into modeling chance processes within the context of the invasive-crab investigation. From the existing large citizen-science data set, we learned that school groups often found sharply unequal ratios between the number of male and female crabs in their quadrat surveys, with the majority finding more males than females. Across four years (sample sizes between 127 to 311 crabs), the sex ratios ranged from 68%-75% males. Across 19 field sites (with more than 10 crabs found in quadrats), the majority of them (17) sites reported more males, ranging from 56%-92% males. The other (2) sites reported more females (42% males and 45% males). We thus anticipated that in their upcoming field trip students would likely find an unbalanced sex ratio of the crabs in their quadrats, and most likely vastly more males than females. As in any ecological sampling, students' observed sample outcome would need to be considered in light of sampling variability. The key question we worked to support students to consider was as follows: *How likely could our sample's observed sex ratio occur just by chance?*

To consider this question, students first needed to develop a grasp for the structure of random variability. Individual outcomes of a random process are uncertain, but outcomes of long-run, repeated random process exhibit structure in the aggregate. We supported students to develop ideas about the structure of chance variability by engaging them in examining behaviors and outcomes of random devices (here, a physical and later digital spinner). We asked pairs/groups of students to conduct an experiment by spinning an equal-split "male-female" spinner 10 times. Students recorded the number of males per 10 spins and repeated the experiment to collect a total of 10 samples of 10 spins. We planned to have each pair represent the results of these 10 samples (each of which was comprised of 10 repetitions of the equiprobable process) as a dot plot of a sample statistic (the number of "males."). Our conjecture was that this would help students start to consider sample to sample variability that could be attributed solely to chance. Next, we planned to ask students to predict shape, and statistics of center and spread of a distribution constituted by growing the number of samples to include all those generated by every pair. The aim was to promote a conception of potential structure in a sampling distribution corresponding to elements of the variability-generating process (i.e., a center statistic representing the signal of its equiprobable structure and a statistic of variability that could be attributed to the randomness of the process and the sample size). Students would then organize the sampling distribution, examine its shape, and reason about the relations between the structure of the spinner and the shape of the sampling distribution. We planned then to introduced a digital spinner (in CODAP) as a way for students to explore effects of sample sizes on sampling distributions.

Next, we planned to ask students to use a (digital) spinner to construct models that represented a situation where there was roughly the same number of male and female crabs in the ocean. Students would then use the models to simulate repeated sampling of a sampleof crabs equal in number to that collected in the field. Based on the model-generated sampling distribution, students would consider how likely their observed sample's sex ratio could occur just by chance. Asking students to make inference about the sex ratio of crabs in the ocean, we anticipated that students would suggest collecting more data, especially if their observed outcome was unlikely to occur by chance. This would then motivate further exploration of the larger citizen-science data set to consider whether other school groups also found similar outcomes as theirs. As mentioned earlier, the sex ratio in the large data set skewed towards males. We would engage students in the discussion on whether and how they wanted to revise their chance models given new information they gained from exploring the larger data set.

Analysis & Findings

We reviewed fieldnotes and video recordings of classroom conversations with an eye towards how students constructed and revised models of chance to represent random variability in the crab sampling process. We attended to key moments in classroom conversations when students modeled random variability, and how students' emerging conceptions of and practices for representing variability supported their reasoning about the ecological system under investigation.

Exploring local data

Students surveyed invasive crab abundance at a state park near the school and catalogued twenty-six crabs found in 16 1-m^2 quadrats sampled along a 60-meter transect. Field protocols specified identifying species of all surveyed crabs, measuring carapace length, recording the number of claws, and identifying sex. Students' exploration of their own sample revealed, as anticipated, a curious outcome: twenty-three of the twenty-six crabs were male, a "wild ratio" of 88% male to 12% female, as noted by the students. Although the outcome was

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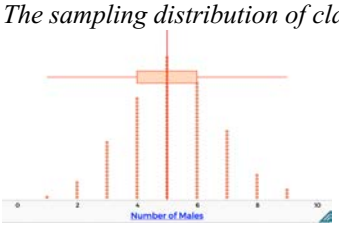
surprising to students, they readily inferred characteristics of the entire population from their single sample. For example, students suggested that the male crabs were "overpopulating" the female crabs, that female crabs were "not surviving very well," and that the overall population of invasive crabs was actually *declining* due to a shortage of female crabs. The classroom teacher, Ms. S., pivoted student attention away from the sample at hand and invited them to imagine other possible samples. She asked, for example, whether it was possible to collect a sample with 88% males and 12% females just by chance? And, if we collected a second sample, could the sex ratio be 50/50? Students considered the "odds" of finding the same ratio of male crabs to female crabs in a second sample unlikely but also suggested several sources of natural variability which might have influenced their outcome including the time of day, the water temperature, and the protocols themselves (sampling the intertidal zone only versus sampling both the intertidal and the subtidal zones).

Examining chance variability with random devices

To consider the structure of variability in a repeated random process, students conducted experiments with random devices. Student groups conducted an experiment, collecting 10 samples of 10 spins on an equipartitioned Male-Female spinner as a way to simulate outcomes of repeated samples of 10 crabs. Each group made a distribution of their sample outcomes, and the teacher collected outcomes from all student groups to make a sampling distribution of 150 samples of 10 spins. Before examining the distribution, the teacher asked students to predict its shape. One student predicted a "hill in the middle," suggesting there could be a few outliers, but most outcomes would be "compacted to the middle." Another student thought the distribution would clump around 5, because the outcomes of his groups' 10 samples also clustered around 5 and included no outcomes of 1, 2, 8, or 9. A researcher asked if they expected more extreme outcomes in the 150-sample sampling distribution. The students thought there would be more extreme outcomes, but concluded most outcomes would still be in the middle. When Ms. S. showed students their aggregate sampling distribution, students noticed that their predictions bore out. Students noted that, as they predicted, "you can see...a clear hill and that five is the median and also the tallest." Additionally, students observed that extreme outcomes, such as 9 males, only happened 3 out of 150 times.

Figure 1

The sampling distribution of class's 150 samples of 10 spins on a 50M/50F spinner



Ms. S then introduced a digital spinner in CODAP, a resource she now framed as a "statistical tool" that expedited explorations of chance processes. Ms. S asked students to predict what happened if they ran the same experiment again, collecting 150 samples of 10 spins. Students predicted that the simulated sampling distribution would look similar to the one produced using hand-held spinners. Ms. S. ran the model while students watched, with much anticipation, in real time as the sampling distribution took shape and saw that the general shape of the distribution was similar to the previous one generated by physical devices. Ms. S then invited a student volunteer to draw on the whiteboard what the shape of the distribution might be if they were to continue the experiment and collect 150 more samples. The student drew a shape that traced the current distribution with a central clump around 5 (or 50%) males, and similar spread. Again, Ms. S. ran the model while students watched in real time as the sampling distribution took shape and saw that the general shape of the distribution did not change.

Using random devices to model chance variability in our crab sampling

Having explored chance variability, the class now turned to consider their own observed sample in light of chance variability under the assumption of equiprobable sex ratio. Ms. S focused her students to the question at hand: *How likely could our sample's observed sex ratio occur just by chance?* She then asked students to return to the digital spinner and to use the spinner to help them answer the question.

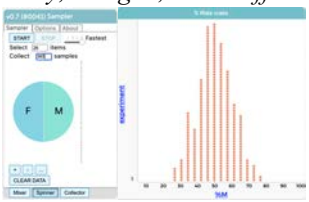
Running their models, students noticed that more extreme outcomes, such as 80% or 90% males, were even less likely with this larger sample size of 26 crabs. For example, during small group work, Anna's model collected 150 samples of 26 crabs using a 50M/50F spinner, and she noted that her model produced no outcomes "over 80 or under 20 [percent male]." A researcher asked Anna if her model's outcomes made her think differently

about how likely the class' observed outcome of 88% male could occur just by chance. Anna responded, "It makes me think that's it's even less likely. Like, I was thinking before that it probably was just by chance when we were [modeling] with 10 [crabs], but with 26 [crabs] it shows that it's even less likely because I didn't even get one point that was above 80 [percent male]."

In the subsequent whole class discussion, other students shared their models and similar observations as Anna's. Lacey, Morgan, and Griffin built a model they described as simulating the collection of "26 crabs a day every day of the year," that is, they used a spinner of 50M/50F and ran 365 samples of 26 spins (Figure 2). Ms. S asked the group about their outcomes:

Figure 2

Lacey, Morgan, and Griffin's model for collecting 26 crabs a day every day of the year



1. Ms. S: On any of those 365 days would we have had a day that we found 90% male crabs just by chance?
2. Lacey: Nope.
3. Ms. S: Really, not a single time in your model?
4. Lacey: Yes.

Having established with the class that outcomes like their observed outcome of 88% male rarely occurred in their simulated sampling distribution, Ms. S asked the class to consider:

5. Ms. S: What does this tell us about the likelihood of getting 88% male at [our field site]? Do we still think that could be attributed because of random chance or are we more convinced there might be something happening?

Ms. S's wondering invited a few students to propose ideas for revising the structure of the spinner to reflect a different sex ratio. Ben wondered if the "actual real" ratio was something different than 50/50, and suggested a ratio of 60 males to 40 females. Denver agreed, excitedly interjecting that he had been "trying to [share] *every single day,*" that there could be more male crabs than female crabs in the ocean. Some students wanted to investigate Denver's claim by going back to the field and collecting more data, with Caleb suggesting, "collecting every crab in the ocean." Other students thought they could first investigate by revising the chance model to reflect class members' guess that there were more male crabs. One student suggested making the spinners 4 slots males, and 3 slots females.

Exploring citizen-science data and revising models

In the following class, Ms. S. revisited students' earlier suggestion to revise the structure of the spinner and solicited the class for proposals for how to revise. Recalling Denver's exasperated statement at the conclusion of the last lesson, Ms. S. invited Denver to restate his proposal. Denver had consistently proposed that "there could just be more male crabs," and he now guessed the ratio to be "65 male, 35 female." As an alternative hypothesis, a researcher proposed maintaining the 50/50 spinner because that was the case for most animals and it was possible that crabs were incorrectly sexed during the field survey. Ms. S., on the other hand, proposed revising the spinner to resemble their observed sex ratio, citing "We practiced the protocol, we did a good job in the field, it's definitely 88% males." The teacher drew each of the proposed spinners—65/35, 50/50 and 88/12—on the whiteboard, and asked the class to discuss which one they wanted to put their votes behind. A handful of students thought it could still be 50/50. Most other students disagreed, however, but were unsure what the ratio should be:

6. Ben: I agree with Denver because I think the [50/50] spinner was inaccurate. I think what we should have is we should have 65 percent of the [spinner] be covered with males, and then 35 covered with females. I think that might be more accurate to our data. We found 88% males, it would just be crazy to find that on our first try if it was really 50/50. I don't think it's 88% males all the time because they would have trouble reproducing.
7. Denver: I agree with Ben, like, when we did the 50/50 spinner, we almost didn't have it up towards 90%, so I think that there's just going to be more males than females out in the ocean.

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8. Anna: I agree, but I don't [know] if it's like the whole ocean has more male than female crabs, it might just be at [our field site]. I definitely think the number of male crabs to female crabs is more than 50/50.

In this exchange, students recalled the outcomes from the equiprobable model (e.g., "almost didn't have it up towards 90%") to argue the equiprobable assumption was inaccurate. At the same time, students were not convinced that the overall sex ratio could really be 88/12 as the crabs "would have trouble reproducing." Other students started to wonder whether their field site was exceptional in some way. As the class was leaning away from 50/50, but also away from 88/12, the researcher made connections to other students' ideas about other ways to find out what the sex ratio might be:

9. Researcher: I've also heard [another] idea, that we could just measure every crab in the ocean. But I'm wondering, is there another place we could look for the kind of data you're craving, Denver?
10. Denver: Well, there's all those other schools that went to those other beaches and we could see their data.
11. Researcher: And what could we do with their data?
12. Denver: We could see if it's close to ours because we found 88% males. If they found 85% males, we know that it's going to be close to more males than females.

As it was not feasible to "measure every crab in the ocean," the class followed Denver's suggestion and consulted "all the data from the other schools" by exploring the large citizen science crab survey data. Here, students also explored trends in sex ratio in relation to sites, time of year, shell conditions, etc. Through their explorations, students also determined the overall sex ratio (of 902 green grabs collected in the intertidal along the coast of Maine) was 71% males and 29% females.

Ms. S posed a challenge: "How could you revise your model to be a better representation of what we think is going on in the intertidal?" Students sketched their ideas for a revised spinner on paper, mostly drawing either a 71/29 spinner or an approximation of it (e.g., 70/30). The class agreed on revising the spinner to 71/29, and before running the model, several students predicted that, now that the structure of the spinner was 71/29, it would be more likely to get a sample of 88% males compared to the previous run with a 50/50 spinner. Because this model was difficult to accomplish on the spinner in CODAP, the class's revised model had to be run on a central computer using TinkerPlots (Konold & Miller, 2011). The 71/29-spinner model was projected on the board and the first sample of 26 spins was collected:

13. Ms. S: We got 66% [males], what should we do now?
14. Griffin: Run it again.
15. Ms. S: Run it again! How many times?

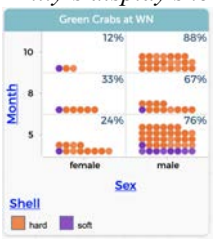
Students suggested running the model more times. This suggested a shift from viewing a single outcome as isolated to viewing an outcome as part of a long-run repeated random process, a shift foundational to understanding the structure of chance variability (Konold, 1989). Students were still developing a sense for how "long" the "run" needed to be, however, and only collected a relatively small number of samples. In response to the teacher's question, one student suggested collecting as many samples as the number of times middle-school students across the state went to collect samples in the field. The class took up that suggestion, and collected 70 samples, i.e., the number of field trips in the data set. As the model was running, the teacher asked the class to consider what the sampling distribution might look like, and students predicted the middle clump would be in the 70s. The resulting sampling distribution had a clump around 70% males, as students had predicted, and it included outcomes in the 80's and 90's, which rarely (or never) occurred in the sampling distribution generated under the equiprobable assumption. This led the class to conclude that their sample was consistent with the overall sex ratio in the larger data set.

Exploring mechanisms for sex ratio differences

Having established that their observed sex ratio was consistent with the overall sex ratio in the larger citizen science data set, the class now searched for possible mechanisms to account for this disparity between the sexes. Earlier, students had explored different data sets: their own field data, data from their site, and the multi-site citizen science data. In their explorations, one student, Emily, discovered an interesting pattern in the number of soft-shell crabs by sex at their field site. Ms. S. shared Emily's CODAP display (Figure 3) with the class, and students noticed that while there were more male crabs across the months, the percentages of male and female crabs surveyed were also changing. In particular, students noticed there were more female crabs found in May and August compared to in October (when they surveyed the site).

Figure 3

Emily's display showing shell hardness by sex and time of year



Ms. S revoiced many students' noticing that the sex ratios appeared to be changing from month to month and asks the class why the ratios might be changing. She notes, "We saw this in our data. … Why would this pattern exist *over the course of the year*?" Students considered variables such as temperature, as well as how molting cycles might influence foraging and refuge-seeking strategies:

16. Denver: We were thinking that it might be because of temperature but we were also thinking that if they're soft shells, they might want to hide and not be on the beaches.
17. Ms. S: Totally, what have we seen in our own tanks, do soft shells last very long? Unfortunately, no.
18. Bella: We thought that maybe it's because of the season, because the most male crabs were in colder … Like [August] and there were very few [male crabs] and that's like summer. And in October, it's colder.

Anticipating connecting students' ideas to scientists' account of the mechanism driving seasonal sex ratios, Ms. S. introduced a video clip of a conversation among the partner scientists on the citizen science project as they interpreted data on crab's sex ratios. Ms. S asked students to listen for explanations for why they see more males than females, and why those ratios "vary so much throughout the year." In the video, the scientists are considering a graph showing the percent male and percent female by year and county.

19. Ms. S: What have we heard so far?
20. Madison: It's mostly because of the molting that we don't see many females. We checked only in the Fall and that's when females go and hide and males are hard shells and don't need to hide.

Ms. S. called attention back to the question the class had been considering: Are there really more males or are the females just harder to find? She notes that the molting cycles, as Madison has suggested and that Emily investigated in their site data, have helped them think about "one part of our question: maybe the females are just hiding more and we can't find them." But she immediately followed this statement by asking "Or maybe there are just fewer of them?" In the video, the partner scientists consider this same question: Are males more easily observed in the Fall or are there more males in general during that time of year? The scientists discuss both movement and habitat preference as possible causes. However, the scientists conclude that this question is still not well understood, something Ms. S. calls attention to to make explicit the epistemic game they, and the scientists, are playing as well as the broader purpose of the citizen science project itself.

21. Ms. S: What did we hear there? Do we know for sure? Are there actually fewer females or are they harder to find?
22. Griffin: They're just harder to find. The males are molting in the spring and summer, and the females molt in the Fall and are harder to find in the Fall.
23. Ms.S.: And even [our scientist] isn't totally sure because they're harder to find or because there are actually fewer of them. So, we don't have a definitive answer and that's the point of all of this [citizen science], so that we can help [our scientist] get to the bottom of this.

Discussion

Ecology is both a challenging and fruitful context for supporting distinctions between random and directed variability. It is challenging because variability-generating processes in ecology occur across temporal and spatial scales that are not immediately tangible to students. Yet, when students have a hand in construction of samples, their direct experience in a sampling process supports their image of long-run repeated process (e.g., running the model to simulate visiting the field every day), and how their decisions about sampling can influence their outcomes.

In this iteration of our design study, we supported students in visualizing, representing, and modeling variability in the context of a citizen science ecological investigation. At the beginning of the focal instructional sequence, students did not consider their observed outcome in light of sampling variability. This was evident in

how students immediately made inferences about crabs in the ocean from their single sample before they considered whether such a sample could be explained by chance. We supported students to consider how likely their observed sample could occur just by chance. Students' developing ways of representing and modeling sampling variability supported them to reject the earlier equiprobable assumption. Students then revised their model to consider whether their observed outcome was consistent with data collected by other schools in the citizen-science data set. Finding that their outcome was consistent with the larger data in turn motivated their search for plausible mechanisms that explain the observed difference in sex ratio.

The current study suggests two potentially fruitful areas for future iterations. First, we can further investigate students' connections to and use of publicly available data. The learning sciences community seeks a vision of Data Science education that is "grounded in consequential investigations in which learners pose questions, obtain data, and communicate findings within meaningful disciplinary contexts" (Wilkerson & Polman, 2020, p. 3). Grounded in consequential investigations, students can use and develop data science tools and methods to employ public data in purposeful ways. Here, we saw evidence of students making connections from their local investigation to publicly available data to further their investigation. Second, we elaborate and extend our instruction design to address relations across different forms of models, and we saw evidence of this practice emerging in this classroom. For example, when students noticed patterns on molting in the large-scale data, the teacher made the connection to their classroom microcosms which had emerged as a site for studying predation avoidance in relation to foraging and refuge seeking. We continue to consult our partner scientists, who employ field study and microcosms to craft models of climate impacts on intertidal ecosystems, to consider how students' inquiry can be supported to coordinate field and microcosm study to get a grip on sources of variability and change in these systems.

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The effect of different sequences of examples and problems on learning experimental design

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Abstract: Example-based learning refers to a pedagogy in which learners are provided with a step-by-step solution to novel problems early in the learning process. Worked examples are most effective when used in tandem with open problems. However, there are still questions regarding the ordering of examples and problems. We compared the effect of sequencing examples and problems on learning and cognitive load. One hundred thirteen middle-school students were randomly assigned to one of three conditions that varied presentation order within each example-problem pair: example first, problem first, or simultaneous presentation. We evaluated students' performances on knowledge application and the transfer of learning on the topic of experimental design. We found no effect neither on learning nor on cognitive load. We compare these results to parallel studies in the literature and identify possible reasons for the null effect.

Introduction

Worked-Examples (WE) is a teaching approach in which students are invited to study the problem formulation, its solution, and the steps leading to this solution prior to receiving open problems to solve (Renkl, 2005). Studies show that for novices, WE improve learning and reduce cognitive load (Gerven et al., 2002; Sweller et al., 2011; Van Gog et al., 2006). Optimal use of WE interleaves them with Problem-Solving (PS) in which learners apply the taught procedure to a new problem (Renkl, 2005; Sweller & Cooper, 1985). Alas, while the benefits of using WE and PS are well documented, results about the timing of WE in relation to PS are inconclusive.

The question of sequencing WE and PS is an interesting one, as it helps clarify (and optimize) the role of examples in learning. Which element within each example-problem pair should be introduced first? One option is to provide learners with WE prior to PS. The rationale for this sequence is allowing learners to devote their cognitive capacity to studying the worked-out solution procedure and construct a cognitive schema for solving similar problems (Sweller & Cooper, 1985). Another option is to introduce PS prior to WE. The rationale for this sequence is that providing challenging questions to learners prior to instruction was shown to better prepare them for future learning from subsequent instruction (Loibl et al., 2017; Sinha & Kapur, 2021). The third option is to present WE and PS simultaneously. The rationale for a parallel presentation is that when learners are challenged with a particular problem, giving an example in parallel could guide them in the solution process, thus could help them develop strategic knowledge. This approach is based on the analogical reasoning literature (Gick & Holyoak, 1980; Renkl et al., 2013).

The current study explores the effects of different sequences of examples and problems on knowledge application, the transfer of learning, and cognitive load. We do so with middle-school students learning about research competencies and focus in particular on learning how to design experiments. To date, most studies of WE have focused on topics such as physics and mathematics (cf., Renkl et al., 2013; Salden et al., 2010). To the best of our knowledge, the effectiveness of this approach to learning research competencies has yet to be studied.

Theoretical framework

Worked Examples

WE include the problem itself, the steps of its solution, and the final answer (Atkinson et al., 2000). Empirically, learners who receive WE followed by PS performed better than learners who receive problems only (Renkl et al., 2013; van Gog et al., 2011). Learning from WE allow learners to form problem-solving schemas that are stored in long-term memory, and these schemas can later be retrieved when solving related or advanced problems (Sweller, 2006). In addition, WE reduce students' cognitive load compared to PS (Sweller et al., 2011; Van Gog et al., 2011).

The WE effect is particularly strong for novice learners (Kalyuga et al., 2001). Example-based learning may become redundant for students with a higher level of prior knowledge as they no longer need the guidance

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provided by WE (Kalyuga et al., 2001). This effect is commonly referred to as the Expertise Reversal Effect (Kalyuga et al., 2003; Salden et al., 2010).

Most research on WE has been done in well-structured domains such as mathematics, physics, and programming (Glogger-Frey et al., 2017; Renkl 2013; Salden et al., 2010). Recent studies show the impact of the WE also in less structured domains such as writing, literacy, and music (Kyun et al., 2013; Nückles et al. 2020; Owen & Sweller, 2008). However, the effectiveness of this approach to learning research competencies has not yet been studied.

The combination of WE and PS

In recent years, extensive research has documented the beneficial impact of the combination of WE and PS on learning (Renkl, 2005; Sweller & Cooper, 1985). However, there is still uncertainty regarding the timing of providing WE in relation to PS. Should the WE be provided before, during, or after the PS? Results vary, and sometimes conflicting results were found by the same researchers. For example, Van Gog et al. (2011) found that WE before PS is most effective for learning, but several years later received different results showing no effect for order (Van Harsel et al., 2020). Similar null results were also reported by Chen et al. (2020). Reisslein et al. (2006) reported a more nuanced finding, where low-prior knowledge students benefited from example-problem pairs, while high-prior knowledge benefited from problem-example pairs. There are strong rationales for the benefits of each sequence:

PS before WE (PS→WE)

When starting with PS, learners search for ways to solve the problem without having sufficient knowledge. While learners may experience this order frustrating, studies show that grappling with novel problems supports learning from subsequent instruction (Chowrira et al., 2019; Sinha & Kapur, 2021). This sequence of PS followed by Instruction (such as WE) is commonly known as PS-I (Loibl et al., 2017; Sinha & Kapur, 2021). These early solution attempts facilitate activation of prior knowledge and recognition of the deep features of the problem, thus preparing students for future learning (Loibl et al., 2017; Sinha & Kapur, 2021). PS-I instruction especially improves students' ability to transfer the taught knowledge, for example, when learners are asked to correct a given faulty model (Holmes et al., 2014). In addition to these cognitive benefits, several studies suggest that initial WE can increase learners' motivation as well as their focus on the unsuccessful steps (Hausmann et al., 2008; Reisslein et al., 2006). However, to be effective, learners need to be able to diagnose their own attempts, which may not be the case with complex skills such as experimental design.

WE before PS(WE→PS)

Presenting WE followed by PS follows a teaching approach known as Scaffolding (Tropper et al., 2015). Scaffolding refers to providing students with support during early stages of learning before removing support and shifting the responsibility to them (Jumaat, 2014). In the context of WE and PS, providing learners with WE before they attempt the problem can equip them with resources to draw upon as they construct their answers. WE have been shown to reduce the demands of complex problems while allowing students to construct their own knowledge schemas (Sweller et al., 2011).

There are several reasons for the advantages of a scaffolding approach for teaching experimental design. The initial use of WE gives learners the opportunity to acquire the correct processes and knowledge, thereby reducing the probability of mistakes and misconceptions (Nigam & Klahr, 2004). In addition, when learners lack the knowledge necessary to solve a problem, they may solve the problems through resource-intensive processes such as trial and error, which increases their cognitive load (Atkinson et al., 2000). However, this approach may be less effective, especially for students with high prior knowledge (Reisslein et al., 2006), for which learning from examples can be ineffective or even impair the learning process (Kyun et al., 2013). In addition, and according to Cooper and Sweller (1985), learning from WE may not support skill transfer to other topics, a crucial feature in learning about experimental design.

Concurrent presentation of WE and PS

Learning from WE and PS is essentially a process of Analogical problem-solving (Gick & Holyoak, 1980), as learners identify key elements in one domain using a source problem and transfer these to a parallel (yet seemingly very different) target problem. The analogical processes are fundamental to human cognition and learning (Gentner, 2010). However, mapping targets on sources is challenging even across short time periods (Gick &Holyoak, 1980; Cushen et al., 2018). To optimize this transfer, one may present the source and the target side by side (Ngu & Phan, 2021). This presentation can support the mapping process and reduce cognitive load. On the other hand, providing a single WE based on a single solution may lead learners towards a single solution

process rather than considering alternative solutions. Furthermore, parallel presentation of source and target may encourage a rote process of read-and-apply, without in-depth encoding of the solution process that supports future independent performance (Pol, 2008).

The present study

As presented above, despite substantial research on example-based learning, the sequences of PS and WE remain an open question. In addition to both types of sequential presentation, as far as we know, no studies to date have contrasted the traditional sequencing with a parallel presentation of PS and WE. The present study aims to investigate the effect of different sequences of examples and problems on novices learning research competencies, a topic that has yet to be studied in WE research. Specifically, we address the following two research questions: RQ1) What is the effect of the sequence of WE and PS on learning, as assessed using application and transfer items? RQ2) What is the effect of the sequence of WE and PS on students' cognitive load during the learning process, as reported by the learners?

Method

Design

We evaluated the three approaches using a pre-treatment-post experiment. The topic of the study was experimental design, as it covered learning outcomes that are required by the curriculum presented by the Israeli ministry of education for seventh-grade students. The curriculum emphasized aspects that students need to consider, such as fixed factors, sample size, control group, measuring a dependent variable, manipulating independent variable and repetitions in a specific context.

Participants

214 seventh-grade students from two Arabic-speaking schools in Israel began the study. All Arab schools in Israel are run in Arabic, and only Arab students attend them. The study ran during the last few weeks of the school year (with a post-test being administered during the last week of classes) and thus suffered a high attrition rate. Our inclusion criteria were that a student had attended school during the study and completed at least half of the activity in the training phase to be included in the analysis. This leaves us with 113 participants overall. There was no relationship between condition and attrition (WE first: 74 students began the study, 40 completed it; PS first: from 68 to 38; PS in parallel with WE: from 72 to 35). To maintain anonymity, students were assigned an arbitrary code on their participation form and the exam.

Procedure

The experiment took three days, with a week between each two days. During Day 1, students were administered a pre-test and confirmed their participation. A week later, during Day 2, participants were randomly assigned to one of 3 conditions: Example-Problem pairs (n=40; WE→PS), Problem-Example pairs (n=38; PS→WE), or an example and a problem in parallel (n=35; WE || PS).

Each participant was given 2 sets of WE-PS pairs. The only difference between the three conditions was the order within each set. After finishing each set, a cognitive load rating scale was administered. Each task had a limited time to finish (see table 1). During the learning phase, there was no intervention by the researchers, and the tasks were solved individually by participants under the supervision of the teacher and the researcher. The post-test was administered a week after the learning phase.

Table 1*: Task Order by Condition in the Training Phase*

Condition	Set 1 (30 minutes)	Cognitive load rating scale (1 minute)	Set 2 (30 minutes	Cognitive load rating scale (1 minute)
WE→PS	WE_1-→PS_1		WE_2→PS_2	
PS→WE	PS_1→WE_1		PS_2→WE_2	
WE || PS	WE_1PS_1		WE_2PS_2	

Materials

Pretest:

The pre-test consisted of one question that asked the students to design an experiment for a given research question with one independent variable and one dependent variable (see Figure 1). The test was analyzed using a multidimensional rubric, as described in the Analysis section.

Figure 1: *The Pretest Question (translated from Arabic)*

16:8 intermittent fasting is a form of time-restricted fasting. It involves consuming foods during an 8-hour window and avoiding food, or fasting, for the remaining 16 hours each day. the effect of this diet on the hormone leptin, which is responsible for the feeling of satiety in the body, is not yet clear.

Design an experiment that would examine the effect of this diet on participants' leptin levels.

Learning materials

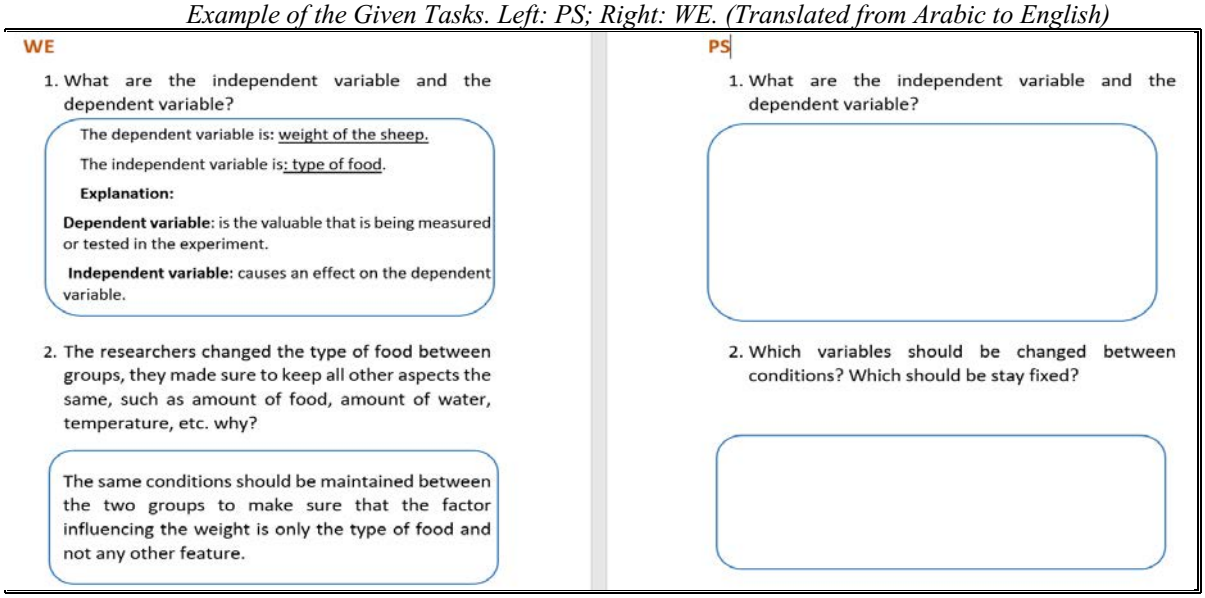
Learning materials were identical across conditions. The learning materials included two sets of WE-PS pairs. The first set included cover stories with categorical independent variables, and the second set included cover stories with scale-independent variables. Within each set, the PS and WE problems were aligned in terms of their content, questions, and topics (see figure 2). The only differences between the WE and PS in each set were (i) the cover story, (ii) whether the question was given with an answer (WE) or without (PS), and (iii) exact values (e.g., 2 groups vs. 3 groups). Each PS and WE problem included 4-5 questions. Each question highlighted a key feature of experimental design, as identified in the Israeli Ministry of Education learning outcomes. The targeted features were: fixed factors, sample size, control group, measuring a dependent variable, and manipulating independent variable. Students were given 15 minutes to solve each task in the 3 conditions.

The cover stories in the first set talked about the effect of types of food on sheep's Weight (WE) and the effect of types of soil on growing plants (PS). In the second set, the first item talked about the effect of grazing hours on the amount of milk produced by goats (WE) and the effect of watering hours on the number of flowers in plants (PS).

In the WE→PS and PS→WE condition, the problems were sequenced so that students first analyzed all questions in their first problem (WE or PS, depending on condition) and then moved to the other problem. In the WE || PS condition, the WE and PS worksheet were presented side by side, with matching items aligned next to each other (see figure 2).

Figure2

Example of the Given Tasks. Left: PS; Right: WE. (Translated from Arabic to English)



Cognitive load rating scale: After each set in the training phase, participants were asked to rate their mental effort during the learning task using Paas's 9-point rating scale (Paas, 1992). This scale is widely used across educational researches (Van Gog et al., 2009, 2011). The scale used by Paas consists of a single item: "doing the preceding problem, I invested...". Responses vary from very, very low mental effort (1) to very, very high mental effort (9). Studies have shown that this measure is an indicator of participants' cognitive load and is sensitive enough to detect small variations in task complexity (Paas, 1992).

Post-Test: The post-test included three items. The first was identical to the item on the pre-test and was analyzed similarly. This item measures the application of the taught knowledge to design a new experiment. Two additional items measured transferability. In one item, students were asked to debug and correct a flawed experimental design (see figure 3a). In the other item, students were asked to design an experiment to a given research question with two independent variables (see figure 3b).

Figure 3: Post-test: *Transfer Items.* (a) debugging and (b) multiple variables

Figure ***3a.***	**Figure** ***3b***.
Jana, a seventh-grade student, claimed that the water we drink contains a lot of microorganisms, and in order to keep the water pure and free of microorganisms, we have to boil it. Her friend Marah wanted to test this claim. Marah brought a glass of water, poured it into a pot, and heated the pot until the water started to boil. She then examined the presence of microorganisms and found none. Her conclusion was that the boiling process killed the microorganism. **The described experiment cannot answer the research question accurately. Specify the error in it and improve the experimental design accordingly.**	Students were discussing the best way to arrive at school in the morning. Several students live in an area close to the school (up to 1 km), others live in the center (1-3 km away from school), and the rest live in an area far from school (over 3 km). Students can walk to school, come by car, or come by bicycle. **Design an experiment that will allow you to determine the best way to get to school.**

Data Analysis

All items were analyzed using a multidimensional rubric that mapped onto the taught features. For each feature, students received a grade of 0 if they neglected to mention it or 1 if they used it correctly. For example, the following answer: *"to have two people, one with diet, one without diet, to check their weight before and after the experiment "*, received 0 for the feature "number of individuals", and 1 for the features "measuring dependent variable" and "control group". The pre-test and application questions included 5 features that were analyzed. The transfer items had 9 features combined. Scores were scaled to 100% on each scale for convenience. 20% of the items were analyzed by the first author and another researcher from the research team. For each of the features, the interrater agreement was greater than 87%, showing a high degree of convergence.

Each student was assigned four values: (i) pre-test score, which was used as a covariate; (ii) post-test application score; (iii) post-test transfer score; and (iv) cognitive load rating, which was the average of the two cognitive load measures (during both sets).

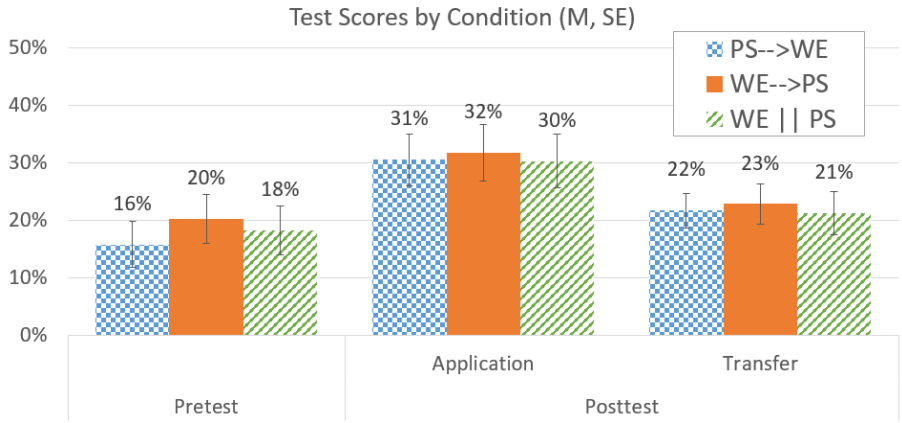
Results

An ANOVA showed no difference between conditions on pre-test: $F(2,110) = .291$, $p = 0.75$. A paired t-test showed a significant improvement from pre- to post-test (application score): from 0.181 ± 0.256 to 0.309 ± 0.289; $t(112) = 4.837$, $p < 0.001$, Cohen's $d = 55$, which correspondences to a medium effect size.

RQ1: Effect on learning.

A 3 (conditions) × 2 (measures) between-subject MANCOVA was performed on two dependent variables: application and transfer scores, controlling for pre-test scores. The Independent variable was condition (WE→PS, PS→WE, WE || PS). There was no significant main effect for condition: Wilk's $\Lambda = .994$, $F(4, 212) = .15$, $p = .963$, partial $\eta 2 = .003$. There was also no significant condition * pre-test interaction (Wilk's $\Lambda = .988$, $F(4, 212) = .315$, $p = .870$, partial $\eta 2 = .006$. Pre-test had a significant main effect on scores: Wilk's $\Lambda = .743$, $F(2, 106) = 18.371$, $p < .01$, partial $\eta 2 = .257$ (see Figure4).

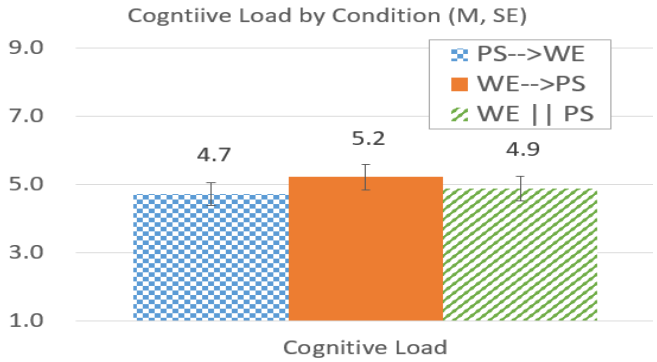
Figure 4: *Pre and Post (application and transfer) scores by condition (M and SE).*



RQ2: Effect on cognitive load.

19 participants had missing values on at least one of the cognitive load measures. That leaves us with 94 participants for this measure. A one-way ANCOVA, controlling for pre-test, found no significant effect for condition: F (2,93) =1.776, P=0.175 (see Figure 5). There was also no significant condition * pre-test interaction: F (2,93) =0.378, P=0.686. Pre-test was a significant predictor of cognitive load: F (1, 93) =4.334, P=0.04

Figure 5: *cognitive load scores in each of the conditions.*



Discussion

The present study investigated the effect of different sequences of examples and problems (i.e., WE→PS, PS→WE, and WE || PS) on learning (as assessed using application and transfer items) and on cognitive load among novices learning experimental design. Results showed no effect for condition on learning nor on cognitive load, and there was no significant interaction between condition and prior knowledge. The question, therefore, is: why was there no observed effect on learning or on cognitive load?

One possible explanation is that the study materials or procedure did not support learning. Furthermore, the post-test was delivered a week following the study, and the short manipulation might not have been sufficient for the effect to carry forward. Alas, analysis found a significant increase from pre-test to post-test, one that corresponds to a medium effect size, regardless of condition. This suggests that the learning materials helped students learn this set of skills without any additional intervention by the teacher or the research team. This also shows that the measurements used in this study were sensitive enough to identify this improvement. Thus, while assessment timing may play a role, we look for a fuller explanation.

A second explanation may be that indeed there is no effect of the sequence of WE and PS on learning each of the studied conditions supports learning by triggering a different cognitive mechanism, thus having its own benefits: scaffolding students, offering opportunities for exploration, or supporting analogical transfer. It may

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be that for this scenario, all approaches are similarly effective. This result echoes earlier findings (Van Harsel et al., 2020; Chen et al., 2021). This is not to say that order never matters, as also suggested by previous results (e.g., Van Gog et al., 2011; Reisslein et al., 2006). Perhaps there are other factors that moderate the effect of the sequence of WE and PS, such as motivation, domain, attitudes, etc. One of these factors may be type of knowledge. Studies that have examined the impact of the order of PS and WE mainly focused on procedural rather than conceptual knowledge. In this study, we investigated the skill of experimental design which is much more conceptual. A study of Chen and colleagues (2021) investigated the effect of types of knowledge comparing different order of WE and PS (WE→PS, PS→WE). Interestingly, also they found that there were no significant differences between WE→PS and PS→WE for learning simple and complex conceptual knowledge. Thus, the interaction of various factors on example-based learning needs to be further studied.

A third explanation has to do with factors specific to this study. One of these is timing. The study ran in June (the last month of the semester), and many students chose not to engage with the study materials. While students who completed the study devoted enough attention to learning the basics, they might not have truly challenged themselves. One indication that this may be the case is the fact that students were far from mastering the skills even on the post-test. This also explains the lack of effect on the measures of Cognitive Load. Self-reported cognitive load was similar across conditions not because instruction had no effect but rather because students regulated (and limited) their effort. Future studies should explore the role that factors such as motivation, interest, and attention play in example-based learning. While certainly not ideal, this aspect highlights the ecological challenges of everyday teaching.

The study has several limitations. One is timing, with post-test being delivered during the final week of classes. Engaging in learning activities during this period is uncommon, which probably affected students' motivation. Another limitation is that this was a single-topic study, and the topic was a challenging one.

Conclusion

A study of different sequences of examples and problems found no effect for order. In this, it adds to the divergent results that similar studies have found over the past few years. Taken together, these results suggest that additional factors that mediate learning from examples and problems should be investigated and studied. It may be that topical factors (such as type of knowledge and complexity), contextual factors (such as timing), and cultural factors (such as school norms and culture, as this was the first WE study in Arabic) affect example-based learning in ways that remain to be explained.

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The Role of Epistemic Emotions During Engagement with Online Information Encounters

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Abstract: This exploratory case study aimed to understand to what extent epistemic emotions are connected to effortful engagement when young adults were incidentally exposed to textual information snippets on a simulated social media timeline. Using discourse analysis, we draw on think-aloud data from fifteen young adults, to identify participants' emotional reactions to different textual snippets and to examine when these might prompt effortful engagement, as indicated by reliance on epistemic beliefs, source evaluation, evidence evaluation or science literacy. Our findings provide two important insights. We found that during online information encounters, frustration, curiosity and confusion were co-occurring with effortful engagement and were triggered, in particular, by posts that included negative words. We also found that epistemic engagement occurred even when boredom was verbalized first and was followed by frustration or confusion. We discuss the implications of this work for informal and formal learning environments.

Introduction

The COVID-19 pandemic, and the viral spread of misinformation through social media outlets, highlighted the importance of citizens' critical consumption of information in online social networking spaces, such as Twitter or Facebook. Amidst an information-saturated environment, snippets of information are constantly vying for people's attention on social media. Given growing concerns about people's ability to critically reason with information when the boundaries of accurate and inaccurate information are not always clear, evaluating information online has emerged as a pressing education challenge, which necessitates new approaches that facilitate learning (Chinn et al., 2020), especially for those outside formal education (Lee, 2018).

Our work is motivated by the belief that the learning sciences should increase efforts to understand social media as contexts where learning can potentially happen and investigate how the experiences in such spaces can be scaffolded to afford more opportunities for learning. These inquiries can also help us examine how we can prepare youth in formal educational settings so that they can develop skills to navigate the plethora of information confronting them in everyday social media use outside of formal educational settings. Recent efforts to conceptualize how informal learning happens during incidental exposure to information online (Greene et al. 2020), situate learning in people's routine online *information encounters*, a term we use to refer to the information that individuals are incidentally exposed to while navigating online spaces.

The data we report on are part of a larger study seeking to understand what influences epistemic engagement with misinformation on social media. During online information encounters, people's knowledge, skills and cognitive biases may limit one's ability to evaluate information using appropriate criteria or processes (Barzilai & Chinn, 2020). However, so can emotions (Martel et al., 2020). In prior work with a representative sample of 177 adults, we found that epistemic beliefs were statistically significant when examining sharing patterns on Twitter: participants who held more salient epistemic beliefs about science were less prone to share misinformation. We continue this work by reporting on efforts to understand the role of epistemic emotions during incidental encounters with online information on social media. In this context, we ask if epistemic emotions are manifested during such encounters, and whether they are connected to epistemic engagement.

Theoretical framework

Online information encounters, emotions and learning

Our work draws from research on informal learning on social media and the role of emotions in cognitive engagement. We next present the main arguments from the literature that informs our work. First, we seek to expand our conceptualization of learning to include learning from incidental exposure to information on social media. Even though social media platforms used for everyday communication were not structured with learning

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in mind, it has been argued that they hold potential for informal learning (Greene et al., 2020; Greenhow et al., 2019; Tabak & Dubovi, 2021). According to Greene et al. (2020), merely coming across and noticing information online does not necessarily predicate engagement. Instead, they posit that noticing can result in automatic processing, which is unconscious, or deliberate information processing, which is effortful. Effortful activity directed at achieving epistemic aims, either individually or with others, can constitute engagement with information when it is supported by cognitive and motivational processes (Hendricks et al., 2020). This is in line with dual process models of cognition (Evans, 2008) though the place that emotion holds in this configuration is less clear (da Sousa, 2009). Second, we know that emotions play a role in whether individuals choose to process information more effortfully, with the literature supporting that reaching an impasse during information encounters is more likely to result in less engagement (D'Mello & Graesser, 2012), which could potentially lead to endorsing information that is inaccurate. Finally, a growing body of empirical research suggests that epistemic emotions, whose focus is the generation of knowledge (Pekrun & Stephens, 2012), can encourage effortful engagement with information (Vogl et al., 2020). However, less is known about the epistemic emotions that emerge during information processing, which have a knowledge-generating focus (Pekrun & Stephens, 2012), and their connection to learning during information encounters on social media.

Epistemic engagement with online information

Hendriks et al. (2020) posit that ***epistemic beliefs***, ***source evaluation***, ***evidence evaluation,*** and ***scientific literacy*** can support effortful engagement with information. Building on the work of Chinn et al. (2014) effortful engagement with online information is grounded in epistemic practices. During online information encounters, individuals effortfully engage with information when they set epistemic aims, such as seeking knowledge; rely on epistemic criteria to evaluate the information at hand; and when they rely on processes and strategies that ensure their epistemic aims are achieved. To this end, ***epistemic beliefs*** can instigate effortful engagement which can lead to the achievement of epistemic aims (Barzilai & Zohar, 2016).

Epistemic engagement can also take the form of ***source evaluation*** when individuals assess the epistemic authority of the person behind the information. The use of scientific language may suggest expertise in a scientific topic (Thon & Jucks, 2017), but evaluating the underlying motives for posting a piece of information – whether to persuade or inform, or when the information is two- versus one-sided – also factors into how a source is evaluated. Evaluating information that comes into conflict with one's prior beliefs about a topic can also encourage more effortful engagement with information (Bråten et al., 2016).

Examining how and if knowledge claims are justified (***evidence evaluation***) can lead to achieving one's epistemic aims. Sinatra and Lombardi (2020) suggest that effortful engagement can stem from plausibility reappraisals, whereby individuals evaluate the connections between evidence and alternative explanations. The amount of evidence that is provided in support of a scientific claim also matters (Corner & Hahn, 2009), as does the type of evidence (Hornikx, 2008). When it comes to evidence, effortful engagement is also aided by ***scientific literacy*** and an awareness of the tentative nature of scientific knowledge claims. Public understanding of science may be bounded, and effortful engagement may be hindered by challenges in reasoning about processes in knowledge and knowing, as well as cognitive biases and misconceptions (Sinatra et al., 2014). During effortful engagement individuals consider how scientific endeavor produces reliable knowledge through epistemic processes (Duncan et al., 2018). By being mindful of the epistemic quality of the information they are incidentally exposed to, individuals' effortful engagement is intentional, guided by the goal to arrive at epistemic ends.

Epistemic emotions and effortful engagement

How individuals experience epistemic emotions is also influenced by one's epistemic cognition (Chevrier et al., 2019). Seven epistemic emotions (***surprise, curiosity, confusion, enjoyment, anxiety, frustration and boredom***) have garnered the most empirical and theoretical attention (Muis et al., 2018). ***Surprise*** arises when information is appraised as novel and involves an incongruity between what one already expects or believes (Meyer et al., 1997); it can often precede confusion when the information encountered is assessed as incomprehensible. The level of surprise may also play a role in what epistemic emotions individuals experience during information appraisals. When the level of surprise is high, individuals are likely to experience curiosity or confusion, depending on the complexity of the information or task at hand. When new information cannot be integrated into existing mental schemata, an impasse is reached, and individuals may also experience ***confusion***, which can trigger ***frustration***, and eventually ***boredom***, which leads to disengagement, if the impasse is not overcome through a thoughtful and reflective process. Overcoming the impasse through cognitive engagement can result in ***enjoyment*** (D'Mello & Graesser, 2012). On the other hand, ***epistemic anxiety*** can lead to more engagement since it alerts to important weaknesses in one's epistemic position (Hookway, 2011); the higher the stakes for not knowing, the greater the epistemic anxiety. Such occasions lead to greater engagement in order to gather more

evidence (Nagel, 2010). Similar engagement can result when experiencing ***curiosity***, which emerges when one becomes aware of a gap between what they know and what they do not (Loewenstein, 1994) and this can influence whether individuals engage with information in a deliberate and intentional manner. However, experiencing curiosity alone may not be enough to ensure that more effortful engagement occurs. Muis et al. (2018) found that curiosity positively predicted a more reflective stance towards information, but the type of textual information (expository or refutational) played a role in this. Prior work by D'Mello and Graesser (2012) has examined the interplay between emotions and engagement — which the authors conceptualized as being in a state of concentrated flow — during complex learning, but what happens during incidental online encounters, where individuals may often be predisposed to approach information with goals other than learning, is less clear.

Methods

Participants and Procedure

Participants were recruited through an open call posted in a Facebook group with 123 members. Fifteen respondents (12 females), ages 20-28 years old, opted to participate in the study. All participants reported using at least two, and as many as seven, social media platforms in their daily routines.

We chose to focus on health as a topic, and specifically on COVID-19. Think-alouds were used to capture participants' reactions as they viewed social media posts using a simulated Twitter timeline. Due to COVID-19, all interview sessions took place online using a video conferencing software. As this study was part of a larger effort examining socio-technical approaches to mitigating online misinformation, all participants viewed the same set of stimuli, which consisted of two baseline posts, without credibility labels, and then six other social media posts that included credibility labels. Posts were a mix of accurate or misinformative posts; four accurate posts were retrieved from news organizations such as The New York Times, and official health organizations such as the World Health Organization and the US Center For Disease Control, while four misinformative posts were retrieved from the International Fact Checking Network (IFCN) Coronavirus Alliance database.

Each participant was asked to share their screen and to externalize their thoughts as they were deciding on whether to take an action (i.e., "like" a social media post). The interviewer first shared the link to the two baseline posts and asked participants to externalize their thoughts. The aim of this task was to familiarize participants with the think-aloud method, but also provide a baseline for comparison for emotions experienced when viewing information with credibility labels. Participants were then presented with the simulated COVID-19-related social media posts on Twitter and were asked to explain whether they would "like" any of the posts. To avoid priming the participants' information evaluation processes, they were not informed of the presence of the credibility labels during the think-aloud. The average duration of each think-aloud session was 14 minutes.

Data Coding and Analysis

All sessions were recorded and transcribed verbatim; they were coded in NVivo, using a coding scheme for epistemic emotions by Chevrier et al. (2019) capturing the seven epistemic emotions that have received the most attention in the literature (Table 1). Data coding occurred in iterative cycles; part of the data were coded by two researchers, then discussed to resolve discrepancies, and the process was repeated. We coded emotion only when it concerned information relating to the social media posts. To answer our research questions, we also analyzed the data using a second coding scheme to capture epistemic engagement by Hendriks et al. (2020): *epistemic beliefs*, *source evaluation*, *evaluation of evidence* and *scientific literacy*. To identify the emotions connected with most epistemic engagement, we examined the coding intersections between the verbalized epistemic emotions and the epistemic engagement episodes, and how these varied across each of the eight social media posts.

Table 1
Coding Scheme For Epistemic Emotions

Epistemic emotion	Description	Example
Surprise	Astonished, amazed	[reads post aloud] '*Experts warn that protective face masks can reduce oxygen flow to the blood by 20%.' What?*" P9
Enjoyment	Excited, enthusiastic	*"OK, it's pretty great, I mean… any person that gets a Nobel, I mean. I see an emphasis on the fact that it's women, which tells me that it's not common for a woman to get a Nobel prize in Chemistry. And it makes it even greater." P3*
Curiosity	Interested, intrigued	"*But I'm also, like, just wondering…where. What is this COVID-alert? Like, who is this account? Like, is it a health*

		organization? Is it just someone compiling loads of information and putting it out there as a sort of COVID account?" P1
Confusion	Puzzled, muddled	"*[reads post aloud] 'Belgian study proves hydroxychloroquine is effective against COVID-19. Specifically, it can help prevent breathing problems.' Yeah, I mean, I don't even… hydro-chro-loro-qui… I don't know what that is.*" P9
Frustration	Irritated, dissatisfied	"*So it makes me feel like someone who wrote it is a bit unreliable and doesn't actually have a clear thing… or a clear understanding of what they are trying to say. And I'm not sure what kind of point… what is the goal of this tweet?*" P11
Anxiety	Worried, nervous	*"I wouldn't like it because then I would also spread panic, without knowing if this statement is true or false, if it can help. Not panic… but to spread this misinformation that, you know, take this thing [hydroxychloroquine] to get better, which might be false, might be true." P13*
Boredom	Dull, monotonous	"*To be honest, if this was on my feed, I probably wouldn't read it. But… I'd probably, like, click on the Covid Alert and click unfollow.*" P19

Findings

This study investigated the extent to which epistemic emotions manifested during incidental information encounters and if these were connected to epistemic engagement. To do this we coded for epistemic emotions and epistemic engagement. All participants expressed epistemic emotions, but these varied across different posts and participants. This suggests that the topic and individual characteristics matter when experiencing epistemic emotions during information encounters. Boredom was the emotion that was most frequently experienced, which is perhaps not surprising considering that the simulated timeline was not customized or curated to match each participant's interests and motivations. However, our findings suggest that even when boredom was the first emotion verbalized during a post, this did not always lead to disengagement. Participants who transitioned to other emotions following boredom, were able to effortfully engage in assessing information reliability. Frustration, confusion and curiosity also emerged as emotions experienced frequently, as did enjoyment. Epistemic anxiety and surprise were not experienced as much. Table 2 provides the frequencies for verbalized epistemic emotions.

Table 2

Frequencies Of Verbalized Epistemic Emotions

	Boredom	Frustration	Confusion	Curiosity	Enjoyment	Anxiety	Surprise	Total
#	40	32	30	29	28	9	4	172

Participants effortfully engaged with information in combination with emotions such as frustration, curiosity, and confusion. Epistemic engagement mostly manifested as source and evidence evaluation. Participants questioned references to abstract sources (e.g., "US scientists"), expressed the desire to check the source, or questioned the lack of URLs to support the claims made in the tweets. These suggest that even though participants could only verbalize their intentions, their engagement was motivated by epistemic aims which could lead to learning. They sought to achieve these aims through follow-up actions, or by maintaining a critical stance towards the information they encountered.

Additionally, participants epistemically engaged with some social media posts more than others. Participants engaged more effortfully with the two media posts which included negative words such as "dangerous", "worse", "death", "kills", and verbalized emotions such as frustration, confusion, and curiosity during these information encounters. Most notable, however, was the post that received the highest count for verbalized boredom, which also received the most effortful engagement; we found that when boredom was experienced first and then other emotions occurred, it led to epistemic engagement. We next present the two main themes connecting the most frequently reported emotions with epistemic engagement.

Theme 1: Frustration, curiosity and confusion were connected to epistemic engagement

Our examination of the coding intersections between the participants' verbalized epistemic emotions and epistemic engagement revealed that frustration was connected with most epistemic engagement episodes (30

coded episodes), followed by curiosity (27 coded episodes), and confusion (15 coded episodes). Frustration was sometimes predicated by confusion. However, frustration frequently served as a catalyst for participants to more consciously engage with the information epistemically, by calling into question the source of information or the evidence used to support the information claims in a post. For instance, in the excerpt below, P11 first experiences confusion, and then frustration, and it is during this emotional response that P11 pays closer attention to the epistemic qualities of the information at hand:

(Confusion) I wouldn't like this tweet because I'm reading it and I don't really understand part of it, because it says that it's only very marginally worse, so the word only and very marginally – only and very contradict each other.

(Frustration) So it makes me feel like someone who wrote it is a bit unreliable and doesn't actually have a clear thing… or a clear understanding of what they are trying to say [**source evaluation]**. And I'm not sure what kind of point… what is the goal of this tweet? [**source evaluation]**.

(Confusion) Because I'm not … I can't understand if it's trying to get me more relaxed or if it's actually trying to make me more alarmed because the combination of "only very marginally" is confusing.

In the above excerpt, the participant more closely evaluates the source and questions the author's intent. The participant is responding to a post comparing the COVID-19 death rate to that of the flu, and which included negative words such "death", "kills", "worse". The emotional reactions to this post suggest that the inclusion of such words may have triggered emotions such as frustration among participants, as they were trying to make sense of the information at hand. Participants responded similarly to a post characterizing the COVID-19 vaccine as "dangerous"; the use of this negative word, possibly in conjunction with the controversial nature of the topic, prompted frustration alone, or frustration experienced with emotions such as curiosity and confusion. In both contexts, participants questioned the evidence in support of the claim. For instance, the excerpt below illustrates how frustration led to paying closer attention to the epistemic aspects of the information encountered.

(Frustration) "It says about a big scientific study, but of course again it doesn't have some… it doesn't have some link, like, 'go here to see this study'. It's just a few words, just like I can write this tweet, with no knowledge **[evidence evaluation]**. Because it says here it's uncertain [reads the credibility label], it's not a very credible Twitter account. Again, personally I wouldn't spread this statement. Even if it's right or wrong. Not right or wrong, but if it's true. I wouldn't like, I wouldn't retweet or share, or even say it myself **[epistemic beliefs]**. And I'm one of those people who mostly think scientifically, not in conspiracies, and I would like more… the evidence of this study to believe it **[evidence evaluation]**." [P13]

In other instances, the use of the word "dangerous" led participants to experience curiosity because they were aware that the topic was controversial or held potential for misinformation, as illustrated by P6:

(Curiosity) "For this one I might search for more information, because there are a lot of hoaxes about microchips, and that the COVID-19 vaccine is dangerous. So, I would search to find out more about why they are saying it's dangerous, and what is this study? Because it doesn't refer to it at all **[evidence evaluation]**."

However, the uncertainty surrounding the topic of vaccination, also played a role in how participants emotionally responded to this post. For instance, in the following excerpt, P5 verbalizes confusion about what to believe on the topic, and also expresses anxiety, albeit it, not epistemic anxiety, since it does not prompt increased engagement with the information, but a tendency to escape it:

(Confusion) "I don't know about this one 'cause I heard that most vaccines, even though it might help with this specific virus or flu, or whatever, it can have some side effects in the future. So, yeah. It's kind of dangerous but we don't know about that because it didn't… we don't know the future, so it is uncertain **[epistemic beliefs]**. Like, it makes my mind go weird like with all of this information, because it does increase anxiety. 'Cause it does conquer our lives, unfortunately. And having a lot of information about it is not nice."

Frustration, curiosity and confusion were also expressed sequentially for individual social media posts, and the transition between different emotions during the online information encounters suggests that far from blocking engagement, frustration may be conducive to prompting more epistemic engagement. The following excerpt by P12 exemplifies epistemic engagement and highlights how frustration may serve to sustain engagement longer while assessing the quality of information claims online.

(Confusion) "So, obviously the "Not Credible" has completely thrown me off **[source evaluation]**.

(Curiosity) 'The Ioannidis study'… the fact that there's a specific study makes me question… I would, obviously, again, go research this study. I want to see more towards what they actually… what variables they used to convey the study **[scientific literacy]**. I also believe that this is just a very generic statement. The fact that "it's only marginally worse than the standard flu", although I… a part of me initially agreed with this statement, I feel it's also very limited. I feel there's no proof towards this… there's not credibility to this, within this statement.

(Frustration) […] I feel like this is a statement that is said… It's my thought process is that this feels like this is a very unprofessional statement. The way it's also written, I don't know why **[source evaluation]**. I don't know if there is hardly any…[pauses] I don't know! I can't think about this.

(Confusion) I just feel like I wouldn't like this statement. I feel like I'd validate… I definitely, again, this "not credible" source is throwing me off **[source evaluation]**. Definitely the fact that there is no… I feel also, when it comes to any statement that has statistics, I believe it more. Even though the first one, with the 20%...I don't, because I feel like that's too much of a perfect number **[evidence evaluation]**.

(Frustration) But it's also this "it's only very marginally worse than the standard flu virus that kills hundreds of sick and elderly every year." It seems very unprofessionally written as well. I don't know why **[source evaluation]**."

Theme 2: Experiencing boredom first does not always preclude epistemic engagement

The post which received the highest count for verbalized boredom was also the one that received the most effortful engagement, as suggested by the source and evidence evaluation statements. When participants verbalized boredom first, and then transitioned from this state of disengagement to verbalize other emotions, epistemic engagement occurred. This was observed during the participants' verbalizations relating to a social media post on research in relation to COVID-19 decontamination using UV light. When participants experienced only boredom, no epistemic engagement was observed. When boredom was followed by other emotions, such as confusion or frustration, participants engaged with the information epistemically. In the excerpt below by P5, the initial emotional response of boredom suggests disengagement, yet P5 is able to transition from boredom to epistemically engage with the information:

(Boredom) "For me, it's irrelevant to me, even though, like, Coronavirus is kind of, like, dictating our lives in a way. There's too much information on the topic so I don't know if I would want to follow it, just because I know cookies exist and more information about the virus would bombard me, so I think…

(Confusion) it's good information, but I wouldn't like it. Cause I don't know what to believe nowadays, like. 'Cause there's so much information going on about it, that I don't know if it's true or not. And I don't know the username. […] And there's no picture in the username, so I don't know if it's a valid point or not, to believe **[source evaluation]**. So yeah, that's it.

(Frustration) And also, Coronavirus is not in capital letter, so it's a bit unprofessional in my opinion **[source evaluation]."**

Another participant (P4) clearly expresses boredom based on the way the information is presented. However, this initial reaction does not prevent epistemic engagement, and in fact the transition from boredom to emotions that enable the participant to interrogate the information quality of the post is illustrated in the following example:

(Boredom) "I don't think I would click it because it's not attracting me to be like, 'Oh yes, like, I like this'. It's something positive, obviously, because it's concerning the pandemic, but it's not something, I guess. It's not worth, I guess, clicking the screen. It's, I guess, good news, yay!

Research! But that's it. It's not really saying who really made the breakthrough or something, it's just saying the statement about the research **[source evaluation]**. Yeah, I don't think I would click like. It's not saying anything else. It doesn't make me want to click the page.

(Curiosity) Actually, I would click the page to find something more available about this statement, but I think it's a bit plain what the research is about. Like, "US scientists" – is it the university, is it private lab? If it is… **[evidence evaluation]**

(Frustration) It's 'Latest News', OK. It doesn't sound like a scientific page because if it was a scientific page, a science-related page, I would assume it would mention more details about the research, but maybe it would be nice if they tagged maybe the page of the scientists that made the breakthrough **[source evaluation]**."

Discussion

During online information encounters, the information individuals are incidentally exposed to can trigger emotions that can impact one's online actions; this has consequences in the context of misinformation. These encounters also hold serious implications for sustaining an engaged and informed citizenry online given that information that appears on social media is often emotionally appealing. In this exploratory study, we sought to gain further insights into the role of epistemic emotions when individuals assess the quality of information they encounter and whether these emotions are connected to effortful engagement with information. Our findings suggest that during online information encounters, frustration, confusion, and curiosity are connected to epistemic engagement. This connection was particularly observed for social media posts that used negative language and for controversial issues. In such posts, participants paid closer attention to the source of information, or requested more evidence to support the claims raised in the post, and sometimes verbalized intentions to take additional actions such as searching for information or checking the source. Our study design prevented participants from following up, which is a limitation; however, these verbalizations signify an intentionality towards achieving epistemic aims. Even when boredom was experienced first, epistemic engagement can occur if boredom transitions to confusion or curiosity. Further understanding the contexts in which experiencing boredom first in a sequence of emotions can preclude disengagement online merits further exploration.

We believe this exploratory study contributes to understanding how epistemic emotions may prompt epistemic engagement with information online. It also underlines the need for new instructional approaches in formal education that can promote epistemic engagement online by supporting students during their online information encounters in differentiating between evidence-based claims versus speculation. Additionally, epistemic engagement in this study mostly manifested through source and evidence evaluation, with fewer instances of epistemic beliefs and scientific literacy. How might instructional approaches to evaluating information quality online be reimagined to strengthen epistemic practices and scientific literacy? Information environments online are not usually designed for learning, and even constrain effortful engagement by design (Hendriks et al, 2020). In such spaces, how might scaffolds aid users outside formal education deepen their epistemic engagement? Understanding the role that emotions play during effortful engagement can also inform the design of authentic online environments that learners routinely navigate to access and retrieve information (Chinn et al., 2020). This may narrow the gap between formal and informal learning.

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Promoting Computational Thinking Through Science-Engineering Integration Using Computational Modeling

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Abstract: Careers in science, technology, engineering, and mathematics (STEM) increasingly rely on computational thinking (CT) to explore scientific processes and apply scientific knowledge to the solution of real-world problems. Integrating CT with science and engineering also helps broaden participation in computing for students who otherwise would not have access to CT learning. Using a set of emergent design guidelines for scaffolding integrated STEM and CT curricular experiences, we designed the Water Runoff Challenge (WRC) - a three-week unit that integrates Earth science, engineering, and CT. We implemented the WRC with 99 sixth grade students and analyzed students' learning artifacts and pre/post assessments to characterize students' learning process in the WRC. We use a vignette to illustrate how anchoring CT tasks to STEM contexts supported CT learning for a student with low prior CT proficiency.

Introduction

Preparing pre-college students for careers in science, technology, engineering, and mathematics (STEM) requires them to engage in authentic STEM practices. These practices increasingly rely on computational thinking (CT) to explore scientific processes and apply scientific knowledge to design solutions for real-world problems (Freeman et al., 2014). The emergence of computation as the third pillar (alongside theory and experiment) of science and engineering and the inclusion of CT in the U.S. *Framework for K-12 Science Education* require that primary and secondary schools incorporate CT into existing STEM curricula (National Research Council [NRC], 2012). Integrating CT with required STEM subjects also helps broaden participation in computing for students who otherwise would not have access to CT learning.

A computational model (CM) is a mathematical representation of a system created using a formal notation (e.g., a programming language) so that the system behavior can be studied using computer simulations (Melnik, 2015). The collective practices of developing, testing, refining, and using CMs (National Research Council, 2012)—can be the central link between students' scientific understanding of a system and engineering a problem solution related to the system, especially for systems that cannot be easily investigated using physical materials. This approach merges the benefits of developing computational artifacts with simulation-based learning and problem solving.

This paper examines how CT can be promoted through science-engineering integration using computational modeling, particularly for younger students with no or limited prior exposure to computing. Recent research on how students develop CMs of science phenomena has mostly focused on integration of CT with either science (e.g., Waterman et al., 2020) or engineering (e.g., Magana & de Jong, 2018) but not both. Introducing CMs for elementary school students presents challenges such as students' limited mathematics proficiency, class time needed to develop programming/modeling skills, and the training needed for elementary teachers who are typically generalists and may not have deep CT, engineering, and/or science expertise. We describe curriculum design guidelines that can promote integration of CT with science and engineering via computational modeling and report on the implementation of an integrated STEM+CT unit designed for fifth and sixth grade students.

Theoretical and Empirical Perspectives

Synergistic learning of STEM and computing

Past research on synergistic STEM and computing learning (e.g., Hutchins et al., 2020; Sengupta et al., 2013; Waterman et al., 2020) has shown that computational modeling can deepen students' science learning. Complex scientific systems become easier to understand when the system structure and behaviors are explained computationally. CMs provide explicit mechanisms for constructing and visualizing scientific phenomena and reasoning about scientific processes as a sequence of step-by-step changes as opposed to creating aggregated mathematical models (Hutchins et al., 2020). Learning to program CMs involves learning how to formally

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articulate mechanisms and explanations, a core scientific practice. In turn, programming also becomes easier to learn when anchored in real-world problem contexts (Sengupta et al., 2013). Alongside documenting the benefits of computational modeling, research has also identified that students may have significant difficulties with developing scientific CMs. Students may struggle with both understanding the science concepts underlying CMs and representing system variable relationships using computational expressions (Sengupta et al., 2013). Students may also have trouble generalizing or abstracting the scientific processes into variables and expressions (Basu et al., 2016). These findings indicate a need to scaffold students' computational modeling experience as they grapple with the multi-fold complexities of scientific knowledge, modeling practices, and computational representations.

Framework for integrating science, engineering, and CT

Relatively little research has examined how CMs can enable the developing or testing of engineering solutions related to science phenomena. We integrate science, engineering and CT via computational modeling by leveraging a design framework (McElhaney et al., 2020) that involves (1) defining an engineering design challenge whose solution is governed by an underlying science phenomenon, (2) supporting students to develop a CM of the science phenomenon, and (3) supporting students to use their CMs to design, test, and refine solutions to the engineering challenge. The framework integrates research on designing computational environments that enable students to model science phenomena (e.g., Hutchins et al., 2020; Sengupta et al., 2013), and research investigating how students use simulations to engage in problem-solving (e.g., Magana & de Jong, 2018; Weintrop et al., 2016). To implement this framework, we leveraged the following design perspectives to integrate science, engineering, and CT. These perspectives guide the design of the Water Runoff Challenge (WRC), the integrated STEM+CT unit used for this study (described in further detail in the Methods section).

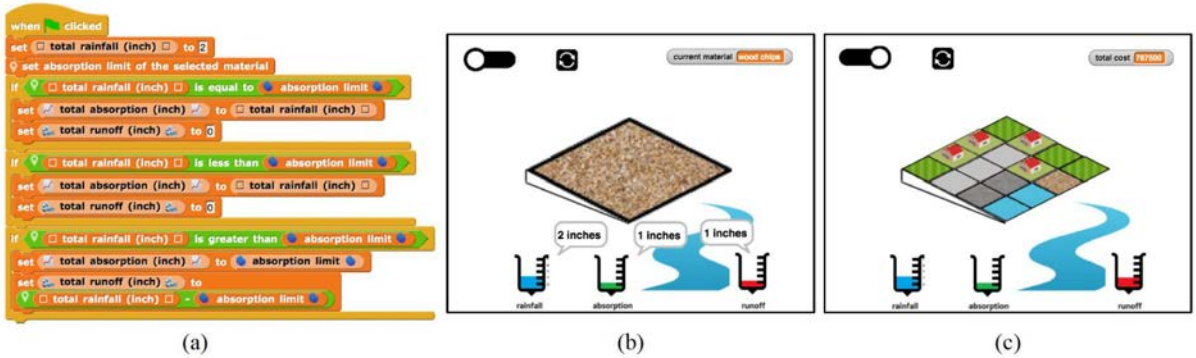
- **Create an explicit need for computational modeling.** To achieve authenticity in the design of a STEM+CT curriculum unit, the overarching design challenges should make the use of computational tools consequential. Students should be able to recognize the unique affordances of CMs for solving STEM problems, making scientific predictions, and designing engineering solutions (Weintrop et al., 2016). This design guideline also promotes the CS practice of Recognizing and Defining Computational Problems.
- **Maintain coherence across system representations.** In a STEM+CT unit, students must interact with and/or generate multiple system representations (e.g., pictorial, mathematical, narrative, and computational) of the science phenomenon being investigated. In order to work together to promote integrated learning, these representations need to be conceptually coherent (Ainsworth, 1999) and consistent with respect to the system variables and their relationships and the computational and scientific terminology employed.
- **Employ a Domain Specific Modeling Language (DSML).** DSMLs reduce the challenges that learners face when modeling scientific scenarios by adapting the level of system abstraction to conceptual levels appropriate for learners (Hutchins et al., 2020). Relative to using a general-purpose programming language to develop scientific models, students can focus on the relevant science concepts and system variables without having to attend to the program syntax. The use of DSMLs for computational modeling reduces the cognitive load associated with learning to program and shifts the focus toward science modeling.

Methods

Designing to promote CT learning in integrated STEM+CT instruction

In activities integrating science, CT and engineering, whether learning CT will promote or interfere with science and engineering learning depends on the learner's ability to manage the challenges of disciplinary integration. The ability to successfully leverage synergies between computing and STEM learning requires scaffolding, especially for younger students. We describe a set of six design guidelines to scaffold young students and improve their understanding of CT with specific examples from the WRC, a multi-week unit that integrates CT with Earth science and engineering for fifth and sixth grade students (Zhang et al., 2020). The WRC uses the design perspectives described above to engage students with the problem of a schoolyard that floods during periods of heavy rainfall. Students are challenged to resurface the schoolyard to minimize the water runoff while meeting design constraints on cost, accessibility for students with physical disabilities, and practical use. Based on the science principle of matter conservation, students create pictorial models explaining how a part of the rainfall is absorbed into the ground based on the surface material properties, while the rest remains on the surface and flows downhill (runoff), resulting in flooding of nearby areas. Students then use a block-based DSML to develop a corresponding CM (Figure 1a) for a unit surface area (one square). The DSML used in the WRC includes domain-specific constructs such as rainfall, water absorption, runoff, and surface material, as well as CT constructs that are needed in the runoff CM. This CM determines the amount of water runoff based on the amount of rainfall and the (predefined) absorption limit of the surface material. As students build the CM, they test it using different

values of rainfall and different surface materials (Figure 1b). After students develop a working CM, their model code is then incorporated into a simulation environment comprising 16 squares for the engineering design task (Figure 1c) where students need to configure a set of appropriate materials for resurfacing the schoolyard.



(a) (b) (c)

Figure 1. *(a) A Working Runoff CM (b) Single Square CM Testing (c) 16-Square Engineering Design*

Below, we synthesize the WRC unit design features into a set of emergent design guidelines encompassing three categories of support for promoting CT in integrated STEM+CT instruction. These design guidelines have emerged from iterative implementation of the WRC unit for fifth and sixth grade students and its refinement using insights from classroom studies (McElhaney et al., 2020; Zhang et al., 2020).

Preparing Students for CM Development

1. **Support conceptual modeling of science phenomena prior to CM development.** In order to successfully develop a CM, students first need a strong scientific and mathematical understanding of the system behavior, which they can then express using CT constructs in a computational modeling representation. Having students first develop a conceptual model of the science phenomenon helps learners establish a firm scientific understanding of system behavior and variable relationships before representing the system computationally using the same variable names and relationships. In the WRC unit, students engage in a series of conceptual modeling activities: (1) a hands-on activity to observe differences in absorption characteristics among surface materials; (2) a pictorial modeling activity (Figure 2a) where students illustrate relationships among rainfall, absorption, and runoff; and (3) articulation of mathematical rules that express water runoff in terms of rainfall and material absorption limits.
2. **Introduce CT concepts required for developing CMs using a familiar context**. In addition to science understanding, students must have adequate proficiency with CT concepts and practices and an understanding of the computational modeling language in order to develop a CM. To design broadly accessible computational modeling experiences for fifth and sixth grade students, one cannot assume that students have prior familiarity with programming or CT. Hence, activities should engage students in CT concepts and practices required for developing the target CM by first presenting them in a familiar (non-scientific) context and in an isomorphic way to the CM. For example, in the WRC unit, we developed unplugged activities that engage students in a series of dice games of increasing complexity before students develop the runoff CM. The dice games introduce students to the concepts of conditionals, variables and expressions by assigning players different scores based on their dice values (Figure 2b).

Supporting CM development

3. **Engage a limited and age-appropriate set of CT concepts and practices**. When engaging fifth and sixth grade students who have no assumed prior knowledge of CT in computational modeling of science phenomena, curriculum units need to limit students' engagement to a small set of CT concepts and practices that are needed to model the phenomenon in a compelling fashion and can be learned with a limited amount of classroom instruction. Because science and CT learning are so tightly integrated in such units, limiting the target CT concepts may also require simplification of the science concepts and system representation by limiting the number of system components and abstracting their relations. In the WRC unit, we target the CT concepts of sequences, variables, expressions, and conditionals (Figure 1a) and the practices of developing, testing, and debugging computational artifacts, as well as using computational artifacts for problem-solving. We arrived at this target CM after several previous implementation iterations that involved several temporal and rate-based variables and the CT concept of repeated conditionals. Although scientific CMs are typically temporal in nature, the temporal runoff CM turned out to be too complex for typical fifth and sixth grade

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students. Hence, we omitted the CT concept of iteration from the current version of the CM to make it mathematically and computationally tractable for young students.

4. **Support model decomposition**. For fifth and sixth grade students using a programming environment for the first time, it can be helpful to decompose the CM development process into conceptually meaningful chunks. For example, in the WRC unit, because the system behavior is modeled according to three rules (rainfall less than, equal to, or greater than the surface absorption limit), we designed one classroom activity for students to program each rule. Each activity guides students through an incremental process of prediction, model development, testing, debugging, and reflection by adding the code for one rule at a time.

Supporting CM Evaluation

5. **Support CM testing and the selection of test cases.** Learners need support on CT practices such as systematically and thoroughly testing CMs and identifying appropriate test cases for CM evaluation. Our initial studies revealed that selecting appropriate test cases is not trivial for fifth and sixth grade students. In the WRC unit, students are prompted to use three test cases corresponding to the three conditional rules in the CM (Figure 2c) and to test their CMs with at least two different surface materials. Students model the CM in parts over three class periods and document outcomes with all three test cases each day.
6. **Include opportunities for students to engage with debugging**. Debugging CMs goes beyond merely identifying and fixing errors in code; it integrates CT and science by requiring learners to determine whether the CM correctly represents the underlying science model. Debugging CMs involves identifying and correcting computational errors as well as errors stemming from incorrect representations of the underlying science content. Embedding explicit debugging opportunities in STEM+C units can help shed light on causes of student challenges during CM development. In the WRC unit, we started some CM development lessons with a short debugging task. Tasks were based on code students had written the previous day and prompted reflection on previous coding activity. We also embedded debugging tasks as part of formative assessments (e.g., Figure 3) that students could complete in class or at home.

(a) (b) (c)

Figure 2. *(a) A pictorial conceptual modeling task, (b) A dice game CT task, (c) A test case selection task*

Classroom study using the WRC unit

We conducted a classroom study with 99 sixth grade students in the southeastern United States. Students completed the WRC unit over 15 class periods in the Fall of 2019, with identical pre-post tests administered before and after the intervention. Students worked for 45 min per day, three days per week during their regular science classes, and 75 min, twice a week, with additional personalized-learning time. Some students had prior programming experience with Scratch, while others had no previous programming experience. The participating teachers were highly experienced with teaching science and received four days of training before the study.

Data sources, scoring, and analysis

We examined four primary types of student data: pre-post assessment performance, final computational models, responses to activities in student workbooks, and responses to formative assessment tasks.

Students completed a paper-and-pencil **pre-post assessment** that was split into a science and engineering component and a CT component (McElhaney et al., 2019). Science/engineering tasks were aligned with several Next Generation Science Standards (NGSS) Performance Expectations in Earth science and engineering (NGSS Lead States, 2013). Of the five science/engineering tasks, three asked students to apply an engineering practice to the solution of a water runoff problem, one asked students to develop a model of water runoff in a context different from the WRC, and one asked students to apply an engineering practice to the solution of a problem unrelated to water runoff. For example, in one task, students compare two street designs based on criteria related to water runoff performance, usage, and cost. The science/engineering task rubrics measured the extent to which students could apply the focal science/engineering practice to the water runoff context and/or other engineering design criteria. The CT assessment tasks were aligned with the CT concepts and practices addressed in the runoff CM.

Students could score a maximum of 23 points on science and engineering and 13 points on CT. The rubrics used for coding and scoring the tasks were updated from our previous work. Two researchers received 5 hours of training on the rubrics, graded 5% of the test submissions (randomly selected) together to establish initial grading consistency, and then graded another 20% to establish inter-rater reliability (Cohen's κ at ≥ 0.8 level on all items). All differences in the coding were discussed and resolved before the remaining 75% of test submissions were graded by a single researcher.

Students' **final runoff CMs** were logged and scored using a rubric targeting conservation of matter rules and conditional statements for the different rules. The rubric rewarded four main criteria of the CMs: (1) assigned appropriate values to the total rainfall and absorption limit variables, (2) included code for three conditional statements that compared the total rainfall and absorption limit variables, (3) updated the absorption and runoff variables correctly for each of the three conditions, and (4) code is generalizable (e.g., assigned variables to expressions rather than to hardcoded numeric values).

Students completed a paper-and-pencil **workbook** over the course of the unit. We scored and analyzed student responses to specific workbook activities such as the conceptual modeling tasks, dice game activities, test case identification tasks, and a CM debugging task. A series of four student **conceptual models** and corresponding written explanations were scored based on their adherence to the conservation of matter principle and articulation of the causal relations governing the flow of rainwater. We also scored student performance on the **dice games** that introduced students to CT skills. Each of the four games were scored based on whether students could correctly evaluate conditional statements and interpret variable assignment statements. We report dice game scores only for students who documented outcomes from all four games ($n = 62$). We scored students' **choice of test cases** for testing the three rules in the runoff CM for a material of their choice based on whether the test cases address each of the model's three rainfall conditions. We scored a **debugging** task where the variable assignment for the absorption and runoff variables were flipped for a particular condition. Finally, we scored student responses to three select **formative assessment tasks** that assessed students' ability to predict the output of given CMs, identify errors, and fix buggy CMs.

We performed paired *t*-tests to measure students' pre-to-post learning on science, engineering, and CT. We also examined correlations among students' pre-post performance and performance on various CM development and evaluation activities to better understand students' learning process in the WRC unit.

Findings

Overall STEM and CT learning gains

Students' science/engineering scores improved significantly with a high effect size ($p < .0001$, $d = 0.81$) from an average of 13.3 (*SD*=2.8) points at pre-test to an average of 15.6 (*SD*=2.9) points at post-test. Students' CT scores also improved significantly with a high effect size ($p < .001$, $d = 0.83$) from an average of 6.2 (*SD*=2.6) points at pre-test to an average of 8.4 (*SD*=2.7) points at post-test. These pre-post changes reflect improvement in students' ability to develop scientific models, define engineering problems and design criteria, and engage with the CS concepts of variables, expressions, and conditionals. Below, we describe relations among students' pre-post changes and performance on curricular activities, and illustrate how students' science/engineering proficiency may be supporting students' CT learning using a vignette.

Student interactions with the computational modeling scaffolds in the WRC

Students demonstrated large variation in their CM construction behaviors, but about two-thirds of the students finally constructed a correct implementation of the runoff CM with instructional support. The average CM score was 13.6 (SD=2.5) out of 15. For students who were not able to construct a correct CM implementation, common challenges included omitting conditional statements (resulting in not covering all comparisons between the rainfall and absorption limit variables), not assigning values to both absorption and runoff variables in each of the conditions, and not assigning variables to correct values or assigning variables to hardcoded values. In particular, many students found it challenging to express the relation "set total runoff to (total rainfall − absorption limit)" when "total rainfall is greater than absorption limit."

These challenges with CM development align with challenges observed when students worked on the conceptual modeling and unplugged dice game activities prior to the runoff CM development. While both these activities prepare students with the science and CT understanding needed to create the runoff CM, both activity performances have small, non-significant correlations with students' CM scores, indicating that the relations may not be linear. Students scored an average of 27.0 (*SD*=4.5) points out of a possible 32 on the conceptual modeling tasks. Students were generally able to conceptually model the conservation principle and numerically predict the values of absorption and runoff given values of rainfall and absorption limit. However, many students struggled

to provide mechanistic explanations for their numeric predictions or articulate generalizable rules to express the system variable relationships. On the dice game activities, 36 students earned the maximum total score of 8 on all four dice games. Students scored an average of 7.2 points (*SD*=1.3). Students were least successful with the fourth dice game, which was designed to be the most difficult - it involved evaluating conditional statements comparing two variables and interpreting variable values assigned to other variables and expressions. Most of the challenges stemmed from interpreting the variable assignment statements correctly.

We observed wide variation in students' performance on the activities designed to scaffold CM evaluation (selecting test cases and debugging). As we expected, model evaluation practices, in particular debugging, were challenging for sixth grade students. Students scored an average of 3.5 (*SD*=2.2) out of 6 points on the test case selection activity and an average of 8.0 (*SD*=3.0) out of 22 points on the debugging activities. Students' debugging performance was significantly correlated with their conceptual modeling scores (ρ= .27, p< .01) and CM scores (ρ= .23, p < .05). This result highlights the nature of debugging CMs in STEM+CT units, which entails both determining the accuracy of the underlying science model and its computational representation. Some common debugging challenges included: (a) the "superbug" challenge (Pea, 1986) where students thought the computer has a mind of its own and will always generate the correct result, (b) identifying and correcting all errors when the CM comprised multiple bugs, (c) believing that variable values cannot be re-assigned once assigned to initial values, and (d) incorrectly switching operands of logical operators and assignment statements.

Relations among computational modeling and pre-post performance

We conducted a correlational analysis among the pretest and posttest scores for science/engineering and CT and students' performance on the learning artifacts described above (see Table 1 for correlation coefficients and significance values). The significant correlations between (i) conceptual modeling and post-science/engineering, (ii) unplugged dice games and post-CT, and (iii) computational modeling and post-CT are consistent with expectations based on the alignment with their respective disciplines. The significant correlation between test cases and post-CT scores reflects how test cases can engage CT constructs such as variables and expressions, conditional logic, and code comprehension in a science modeling context. The significant correlations between students' debugging performance and posttest scores in both science/engineering and CT further illustrates the extent to which debugging a CM is an integrated activity—debugging a CM entails evaluation of both the code itself as well as the underlying scientific system model.

Table 1. *Correlations among pre-scores, post-scores and curricular activity performance (** p < .01, * p <.05)*

	Pre - science & engineering	Pre - CT	Conceptual modeling	Unplugged dice games	Computational modeling	Selecting test cases	Debugging
Post - science & engineering	.390**	.064	.247*	.127	.061	.176	.251*
Post - CT	.432**	.609**	.125	.319*	.215*	.206*	.310*

Finally, we note that there was a higher correlation between pre-science/engineering scores and post CT scores than between pre- and post-science/engineering scores. This somewhat unexpected finding may reflect the extent to which students' science/engineering knowledge and skill could be "bootstrapping" CT learning by enabling students to leverage STEM concepts and practices toward the advancement of their CT proficiency. We illustrate examples of how the integrated performance tasks may be enabling students' science/engineering proficiency to support their CT learning in a vignette below.

Improved CT through science & engineering integration and CM scaffolds

We highlight the work of a particular student, Taylor (pseudonym), who illustrates how science/engineering proficiency may be supporting CT learning across the STEM+CT integrated computational modeling activities in the WRC unit. Taylor achieved a high pre-science/engineering score of 17.5 (93rd percentile) and maintained the same score on the posttest (67th percentile). They achieved a low pre-CT score of 4.5 (25th percentile) and improved to the maximum post-CT score of 13. The pretest scores suggest that at the beginning of the study, Taylor was a proficient science student with little previous exposure to programming.

Despite achieving a low pre-CT score, Taylor exhibited a particularly high level of performance on activities associated with post-CT performance. Taylor earned the maximum score of 8 points on the dice game activities, achieved by only about one third of the students in the study. Taylor also exhibited a strong conceptual

understanding of test cases, earning 5 out of a possible 6 points on the test case selection task and with the only error being arithmetic in nature (incorrectly transforming the number 0.09 to 0.9 prior to performing the test). Taylor's strongest performance was in the difficult debugging tasks, earning 14 points (the second highest among all students in the study). For instance, in response to the task shown in Figure 3(a), Taylor identified both instances where the system variables were incorrectly reversed, writing "In many occurrences (sic), Sumi needs to switch the Total Rainfall and Total Absorption twice on the second IF THEN statement." In response to the task in Figure 3(b), Taylor correctly predicted that the code in the nested 'if' block would not be executed for an absorption limit of 0.8 inches and correctly articulated that moving the nested 'if' block to the end of the program would debug the model. Taylor's responses to both the test case activities and debugging activities illustrate how designing CT tasks to be embedded in STEM contexts have the potential to help students leverage STEM understanding toward advancing their CT proficiency (including programming skill).

(a) (b)

Figure 3. Formative debugging task assessing (a) variable assignments and conditional expressions and (b) code sequencing and control flow in conditional structure

Discussion and Conclusion

This paper illustrates how CT learning can be promoted for upper-elementary school students through the coherent integration of science, engineering, and computational modeling. We describe activities such as conceptual modeling, unplugged dice games, test case identification, and CM debugging that support the integration of STEM and CT disciplines and discuss how students' engagement with them may be associated with learning in STEM and CT disciplines. These activities enable students having no prior programming experience to successfully develop CMs with minimal programming instruction and offer the potential for students to use their science and engineering knowledge to bootstrap their CT proficiency. Though students' pretest and posttest scores were strongly correlated, the design guidelines related to CM development and evaluation informed scaffolding for students' CT learning even when students started with low CT proficiency.

Our design for promoting CT for fifth and sixth grade students using computational modeling in an integrated science-engineering context also contributes to ongoing research on the nature and extent of CT integration and the feasibility and usefulness of programming and deep CT integration for upper-elementary students and teachers. Analyses of elementary teachers' plans for integrating CT in science lessons (Coenraad et al., 2022) reveal the use of computer simulations and data as some of the most common CT practices integrated while programming is one of the least common practices. When programming is used, it is often used to exhibit science knowledge gained through other means rather than further science learning. Overall, the integration is often limited to the bottom two levels of the CT integration framework (Coenraad et al., 2022) - *exist* (identify science practices that also count as CT) and *enhance* (use small CT activities to support science learning). This finding highlights the importance of presenting teachers with usable models of deeper CT integration that include a range of CT practices. The WRC demonstrates the feasibility of a science and engineering curriculum for fifth and sixth grade students involving numerous CT practices (computational simulations, programming, systems thinking, using data) and a deep level of CT integration where CT and science learning are mutually supportive.

Further, our findings add to a growing body of research examining the relationship between learning in CT and STEM disciplines (Lee at al., 2020). The framing of CT as a science and engineering practice in the US Science Education Framework, as well as schools' typical implementation of STEM as core subjects into which CT can be inserted, position CT as domain-general skills that advance STEM learning and prepare students for success across STEM disciplines. Our findings provide preliminary evidence of the converse relationship, where STEM disciplinary proficiency supports CT learning. Additional research studies are needed to clarify the mechanisms by which CT and STEM proficiency support each other. For instance, our findings align with studies (e.g., Hutchins et al, 2020) that identify debugging as an especially important connection between CT and scientific modeling.

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Apt Epistemic Practices in a High School Science Classroom: A Contrastive Case Study

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Abstract: In the current "post-truth" era, there is a growing need to promote apt epistemic practices in science education. In this study, we investigated two high-school biology students' epistemic practices during a modeling unit and appraised them for aptness using the Apt-AIR framework. Additionally, we analyzed their responses to a post-implementation focus group interview, designed to elicit their metacognition regarding epistemic practices, as they answered probing questions about practices within the curriculum and reflected on video clips of other students engaging with the units. We document the epistemic practices that students engage in during a modeling unit and evaluate the extent to which they are apt. Findings suggest a disassociation between students' cognitive engagement in modeling practices and their metacognitive understanding.

Introduction and Theoretical Background

In the current "post truth" era, science denialism and the spread of misinformation are prevalent, and science education has failed to meet these challenges (Chinn et al., 2020). The widespread rejection of well-justified scientific consensus on matters such as COVID- 19 risks, vaccination safety, and climate change demonstrates the urgent need to develop and implement instructional strategies that enable students to accurately appraise scientific information (Barzilai & Chinn, 2018; Chinn et al., 2020; Duncan et al., 2018; Kavanagh & Rich, 2018). To address these challenges, we examined an existing high-school science learning environment that seeks to promote apt epistemic practices in science classrooms. Our approach builds on Barzilai and Chinn's (2018) analysis of apt epistemic performance, defined as successful performance (e.g., reaching an accurate conclusion about vaccination safety) that is produced through competence (e.g., one's ability to evaluate the evidence, identify scientific consensus, and integrate the relevant information). Apt epistemic performances are further unpacked in terms of:

- *Aims* (e.g., aiming to reach an accurate conclusion)
- *Ideals* or standards for evaluating whether an aim has been achieved (e.g., fit with relevant evidence and the consensus of experts as ideals for determining whether an accurate conclusion has been reached)
- *Reliable processes* (RPs) that are used to achieve the aims (e.g., evaluating multiple sources of information, evaluating the expertise of sources, and so on)

Apt epistemic practices (AEPs) are clusters of interrelated apt epistemic performances that are governed by shared community norms. Examples of such clusters of AEPs are constructing scientific models, running and interpreting simulations, and engaging in argumentation. The various aims, ideals, and RPs used in these practices are shared by a community; for example, a community can share the aim of reaching well-justified conclusions, adopt ideals such as fit with ample evidence, and employ processes such as gathering and weighing large numbers of studies to ensure ample evidence. Our goal is to promote growth in AEPs that can be used inside classrooms in inquiry and that can be adapted for use outside classrooms to evaluate scientific claims encountered in the contemporary information society.

The first objective of this study is to examine the interrelations between cognitive and metacognitive aspects of epistemic practices. AEPs encompass both cognitive uses of relevant aims, ideals, and processes (e.g., members of a community regularly conduct multiple experimental trials to improve the reliability of data) and a metacognitive understanding of these aims, ideals, and processes (e.g., understanding as a community that multiple trials are needed to avoid being misled by outliers) (Barzilai & Chinn, 2018). Both cognitive and metacognitive aspects are important to epistemic competence (Ford, 2008; Hofer, 2005; Barzilai and Zohar, 2012, 2014). Although some research suggests close connections between metacognitive and cognitive aspects of performance (e.g., Barzilai & Zohar, 2014), other research suggests that associations between cognitive

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performance and metacognitive understanding is low (e.g., Van der Stel & Veenman, 2010). Yet there are reasons to think that metacognitive understanding might help support improved cognitive performance. For example, if students metacognitively grasp that multiple trials are needed in experimentation to establish stable, average effects, then the students may be more likely to use such practices themselves and to notice if others do not use them. Accordingly, this study uses a comparative case study approach to examine the relationships between students' metacognitive understanding of AEPs and their cognitive use of these practices in their own inquiry.

A second goal of this study is to contribute to the field's understanding of what growth in epistemic practices looks like during inquiry. There is a need to develop more comprehensive accounts of what epistemic growth involves as well as how to promote it (Barzilai & Chinn, 2018). In this paper, we seek to apply the Apt-AIR framework developed by Barzilai and Chinn (2018) to understand students' epistemic practices, and thus explore the affordances of this framework in identifying epistemic practices that students engage in, and how these epistemic practices might be improved. This approach is line with other approaches to define and promote epistemic growth (Berland et al., 2015; O'Neill & Polman, 2004; Osborne et al., 2003). Thus, we employ the Apt-AIR framework as a lens to characterize epistemic growth in terms of aims, ideals, and RPs, and we ultimately intend to promote growth in aims, ideals, and RPs in science classes.

The focus of this study was to examine the epistemic practices of students using the Apt-AIR lens, and to examine the extent to which students' metacognitive understanding of epistemic practices was similar to the epistemic practices they demonstrated in their own inquiry. To address these goals, we used a comparative case study method: We investigated two students' epistemic practices while they participated in a widely accessible, agent-based modeling curriculum titled BioGraph, in which students experiment with and learn about complex biological systems (Yoon et al., 2017; Yoon at al. 2018). Additionally, we analyzed post-implementation focus-group interviews in which students metacognitively identified ideals and RPs. We address the following research questions: (1) What ideals and RPs did the students discuss in the focus-group interviews? (2) What ideals and RPs did students demonstrate in the classroom as they participated in the BioGraph unit? (3) What was the relationship between the cognitive classroom performance of these students and what they metacognitively identified in their post-implementation focus group interview?

Methods

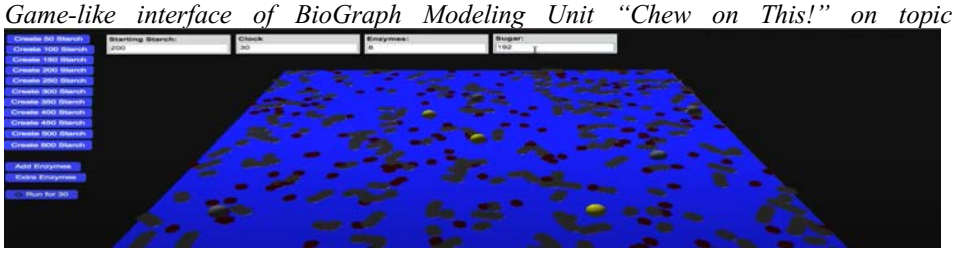
Context

In 2013, BioGraph researchers conducted an exploratory study in which students worked in groups of 2 to 4 with two to three units of the BioGraph curriculum, which offers five biology units on the topics of Genetics, Evolution, Ecology, Sugar Transport, and Enzyme Kinetics. In the units, students worked with agent-based simulations that combine graphical blocks-based StarLogo programming with a 3-D game-like interface (see Figure 1). The curricular materials for each unit took 2–3 days to complete and included popular and academic literature about complex systems as well as short movies, PowerPoint presentations, and teacher and student activity guides (Yoon et al., 2016; Yoon et al., 2017).

In the present study, we used two sources of data: students' classroom interactions while actively participating in the BioGraph unit *"Chew on This!"* from the 2020-2021 school year. In this unit, the learning objectives were: (1) Recognize that enzymes speed up chemical reactions that take place in cells, (2) Explain the shapes of the reaction rate curves both with and without enzymes, (3) Understand that enzymes and substrates interact with one another due to random (not directed) motion of molecules. Additionally, some students volunteered to participate in a focus group interview, post implementation. According to teachers, the students in the focus groups represented a broad range of students. In the focus group interview, we used for some questions previously collected video footage from the BioGraph research project from 2013. The clips included students interacting with the *"Chew on This!"* unit and the *"Gene Regulation"* unit. There were minimal changes made from the 2013 modeling curriculum to 2020-2021; thus, the clip content was familiar to the students.

Figure 1

Game-like interface of BioGraph Modeling Unit "Chew on This!" on topic of Enzyme Kinetics



Participants

In this comparative case study, we focus on two students—pseudonyms Nate and Hannah—who were ninth grade, accelerated biology students from a public high school in northeastern USA. Both students were in the same biology class and were in the same group of four students while they participated in the BioGraph unit. Nate was a male student, and Hannah was a female student. Both identified as White, non-Hispanic. Nate was a vocal member of the group while he engaged with his groupmates as they worked through the BioGraph unit as well as when researchers asked questions in the focus group. Hannah made fewer verbal contributions than Nate in both formats yet participated relatively frequently in the focus group. Nate and Hannah were selected for this case because of their participation within the same group both in class and in the focus group.

Data Sources and Analysis

We analyzed classroom data from February 2021, when the class was virtually conducted over Zoom due to the COVID-19 pandemic. Nate and Hannah were in the same student group participating in an Enzyme Kinetics unit titled "Chew on This!" with two other students. We video recorded the students as they engaged in inquiry with the modeling unit for one class period, or roughly 30-minutes. Additionally, we conducted a 60-minute post-implementation focus group interview in May 2021. In the interview, we prompted students to examine and reflect metacognitively on scientific practices. The questions were designed to elicit comments about the ideals they endorsed for good models (whether normative or not) and the processes they viewed as reliable for engaging with simulations on complex systems (see Table 1). In the focus groups, students were also shown clips from previously collected data of students participating in BioGraph units, and they evaluated and reflected on the epistemic practices demonstrated in the clip.

Table 1

Examples of questions asked by research team and the AIR components (Ideals and RPs)

Questions and goals of questions
What are the most important criteria or characteristics of good scientific models and/or good explanations? Which is most important and why? [This question invites students to express what they view as ideals for good models such as: Models should fit the evidence. Models are understandable. Models have mechanisms that show unseen entities and step-by-step processes.]
When working with BioGraph models, what steps did you or might you take to make your prediction? In other words, how would you justify that your prediction was reasonable when answering a question (i.e., what sources or knowledge would you use to make a prediction)? Do you think it is useful to make a prediction before conducting an experiment? Why or why not? [In response to this question, students might mention ideals such as fit with prior knowledge or the use of good models to make accurate predictions. They might also mention processes such as checking predictions against outcomes, basing their prediction on their last experiment, discussing ideas with their team, etc.]
Students watch a video clip of two students working on a unit on enzymes. In this unit, the students enacted some less RPs , including considering only one prediction, cherry-picking data to match their prediction, using data points as distinct, instead of computing averages Then they were asked: **How would you describe what the students are doing to collect data?** [With this question researchers probed students' ability to metacognitively critique the videorecorded students' use of ideals and RPs. The question provides an opportunity to identify the less RPs evinced in the clip and to suggest what ideals and processes that are better, such as checking for random variation, evaluating evidence consistently, aligning beliefs with evidence, etc.]
Researchers showed some example graphs from the student worksheets to jog memories about how they may have used them. Then asked: **Why do you think this is useful to create graphs when learning about science?** [This question elicits the ideal of emergence—that micro interactions produce macro level patterns which can be depicted through graphs. Students might also suggest processes such as comparing the qualitative pattern on the screen with the graph, which can aid in describing trends and synthesizing information.]
Averaging data and creating graphs are two scientific skills. Can you think of any other scientific skills that you practiced when working with the BioGraph lessons in general? [In response to this question, students might consider RPs such as using evidence to justify a claim, collaborating with peers in inquiry, collecting and recording data, etc.]

Students' ideals and RPs were analyzed based on student discourse in both the classroom inquiry and in the focus group data. (Students seldom mentioned aims explicitly, so we will not analyze them here.) Ideals and

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RPs were coded using both top-down and bottom-up methods. As a starting point, previous research on ideals and processes on science tasks provided a guide to possible ideals and RPs that might emerge (Barzilai & Eilam, 2018; Schwarz, et al., 2009; Pluta et al., 2011). Yet the data were coded with the expectation that new ideals and processes would emerge that had not been previously found. The team developed a comprehensive code book through a constant comparative method with multiple iterations, views, and negotiations of the data sources as well as interactional analysis (Jordan & Henderson, 1995). From this code book, Table 2 presents those codes that are most relevant to the data presented in this paper. Note that students sometimes used or advocated processes that could be considered less reliable. For example, for some students, many trial runs of the simulation were needed to establish stable conclusions (more reliable), but for others, two or three trials, or even just one trial (less reliable), was sufficient.

Table 2

Coding List of Ideals and RPs with their Explanations

Ideals	***Explanation***
Fit with ample evidence	Good models fit not only some evidence but a sufficient amount of evidence (e.g., fit with multiple simulation runs rather than just one run).
Fit with systematic evidence	Good models fit not only evidence from single trials, but from careful, controlled experimentation that tests many combinations of variables.
Understandability	Good models are clear and understandable.
Incorporation of underlying biological processes	Good models incorporate underlying, step-by-step biological processes hypothesized to produce the phenomenon.
Fit with prior knowledge	Good models fit with prior well-established knowledge.
Randomness	Good systems models include random variation in their processes.
Successful prediction	Good models can be used to make accurate predictions.
Causal complexity	Good models are complex with many causes and many effects.
Processes viewed or treated as reliable	***Explanation***
Develop arguments with evidence-based reasons	Giving reasons grounded in data/evidence to support ideas.
Consider and test multiple hypotheses	Making predictions based on two or more alternative hypotheses and testing them together.
Consider and test single hypotheses (less reliable)	Making and testing a single prediction.
Run and gather data from multiple trials	Running simulation multiple times to establish average phenomena under the same starting conditions.
Run and gather data from single trials (less reliable)	Running a simulation only once and using the results only from that single run.
Conduct careful experimentation	Planning/running systematic series of controlled experiments carefully contrasting different starting conditions.
Evaluate evidence consistently	Treating information that supports your ideas consistently with information that contradicts your ideas when gathering data (e.g., don't dismiss a single simulation trial that goes against your ideas while accepting a single trial that contradicts your ideas).
Cherry-pick data (less reliable)	Selecting data points in biased ways to confirm prior prediction/beliefs.
Align beliefs with evidence	Revising explanatory models when there are large or even small discrepancies with evidence.
Evaluate evidence based mainly on prior beliefs (less reliable)	Deciding to believe evidence is "correct" to determine whether to keep or discard a data point.
Average data from trials	Calculating the average of data across multiple trials.
Identifying trends	Identifying trends in the data output.
Determine biological processes	Examining simulations carefully to determine underlying biological processes.

Table 2 (continued)

Using prior scientific knowledge	Using scientific knowledge developed or learned previously to evaluate and understand simulation phenomena.
Checking whether agents are behaving randomly	Observing agents' behaviors in the simulations carefully to judge whether the behaviors are partly random.
Explaining using multiple interacting agents	Explaining that multiple interacting agents produce system level outcomes rather than a single leading agent.
Compare simulation phenomena with graphs	Comparing the qualitative pattern on the screen with the graph.
Collaborate with peers	Collaborating with peers and working together to develop a consensus of ideas.
Apply ideas out of school	Applying what is learned in class inquiries to outside-of-school situations.

Results

We present the results in three parts. First, we analyze Nate and Hannah's responses relating to ideals and processes in the focus groups, including their reflections on the presented video clips. Second, we present the ideals and processes that Nate and Hannah used while they participated in the modeling unit. Lastly, we integrate and investigate the results from both contexts to bring forth the relationship between students' cognitive and metacognitive grasp of ideals and RPs.

Ideal and Processes Present in the Focus Group Interview

Analysis of the focus group responses indicate that Nate and Hannah explicitly and implicitly invoked an impressively wide range of RPs and ideals (See Table 3). Nate made multiple references to the ideals *Fit with ample evidence* and *Fit with systematic evidence,* as well as to the RPs *Evaluate evidence consistently* and *Align beliefs with evidence.* He explicitly identified seven of the eight ideals captured in our coding scheme and articulated a wide range of different RPs, as shown in Table 3, which presents several of his comments. Hannah articulated three of the eight ideals: *Randomness, Successful Prediction, and Understandability.* She also identified several RPs. She specifically mentioned the following RPs at least twice: *Run and gather data from multiple trials, Conduct careful experimentation*, *Utilize graphs for insight, Align beliefs with evidence,* and *Evaluate evidence consistently.* Several of her contributions are also highlighted in Table 3. Hence, the two students successfully identified an impressive range of ideals and RPs when they were metacognitively asked to reflect on probing questions and video clips from other students engaged in BioGraph units.

Epistemic practices present during classroom inquiry

In the classroom data, there were two instances in which Nate explicitly engaged with appropriate ideals and RPs. He employed the RP of *Running and gathering data from multiple trials*, as he said, "I clicked for 30 multiple times…" Additionally, he implicitly demonstrated the ideal *Incorporation of underlying biological processes* when considering models to explain the phenomena of enzymes breaking up the starch molecules. He slowed the simulation to make sense of this phenomena before he articulated the underlying processes. Hannah demonstrated use of only one ideal and no RPs in the classroom data. Like Nate, she implicitly demonstrated the ideal of "*Incorporation of underlying biological processes"* by saying that she would slow down the simulation to grasp the biological phenomena to express how enzymes were breaking up the starch molecules.

Nate and Hannah also employed less RPs and less appropriate ideals in the classroom inquiry. Indeed, their inquiry practices included some of the less RPs that they had criticized in the focus group. Both students exhibited *cherry picking, considering and testing a single hypothesis, and evaluating evidence based on prior beliefs*. These practices directly conflict with the normative ideal *Fit with systematic evidence* and the RPs *Evaluate evidence consistently, Consider and test multiple hypothesis* and *Align beliefs with evidence*. For example, Nate endorsed the group's practice of cherry-picking data in comments about trials such as "Don't use the 17" and "I think 54 is very off" (because these were not close to his prediction of 30). Instead of considering all data as evidence, it was clear that Nate and his groupmates (including Hannah) selected data points that justified their favored group hypothesis. Although Hannah did not actively contribute to her group's evidence selection, she also did not push back on the groups' practices, and she reported the same answers as her group in her student activity guide. Thus, both students used less RPs more frequently they used more RPs, and their judgments were guided more by the ideal of fit with prior expectations than by the ideal of fit with evidence.

Table 3
Examples from Transcript of Focus Group with researchers coding of the excerpt

Examples of students' responses to the focus group questions	Ideals/RPs metacognitively discussed
Nate's responses	
Nate: A lot of the different things require ATP for energy, ATP is going to be created using other things. Everything requires certain factors in order to work, and then to create those factors it requires other factors. So all these processes rely on other processes.	*Ideals:* Causal complexity; Incorporation of underlying biological processes *RPs:* Explaining using multiple interacting agents
Nate: The graph there in the Gene Regulation, that's useful. So it's not just that I think there's more of these over time and then they decrease, you can see the graph, you can see it's actually happening. Also, I think the randomness.... In all of these, if you run the simulation multiple times, it's not just the same exact thing. The factors are working off each other with a bit of randomness. You can tell that whatever is happening is actually happening. In the real world, it's not going to be the same every single time. It's more realistic.	*Ideal:* Randomness *RPs:* Utilizing graphs for insight; Explaining using multiple interacting agents.
Nate: And also, one very important thing in science is going to be building off of other scientific research that's already been done. By doing these CER questions, we're able to do this research ourselves and learn about how to use other people's studies that they've conducted to create our own.	*Ideal:* Fit with prior knowledge *RP:* Using prior scientific knowledge
Nate: If you're looking for a specific result, you can make the data match that. For example, as soon as they saw the result that there's 49, they went with that instead of looking at the overall average which disproved their hypothesis.	*Ideal:* Fit with ample evidence *RPs:* Evaluate evidence consistently; Align beliefs with evidence; Average data from trials
Nate: Also, to help you stop conforming your data to your hypothesis, you need to know how many trials you're going to do ahead of time. Otherwise, you might just keep saying, "One more trial" until you get a result that matches what you want to see.	*Ideal:* Fit with systematic evidence *RPs:* Run and gather data from multiple trials; Evaluate evidence consistently; Align beliefs with evidence.
Hannah's responses	
Hannah: It's different every time, so that way when you see it again you don't necessarily get the same data over and over again. That can give you the impression that there is going to be the same data over and over again when of course there wouldn't be. Interviewer 2: Can you explain that a little bit, by "of course there wouldn't be the same data every time"? Hannah: In the case of lactose, for example, if you consume more lactose, there'll be more lactose in your body, as a base point. But if it always came up with 20 lactose, for example, at the beginning, that could give you the impression that there's always going to be 20 lactose at the beginning instead of, you eat more of a dairy product and now you have more lactose in you.	*Ideal:* Fit with ample evidence *RP:* Run and gather data from multiple trials [to deal with the randomness that can affect results from a single trial)
Hannah: We were seeing the same thing, but we had completely different ideas. Interviewer 1: Do you remember what you did to work out the conflicting ideas that you had? Hannah: We just looked at everything else we had said and tried to piece together a step-by-step process that would make sense. That's how we decided which one was correct.	*Ideal:* Incorporation of underlying biological processes *RPs:* Gather and use conclusive, systematic evidence through careful experimentation; Consider and test multiple hypotheses

Table 3 (continued)

Examples of students' responses to the focus group questions	Ideals/RPs metacognitively discussed
Hannah's responses (continued)	
Hannah I was going to say the same thing. It's bad if someone's stuck to one idea even when all the evidence is going against that. Interviewer 1: That's an important point. Interviewer 2: What do you do when that person is stuck on an idea, even if all the evidence is going against that, what would you do to try to convince the other person? Hannah: I would try to explain what the evidence is actually supporting."	*Ideal:* Fit with ample evidence *RPs:* Align beliefs with evidence; Develop arguments with evidence-based reasons
Hannah: If there's a graph provided, I would definitely try to use the quantitative data and identify the trend.	*RPs:* Identify trends, Utilizing graphs for insight
Hannah: I would say the ability to make a prediction is very important in everyday life because there are a lot of times you just need to guess based on what you know. Interviewer 1: … do you mind, if you have one in your head, can you give an example of when you might make a prediction in everyday life? Hannah: If there's rainclouds out, you'd be able to make a prediction that it's going to rain. Then you might have to change your plans…."	*Ideal:* Successful prediction *RP:* Apply ideas out of school

Relationship between the Cognitive Performance and Metacognitive Identification

The findings revealed a disassociation between students' metacognitive grasp of ideals and RPs. Students identified and elaborated on significantly more ideals and RPs when asked to metacognitively reflect on probing questions and critique other students participating in a BioGraph unit in video clips. Even more tellingly, Nate and Hannah both identified and suggested the use of RPs such as *Evaluate evidence consistently, Consider and test multiple hypothesis* and *Align beliefs with evidence*, whereas they violated these very RPs in their own inquiry learning as they engaged in less RPs such as *Cherry-pick data, Consider and test a single hypothesis, and Evaluate evidence based on prior beliefs*. Thus, these students' metacognitive understanding on ideals and RPs surpassed their use of these same ideals and RPs in their own inquiry.

Discussion and Conclusion

In this contrastive case study, two students excelled at metacognitively identifying appropriate ideals and RPs, in contrast to their cognitive engagement with these ideals and RPs while working with the BioGraph unit. Classroom data suggested that students engage in less RPs, whereas in the focus groups, the students expressed impressive metacognitive knowledge of what ideals and RPs are apt. Interestingly, students engaged in the same less RPs in the classroom that they critiqued in the focus group video clips. Thus, they expressed a good metacognitive grasp of AEPs that they did not implement in their own inquiry.

This study expands on Van der Stel & Veenman's (2010) work by showing the dissociation between the cognitive performance and metacognitive understanding in an inquiry task. Further, it provides valuable insights for researchers on what epistemic practices are present in science classrooms by using the Apt-AIR framework (Barzilai & Chinn 2018) to promote educational efforts to encourage better epistemic practices (e.g. Berland et al., 2015; O'Neill & Polman, 2004; Osborne et al., 2003) We acknowledge the limitations arising from our analysis to date of only two students; research with larger samples is needed to see if these initial findings are borne out in analyses of larger samples.

An important implication of this study for the design of inquiry environments is that at least some high school students have a metacognitive grasp of AEPs that designers and teachers can build on in classroom inquiry. Designers and teachers might incorporate metacognitive discussions within inquiry units to help students make the connections between their metacognitive grasp of AEPs and the practices that they are actually using in the classroom. These metacognitive discussions might serve to help students develop publicly endorsed norms for engaging in their own inquiry (cf. Barzilai & Chinn, 2018).

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Investigating Synchronous & Asynchronous Feedback in an Elementary School Maker Education Classroom

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Abstract: Providing and receiving feedback is a crucial aspect of K-12 education, and is foundational to building a strong student-educator relationship in project-based learning. Previous research has highlighted the importance of student documentation, thus we study the implementation of a mobile application prototype (CoCreator App) that encourages student documentation along with features for asynchronous educator feedback. We observed and analyzed how educators provided synchronous feedback when conversing in-person with students. Our analysis indicates a variety of differences between synchronous and asynchronous feedback. Asynchronous feedback was typically used for praise and encouragement, but also offered additional opportunities for educators to notice student struggles that may not have been visible in class. Synchronous feedback was largely used to provide process-oriented feedback. Looking ahead as the COVID-19 pandemic prevails, we suggest practices and workflows for maker educators to consider as they provide both synchronous and asynchronous feedback in interdisciplinary (and potentially hybrid) learning environments.

Key terms: feedback, formative assessment, maker education, synchronous, asynchronous

Introduction

Feedback is regarded as a primary component of formative assessment (Black & Wiliam, 1998), where the intention is to communicate new information to the learner to modify his/her thinking to improve learning (Shute, 2008). Using Hattie & Timperley's definition, feedback is information provided by an agent (such as a person, experience, or self) regarding aspects of one's performance or understanding, a "consequence" of performance in a spectrum from instruction to feedback (2007). For feedback to be helpful, the provider needs to take into account the many ways learners might interpret feedback, and characteristics like timing and how information is delivered (Havnes, Smith, Dysthe & Ludvigsen, 2012).

In maker education, a particular form of project-based learning where students are tasked with using a variety of traditional and highly technical tools to create physical artifacts, feedback is vital to ensure students progress down a productive path. Feedback has typically been given synchronously, where teachers visit students' work areas, providing feedback and encouragement throughout the construction process. In interdisciplinary settings such as a makerspace, synchronous in-person feedback has demonstrated huge benefits to students, as students and educators can troubleshoot problems quickly by using demonstrations and sharing tools. However, the prevalence of digital portfolio systems and the expansion of remote learning experiences (especially due to the COVID-19 pandemic) has meant that maker educators are often providing feedback asynchronously. Asynchronous feedback has also positively impacted students' self-efficacy and self-regulation too (Tseng, 2016; Litts et al., 2016). We are interested in exploring situations in maker education where there are avenues for both synchronous and asynchronous feedback.

In this study, we explore the following research questions: What types of feedback do maker educators provide at various stages of students' interdisciplinary maker projects, and how do asynchronous and synchronous modalities impact the nature of this feedback?

Literature Review & Prior Work

Educators often use technology as part of their pedagogical and formative assessment practices. Using learning management systems or collaborative editing software has helped educators support their students' needs asynchronously and synchronously (Ames, Harris, Dargusch & Bloomfield, 2021; Irons & Elkington, 2021).

In Hattie and Timperley's (2007) systematic review of literature on feedback processes, they identified four main types of feedback students typically receive: *Task Feedback, Process Feedback, Self-Regulation Feedback,* and *Praise/Self Feedback*. Task feedback provides students with information about whether their work is correctly executed or not; Process feedback encourages deeper reflection on the extent of success to which a task was done and areas for improvement; Self-Regulation Feedback challenges students to self-assess their work and develop self-directed learning skills; Praise/Self Feedback focuses more on the student rather than the task at-

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hand, and may not necessarily encourage students to invest more effort in a task (Van Boekel, Weisen & Hufnagle, 2021; Hattie and Timperley, 2007). Later in data analysis, we use Hattie and Timperley's categories to identify instances of synchronous and asynchronous feedback that we observe.

Synchronous In-Person Feedback as Formative Assessment

During in-person maker experiences, educators are generally able to quickly determine students' progress and struggles. These formative assessment opportunities emerge either when students come to educators for clarifications or when educators notice students' progress while pacing around the class, particularly when similar misconceptions surfaced across a sizable proportion of students (Jayathirtha, Fields, Kafai & Chipps, 2020). Maker educators also often facilitate peer-to-peer feedback so that students interact with and learn from each other by discussing each other's code or prototypes. This mode of feedback has its advantages because educators can command all students' attention to troubleshoot or clarify their misconceptions immediately (Jayathirtha, Fields, Kafai & Chipps, 2020). The in-person setting also allows educators to improvise in the moment with just-in-time ideas (Vossoughi, Escudé, Kong & Hooper, 2013).

Asynchronous Online Feedback as Formative Assessment

Educators might use online platforms for formative assessment, as online platforms afford higher visibility of patterns across artifacts that students upload (Wong & Yang, 2017). A maker education class may take place online too, as observed during the COVID-19 pandemic when schools switched to emergency remote teaching, or in distance learning when students and educators are at different geographic locations. In such cases, the educator's feedback would usually be personalized for each student. Educators may be able to spot patterns in students' submissions, and thus identify common struggles (Jayathirtha, Fields, Kafai & Chipps, 2020). However, there may be missed opportunities where the entire class could learn together, as there are fewer or minimal opportunities for peers to view each other's work, depending on the type of platform (Fields, Jayathirtha & Kafai, 2019).

Methodology

Our literature review has demonstrated affordances of both synchronous in-person and asynchronous online feedback, thus we decided to conduct a study where maker classes occurred in-person during formal school curriculum periods, with an added component of asynchronous online documentation for students and educators to use. This was an eight-week in-person classroom study with 24 fifth-grade students (11-year-olds) and 2 maker educators (one primarily taught music, the other visual art) in a public school in Singapore. All participating students had prior experience in maker education from activities in third and fourth grade. In these previous maker experiences, students kept a booklet to occasionally jot ideas or sketches down and had intermittently used Seesaw, a commercial mobile application, to share photographs and videos with other teachers and their parents of the work they do in school for various subjects. However, the students were generally new to regularly documenting their own work and receiving feedback via a mobile application. The participating maker educators are strong advocates of documentation and iterative feedback, and were very familiar with using Seesaw to document their students' activities. The maker education classes were held once a week for 1h 20 minutes during the time these teachers would normally provide visual art and music instruction. The first author observed the in-person classroom sessions during the study.

Content & Curriculum

The participating teachers Mrs Lee and Mr Tan (name altered) created this maker education curriculum for their fifth-grade students three years ago when this school's makerspace first began running. The school itself was designed by Singapore's Ministry of Education to be a lead school of maker education, therefore the schools' teachers participated in additional professional development with the ministry's Education Technology Division. As Mrs Lee is a visual art teacher and Mr Tan is a music teacher, both decided to collaborate to develop an interdisciplinary curriculum for the term (2-3 months long) where students would incorporate both elements of visual art and music in their projects, and also learn other concepts such as computer programing, circuitry, and material science.

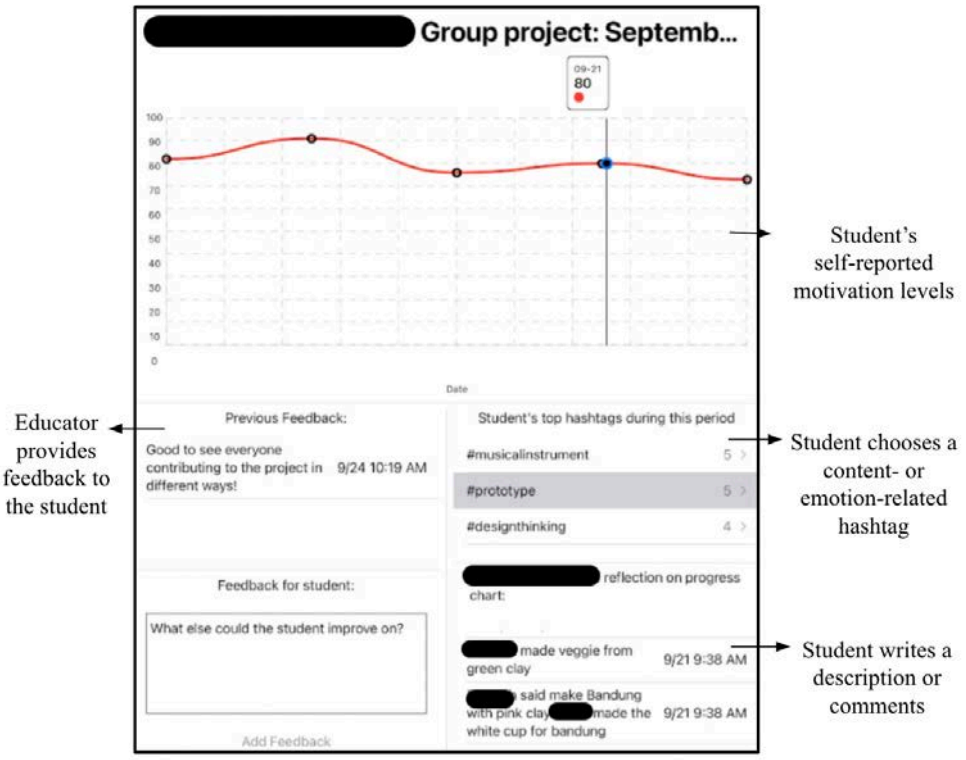
For this eight-week study, Mrs Lee and Mr Tan's primary learning objectives for their students included: 1) to understand and implement the design thinking process that the Stanford d.school established - Empathy, Define, Ideate, Prototype, Test; 2) learn to compose Singaporean folk songs with the right chords and notes through computer programming with Scratch; and 3) apply aesthetic design principles and knowledge of various types of art materials to sculpting. For the first two lessons, students embarked on individual assignments to learn computer programming with Scratch and circuitry with the Makey Makey microcontroller, then worked in groups

of 4 to 5 to develop their projects for the remaining weekly lessons. The maker educators tasked students with using the design thinking process, requiring students to interview non-teaching staff members to identify their hobbies and interests, and then construct a musical instrument using recycled and craft materials following the non-teaching staff members' preferences. Each group assigned one or two students as "documentation leaders" who were responsible for taking and uploading photographs of work in progress and self-reporting their group's motivation levels.

Features of the CoCreator App

The CoCreator App (Figure 1) was developed to encourage students to upload photographs of their works-in-progress with hashtags related to content and emotions, to self-report motivation levels throughout their maker classes, and to input comments or descriptions about their work in a text box below. Educators are notified about new posts that students make on their account, and also have text boxes where they are encouraged to provide feedback to students. Students receive a notification when the educator comments on their posts.

Figure 1
Screenshot of the CoCreator App's interface



In class, the educators instructed students to use the CoCreator App throughout the 1.5-hour period to document activities and assignments they are working on. The educators encouraged students to document photographs of works-in-progress, instead of only showing finished work. To provide a bit more structure to documentation, the educators assigned at least one student per group to be the "documentation leader" so that this student will be responsible for taking photographs of his group's work and reminding his group mates to document any individual work. The educators also suggested that students should take at least five photographs spaced out throughout the 1.5-hour period, and not a bunch of photographs during the last few minutes.

The objective of the CoCreator App is to assist educators in noticing information about students or groups that they may not have observed during in-person classes, through data from students' photographs, comments and/or self-reported motivation levels. From this study, we observe that educators choose the modality in which they provide the feedback (i.e. either synchronous or asynchronous or both), then ponder over the feedback they are about to provide. Usually, the modality where they encounter students' work prompts them to consider certain aspects for feedback, thus the type of feedback they provide synchronously and asynchronously usually differs for similar tasks or stages in students' projects.

Data Collection & Analysis

We examined three primary types of qualitative data: educators' asynchronous feedback on students' posts using the CoCreator App, educators synchronous feedback given to students as captured by in-class video-recorded observations, and field notes that the first author took during the in-person observations.

For in-class synchronous feedback sessions, we observed how educators interacted with students to deliver the feedback. Although the first author took field notes during the class, we added additional context and observations to these notes by watching video recordings of in-class sessions. We base our analysis on traditional interaction analysis (Erikson, 2006), where we ground our observations focused on modalities of interaction such as pace of speech, tone of speech, shifts in body language and posture, changes in facial expressions, hand gestures etc. We generated transcripts of selected observations of feedback sessions to document their content and attributes related to student-educator interaction. From these transcripts, we locate key moments where the educator modifies tone and expression to emphasize certain points while providing feedback, and where the students ask clarifying questions or respond to the educator's questions. We would mark a phrase or behavior as "feedback" if the educator provides additional ideas, support, clarification, or correction to a student's activity or work in class. Examples are demonstrated in the next section.

We categorized educators' feedback into the four main types of feedback that Hattie and Timperley had identified: Task Feedback, Process Feedback, Self-Regulation Feedback, and Praise/Self Feedback (2007). Next, for each type of feedback, we further categorized them into sub-codes based on emerging themes we observed from content and tone: *encouraging*, where the educator wrote positive comments meant to motivate the student, *checking in*, where the educator suggests that the student follows up either on the application or in class, and *troubleshooting*, where the educator points out where a student may be stuck or is doing something wrong, unplanned, or unexpected.

For select situations where data is available for both synchronous and asynchronous settings on the same stage of a group's project, we compared how educators delivered feedback via two different modalities, using field notes to capture synchronous feedback observed during in-class sessions and log data on the CoCreator App to capture asynchronous feedback.

Findings & Discussion

The following examples show educators providing students with feedback synchronously in class and asynchronously through the CoCreator App, where students document their project work by uploading photographs they had taken in class and self-reporting motivation scores for specific tasks.

First, we tallied the types of asynchronous feedback we observed from the CoCreator App. Overall, there were 10 occurrences of asynchronous feedback - 2 of which were task feedback, 0 process feedback, 1 self-regulating feedback, and 7 praise/self feedback. The total number of asynchronous feedback occurrences paled in comparison to the total number of synchronous in-class feedback (100+ occurrences) across 5 observation sessions. On average, both Mr Tan and Mrs Lee individually rotate to each of the 5 student groups at least twice during each class to provide feedback. This means each group should receive at least four instances of synchronous feedback in one class, and over the 5 observation sessions, each group will have received at least 20 instances of synchronous feedback, hence totaling to 100+ expected occurrences overall.

During each weekly class, we observed at least 1 out of 5 groups. For synchronous sessions that we observed in detail with fieldnotes, task feedback occurred overall 18 times, process feedback 5 times, self-regulation feedback once, and self/praise feedback thrice (although one of which was criticism, not praise). Task feedback occurrences were in the majority, and task and process feedback mostly intersected with the sub-codes *checking in* or *troubleshooting*. Synchronous self-regulating feedback happened the least number of times overall, and the particular instance we observed intersected with *encouraging*, where the educator told a group of past emotional challenges that a student group from last year had faced. Two instances of self/praise feedback intersected with *encouraging* because the educators praised students for completing a certain stage of their project; the third instance of self/praise feedback intersected with *troubleshooting* as the educators realized students ran into issues in their project, not because they did not understand a task, but because they executed the task in a lackadaisical manner (as perceived by the educators). We demonstrate examples that highlight the various types of feedback and interactions.

Theme 1: "Teacher Moves" supported in Synchronous Feedback

For asynchronous feedback, the most prevalent codes are *praise/self feedback* + *encouraging*. For synchronous feedback, they are *task feedback* + *troubleshooting* (an example shown in the quote from Mr Tan). Group A had interviewed the school's security guard and noted that his preferences and hobbies are: chicken rice (a local dish), Shih Tzu dogs, the color blue, and soccer. The students wanted to create a musical instrument that represented at

least one of his preferences, but were indecisive. Upon noticing that Group A had rather disparate ideas and had not settled on a direction to start making, Mr Tan strongly emphasized the importance of time management and brainstorming feasible ideas with repeated phrases (left out in the quote due to space constraints), which we classified as *task feedback*. He stood at the group's table where Group A's 5 students were seated around it, and verbally highlighted a few points:

> If the project is going to be chicken rice, how are you going to make chicken rice look like chicken rice? … Think about it; don't throw out ideas blindly without thinking about the processes ahead! … If at the end you know you are going to struggle to make a physical product, then that idea I would think - don't even consider it because you need to think ahead, because you don't have time.

After Mr Tan left this group, while searching for images of chicken rice made of clay, the students stumbled on an aesthetic image of nasi lemak (a different local rice dish but with some similar ingredients as in chicken rice) made of clay. They latched onto this new idea to create nasi lemak instead of chicken rice, and started assigning amongst themselves on items to create. In class upon noticing this sudden change, Mr Tan prompted the students: "So now you're making nasi lemak (a Singaporean Malay rice dish) instead of chicken rice (a Singaporean Chinese rice dish)?" Mr Tan used a surprised questioning tone, raised his eyebrows and widened his eyes, and looked around the table to gauge students' reactions. This was meant to be a subtle hint to students questioning why they had changed their idea suddenly, as Mr Tan was trying to make them aware that nasi lemak is ***not*** one of the preferences that their interviewee had listed. Mr Tan used an inquisitive questioning tone, rather than an instructional tone, which made his hint more subtle when delivered in-person instead of through asynchronous feedback (text) if it were written on the CoCreator App. Out of the students' earshot, Mr Tan let the researcher know:

> (Group A's students) might not pass their project because they've missed the objective, which is to create a sculpture in line with the user's preferences, not a random thing they thought of suddenly. But don't tell them! I want to see how this all turns out, and let this be a teaching moment for this group and the entire class about the Design Thinking step *Empathize*.

It is interesting to note that *task feedback + troubleshooting* did not surface in asynchronous feedback on the CoCreator App. On the CoCreator App, Mr Tan commented with a message that responded to the comments the student documentation leader had written, and we classified this as *praise/self feedback + encouraging*. This comment was a response to Group A's documentation leader's comments about various tasks that each student is doing, and the relatively high self-reported motivation scores (70-80 out of 100) from the group throughout the lesson.

> Documentation Leader Deepak (student names altered) recorded the comments below on his team's work:
>
9/21 9:38am	Dara made veggie from green clay
9/21 9:38am	Dara said make Bandung with pink clay. Ivan made the white cup for bandung
9/21 9:39am	Sahil wrote chicken rice idea and presented
9/21 9:39am	Aaron made the egg and yolk from white and yellow clay

> Mr Tan commented a few days later:
>
9/24 10:19am	Good to see everyone contributing to the project in different ways!

This example is a strong representation of asynchronous and synchronous feedback instances, as we observed multiple instances of asynchronous prase/self feedback and synchronous task or process feedback.

Theme #2: Extracting New Information from Asynchronous Feedback

Different from the previous theme, the educator here discerns new information about Group B and C students' progress and understanding of concepts through their documentation, comments, and self-reported motivation levels. Keeping in mind that these are subjective scores, we do not compare students' scores with one another, but we compare how students rate their motivation levels multiple times during the same class period, or across different weeks.

Group B was generally on-task in class and completed their coding portions swiftly. As a checkpoint, the educators instructed students to check in with them before proceeding to work on the portion with the MakeyMakey. Below is an extract of the first author's fieldnotes:

> When Mr Tan checked that Group B had completed coding their musical chords on Scratch correctly, he signalled to the group to follow him to the corner where MakeyMakey microcontrollers were kept in the classroom. He prompted them "You know the difference?", holding up a couple of alligator clips. He instructed them to collect the wires and microcontrollers and move on to the next step to connect their Scratch code to the MakeyMakey. This interaction lasted nearly 1 minute.

During the in-person interaction, it seemed that Mr Tan did not recognize or was unaware that Group B students still felt somewhat uncertain about the coding assignment even though they had completed it. Perhaps this is because the students did not voice out their questions directly to Mr Tan, and he checked for task completion, then moved them swiftly to the next stage. On the CoCreator App later, we noticed that Mr Tan wrote "Do approach me if the group needs more help" on a Group B student Pratama's post. During our interview with Mr Tan, he stated that he noticed the students lowered their motivation score from 100 to 50 in the same lesson with no written comments from the student, thus he felt that there could have been an unresolved issue from the class. We classified this as *task feedback + checking in*. Mr Tan noted that this specific student is typically conscientious and grasps new concepts well, but is soft-spoken and lacks confidence in the activities he does, which may have been a factor that led to a dip in self-reported scores.

During our interview with the student Pratama, he explained that he still felt unsure about coding on Scratch although he seemed to have completed the assignment correctly in class, thus he chose to go with the flow when his group started the next MakeyMakey stage, but decided to note his drop in motivation level on the CoCreator App. Here, Pratama's self-reporting and documentation on the CoCreator App provided Mr Tan an indication of his lack of confidence in the coding assignment that he did not feel comfortable articulating in class or in front of his groupmates - a separate avenue that could spark a follow-up conversation with Mr Tan.

Group C's situation was slightly different from Group B's. For a particular session, the researchers observed minimal synchronous educator feedback for Group C. Group C's students completed the coding assignment in class, and asked each other within the team for help if one of them ran into issues.

> Group C's documentation leader Zi recorded comments below on his work (Figure 2 below):
> 9/14 8:58am Coding the chords and changing the numbers were hard. I didn't understand what the chord numbers mean
> 9/14 9:01am It means that each number has a letter to make the chord. Which means that 48 is the letter C, 52 is the letter E and the number 55 is the letter G.
>
> Mr Tan commented a few days later:
> 9/17 10:17pm Do take note of the octave for your notes. Remember Mr Tan said notes 42-60? [Mr Tan wrote this on the school's learning management system, a different platform.] Check your codes if you have the time and identify the error.

Through the CoCreator App, Mr Tan noticed that Zi actually struggled with coding the musical notes during class, although Zi had not asked for help directly in class - this would not have been obvious in the synchronous session as Mr Tan would have assumed that the entire Group C had understood the concept and could move on to the next activity. We classified this piece of feedback as *task feedback + troubleshooting*.

Discussion & Conclusion

This study explores feedback given from an educator to students in an in-person maker classroom where both asynchronous and synchronous modes are available. The educators used synchronous feedback to provide detailed process-related suggestions for all groups and to offer immediate help when students ran into difficulty, whereas they used asynchronous feedback mainly for encouragement. However, there were a couple of occasions where students indicated confusion in concepts or processes in the CoCreator App, rather than during face-to-face interactions with the teacher.

In this study, it seems that the educators mostly used the CoCreator App to check students' work briefly and provide simple feedback, leaving more detailed feedback for synchronous time in class. During a post-implementation interview, educators indicated they worried asynchronous feedback might not be noticed by

students as they are only able to use the CoCreator App when using the school's iPads during their once-a-week class sessions. Results from this study may have been different if the educators allotted more time to provide various kinds of feedback on the CoCreator App, and if the educators structured the in-person session for students to review feedback they received through the CoCreator App.

More attention to in-person and synchronous feedback, when it's available, is a good thing! Future iterations of the CoCreator App could optimize this face-to-face feedback by automatically evaluating student posts and notifying educators of potential concerns. For example, the app could detect a drop in motivation levels or increased use of hashtags related to emotions such as frustration or dejection.

Another area for potential research is to study self-regulation feedback - educators providing feedback to students about self-assessment of their work. For this participating school, the educators had organized a peer feedback session where students rotated to different groups to provide feedback to one another based on rubrics and criteria. Although we observed minimal feedback from the educators about students' participation in this peer feedback session, in another study, we can investigate students' processes and perspectives of peer-to-peer feedback (Parenti, 2013). For future design iterations, the CoCreator App could also support asynchronous peer-to-peer feedback by providing students with features to comment on other groups' work. This would hopefully enhance the amount of self-regulation feedback that occurs in the maker classroom, as educators will have more opportunities to identify how students are assessing their own and their peers' work.

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The Zone of Proximal Self Model to Improve Equity in Higher Education

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Abstract: This paper introduces a sociocultural framework called the zone of proximal self to reimagine how higher education institutions can support students from first-generation, low-income, and marginalized backgrounds. Employing mixed-method approaches, we analyze diary entries, surveys, and interviews of 50 students who met with a counselor/advisor during the Covid-19 pandemic. Thematic qualitative analyses reveal a model of effective practices characterized by creating a brave space, validation, and strengthening students' social-emotional competencies in culturally mindful ways. Case examples highlight features of this model including building working partnerships, understanding students' cultural backgrounds, validating students' experiences, and organizational brokering. Results from multiple linear regression models suggest that students, on average, have higher growth towards their professional and personal goals when exposed to more of these model practices. Taken together, the findings call for future research directions and designs of learning environments to consider cultural, relational, and social-emotional interactions in improving equity in higher education.

Introduction

In higher education, students' professional and personal development are impacted by educational inequities in socioeconomic privilege, resources, and access to opportunities (Tinto, 1987). The negative impact of educational inequities was exacerbated during remote education in the Covid-19 pandemic, which surfaced challenges including students' basic needs, social emotional well-being, and familial obligations (Fain, 2020). Thus, it is imperative for educators to reimagine how higher education institutions can support students' learning and development in a way that is situated in cultural contexts. The purpose of this study is to contribute to this reimagining by understanding an empirically grounded model of practices that can advance the professional and personal development of students from first-generation, low-income, and marginalized backgrounds (FLM). Since previous literature noted how out-of-class spaces such as counseling and advising can be promising for learning, the present study focuses on effective practices that happened virtually during the pandemic between counselors/advisors and undergraduate students from FLM backgrounds (Astin, 1993).

Literature Review

Culturally organized learning pathways

This work conceptualizes learning as a cultural process by drawing on the learning pathways framework in which learners engage in activities that draw them towards or away from competencies in context-specific situations (Nasir et al., 2020). Culturally organized learning pathways 1) are in relation to a sense of identity with relational, affective, and motivational components, 2) are built from socially constructed practices over time, and 3) reveal power dynamics from structural institutions experienced through interactions with families, peers, and school. This study focuses on the culturally organized learning pathways of undergraduate students from FLM backgrounds: how their identities, or who they are in the process of becoming, are impacted by interactions with counselors and advisors across time and settings which are influenced by college institutions and structures. This work aligns with the literature on culturally organized learning pathways by shifting the unit of analysis from academic learning outcomes to "specific and consequential learning resources or experiences that learners are able to access" which include counselors and advisors in their institution (Nasir et al., p.198).

Organizational brokerage

Previous research in learning pathways have shown how parents acted as brokers connecting children to experiences, people, institutions, or information (Barron et al., 2009). The present study examines the role of higher education counselors and advisors as organizational brokers. Organizational brokerage is defined as "the process by which an organization connects an individual to another organization or to the resources they contain"

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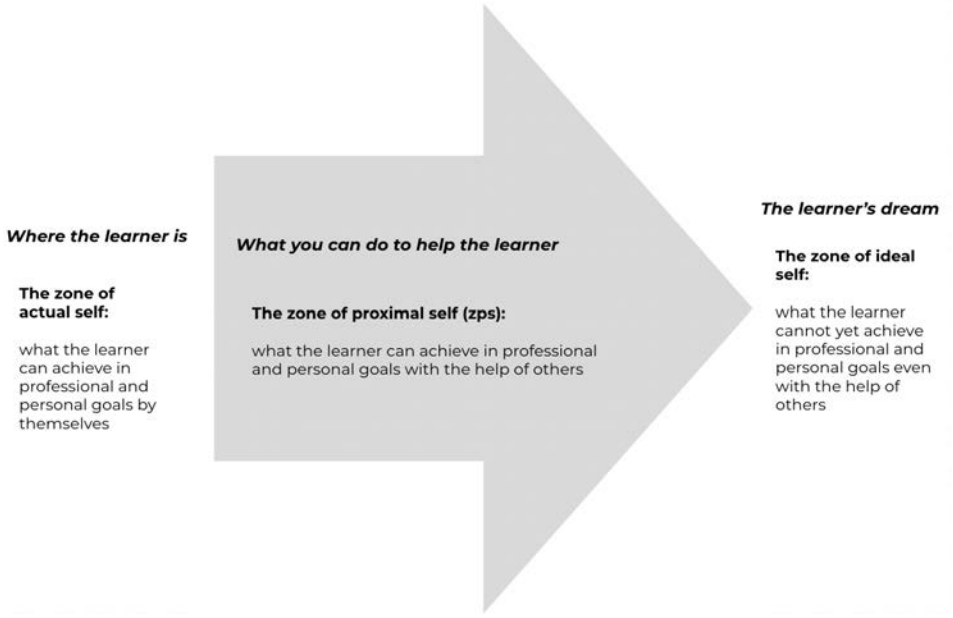
which can be implemented at the individual level through behaviors of school personnel and at the institutional level through administrative policies, infrastructure, and culture (Small, 2009, p. 19). There are different mechanisms in which organizational brokerage can occur including storage (i.e., broadcasting opportunities), validation (i.e., confirming right to use resources), referral (i.e., direct linking to an organization), and collaboration (i.e., working with another organization to provide social good).

Examining organizational brokerage and institutional roles moves away from a discourse of student independence and meritocracy to one about organizational and collaborative support of students from FLM backgrounds. The dominant narrative in higher education, especially in Science, Technology, Engineering, and Mathematics (STEM), have espoused the myth of meritocracy where successful students are the ones who "pull themselves up by the bootstraps" and navigate the hidden curriculum independently (Carnevale et al., 2020); however, this myth of meritocracy is detrimental to equity in higher education since it fails to recognize how students' lives are connected in critical ways to social opportunities and/or constraints. Hence, it is important to shift the narrative away from students' responsibilities in looking for resources by themselves and instead on the role of higher education organizations in supporting equitable learning pathways and resources.

The zone of proximal self conceptual framework

Aligned with a culturally organized learning pathways perspective and a focus on organizational brokerage, the zone of proximal self (ZPS) is a conceptual framework to theorize how learners interact with people, resources, and materials within their institution to develop competencies in pursuit of their possible selves. As illustrated in Figure 1, ZPS is the distance between an individual's actual and possible selves that can be bridged with the support of institutional people and resources. Furthermore, ZPS exists across a wide learning ecology in higher education, or the activities, resources, relationships, and interactions that occur across multiple contexts in physical and virtual spaces (e.g., classrooms, advising/counseling, peer groups, home contexts, programs, organizations, etc.) (Barron, 2006). This process transforms the relationship between the learner and learning environments, positioning students to explore new opportunities and identities within their institutions.

Figure 1. *The zone of proximal self conceptual framework*



Lev Vygotsky's sociocultural theory and zone of proximal development form the base of this conceptual framework. Vygotsky (1978) described how children's learning exists within a zone of proximal development, "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (p. 86). The ZPS framework extends Vygotsky's zone of proximal development from the context of developing problem-solving competencies to the context of developing social-emotional competencies to pursue possible selves in a professional community. Possible selves refer to the imagined selves that we could become, and also the selves that we are afraid of becoming (Markus & Nurius, 1986). ZPS regards possible selves as more than a dream job: they are dynamic visions of one's future self connected to holistic professional and personal goals influenced by cultural backgrounds, experiences, and home communities.

In this study, possible selves are operationalized through students' professional and personal goals for themselves which can be reached through the development of social-emotional competencies. Social-emotional competencies include cognitive, affective, and behavioral skills that can be developed over time, such as self-awareness, self-management, social awareness, and relationship skills (Kraft, 2019; Zins & Elias, 2007). Social-emotional competencies are similar to soft skills; however, the ZPS framework conceptualizes social-emotional competencies differently than skills discourses, or discourses commodifying soft skills for the job market without attention to cultural contexts (Hora et al., 2019; Urcioli, 2008). Instead, social-emotional competencies are envisioned as situated, culturally organized, and linked to new forms of social and learning-oriented activity.

Methods

Methodology and research questions

This study aims to refine the ZPS framework and contribute a ZPS model of practices grounded in empirical data of how counselors/advisors support students' professional and personal goals. Towards this aim, this study employs a mixed-methods approach to triangulate findings to the following research questions:

Research question 1. How are counselors and advisors supporting students from FLM backgrounds within ZPS? What are effective practices that constitute a ZPS model for supporting students?

Research question 2. Does the use of ZPS model practices in meetings between counselor/advisors and students predict greater gains in students' professional and personal goals over time?

Participants

Participants of the study include 50 undergraduate students who were recruited from equity-oriented programs at a large public R-1 university in California. Of the students, 74% were first-generation; 74% were female and 4% were gender-nonbinary. Students were from diverse racial/ethnic backgrounds: 52% Latinx/Chicanx, 22% mixed race, 12% East/South Asian, 8% White, 4% Black, and 2% Southeast Asian. Most students were sophomores (42%) or juniors (34%), with some freshmen (2%), seniors (16%), or super seniors (6%). Students were balanced between Social Sciences and Humanities (23%), STEM (22%), and interdisciplinary studies (10%). Additionally, 4 counselors from equity-oriented programs participated in an interview.

Study procedures and measures

Student participants were asked to meet virtually with a counselor or advisor at least three times throughout an academic 14-week semester. The meetings were about once per month corresponding to a pre-, mid-, and post-time period. For meetings, 42% of students met with the same counselor or advisor (n=21) and 58% of students met with different counselors or advisors (n=29). The following were the measures in the study:

Diary Entries

All student participants completed diary entry submissions after each meeting with a counselor or advisor. The diary entries asked for who they met with, the meeting duration, topics discussed, what happened, and how students felt about the sessions. Example questions include "Describe your meeting and what you got out of the session." Diary entries were completed through online submissions using the Qualtrics platform.

Pre- and post-surveys

All student participants completed an online Qualtrics pre- and post-survey assessing their growth towards professional and personal goals. Professional goals were assessed in an open-ended question of "What are your professional goals?" followed by a Likert-scaled response item on a scale of 1-7 to the question "Select the statement that best represents your progress in pursuing your professional goals." Personal goals were assessed with the same questions but with personal instead of professional goals in the question stem.

Interviews

44 students opted in to virtually participate in a semi-structured interview at the end of the semester which lasted between 30-60 minutes. Students were asked to elaborate on their diary entry submissions with additional details and specific strategies that their counselor or advisor employed. For counselor interviews, counselors were asked to describe their counseling philosophy and practices.

Data analysis

Qualitative inductive thematic coding

The diary entries were qualitatively coded using inductive thematic coding (Saldaña, 2015). The initial pass of open coding included breaking the data into codes with parent codes and child codes. The parent codes included codes such as connections and resources, strengths-based communication, motivation, professional goals, personal goals, mental health, introspection, and time management. Table 1 illustrates an example of three child codes within the parent code of connections and resources. The open codes were followed by axial coding to draw connections between the codes into categories. Finally, the categories were connected together in selective coding to form a core category grounding a model of practices.

Table 1. *Slice of codebook for parent code of connections and resources*

Code	Description	Example Quote
Professional resources	Connecting student to resources related to their professional goals, such as internships or the career center	Asked questions about graduate school (i.e. application, financial aid resources, timeline, etc.) and was able to learn about resources like [mentorship program] and how to set up an appointment with [a career center counselor] to talk about graduate school. (diary 1; student 26)
Academic resources	Connecting student to resources related to their academic goals, such as major specific advisors or course planning templates	[Counselor] provided me with an abundance of resources for looking into pre-health options and how I could fit some of those into my schedule before I graduate. (diary 2; student 39)
Basic needs	Connecting student to resources related to financial aid and basic needs such as grants or housing assistance programs	[Counselor] ended up discussing possible organizations I should reach out to because having a stable computer is essential for my learning and shouldn't be a reason for me to keep being stressed out. (diary 1; student 37)

Qualitative case study approach

To provide an information-rich description of the ZPS model, a case study approach was employed to select case examples between a counselor and two students (Yin, 2017). One of the four counselors was selected based on having cases of how they were able to support two different students — a student with a similar and a student with a different background — while using the same effective practices.

Quantitative regression analyses

The surveys and codes from the diary entries were used in quantitative multiple linear regression analyses to assess growth of personal and professional goals as it relates to the ZPS model. Continuous variables were normalized to interpret results in standard deviation units. The following variables were used in the analyses:

Gain score in professional goals. This score was the difference between the post-survey and pre-survey score of growth in professional goals that was on a scale of 1-7.

Gain score in personal goals: This score was the difference between the post-survey and pre-survey score of growth in personal goals that was on a scale of 1-7.

ZPS model score *(ZPS model)*. This was a score ranging from 0 to 9 which is the total number of times that ZPS practices were found across all 3 diary entries for a given student.

Meeting with the same or different person *(same person)*. This was a binary variable indicating whether or not the student met with the same counselor or advisor throughout all three meeting sessions.

High school preparation *(high school pre*). This was an ordinal variable on a 1-5 Likert scale in response to the question "How well did your high school prepare you for college?"

The following are the regression models used in the analyses with a 5% significance level:

$$professional\ \text{gain}_i = \beta_0 + \beta_1 zps\ model_i + \beta_2 same\ person_i + \beta_3 high\ school\ prep_i + \epsilon_i$$
$$personal\ gain_i = \beta_0 + \beta_1 zps\ model_i + \beta_2 same\ person_i + \beta_3 high\ school\ prep_i + \epsilon_i$$

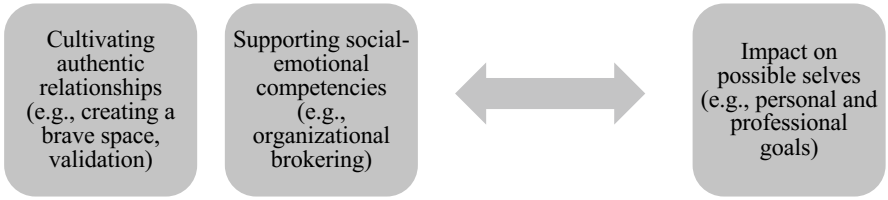
Gains in professional and personal goals were treated as separate outcome variables of interest. The main predictors included the ZPS model score, whether students met with the same person, and their high school preparation. The distribution of the residuals was approximately normal, and the outcome variables showed an approximately normal distribution. Nevertheless, a regression with robust standard errors based on a sandwich estimator was performed since they are more robust to violations of the model assumptions.

Findings

Research question 1: ZPS model of effective practices

Thematic coding of diary entries revealed three prominent categories of codes: counselors and advisors 1) cultivating an authentic relationship with students through creating a brave space and validation 2) supporting students with social-emotional competencies, and 3) students' perceived impact on their professional and personal goals. Taken together, these categories formed the core category: Creating a brave space, validating students, and supporting social-emotional competencies in culturally mindful ways is related to students' professional and personal goals. This core category forms the basis of the ZPS model in Figure 2.

Figure 2. *The zone of proximal self model*



ZPS model in action: Case example with counselor Sofia and students Emilia and Melody

To describe the ZPS model with real-world examples, this section details how a counselor, Sofia Aguilera[1], applied effective practices in the model to work with two different students. Sofia is female, first-generation, low-income, and Mexican American. Similarly, one of the students, Emilia Noguero, who met with Sofia, is a second-year public health major who also identifies as female, first-generation, low-income, and Mexican American. Meanwhile another student, Melody Hayashi, a third-year cognitive science major, is also female and low-income, but identifies as continuing-generation and Asian American.

Brave space: Building a working partnership. Sofia and both students discussed how Sofia cultivated an authentic relationship by creating a brave space for conversation and collaboration. One effective practice was to explicitly communicate the relationship as a relational and working partnership where the counselor works with students rather than acting as the expert holding all the knowledge. The following quote from Sofia expressed this: "I've had students call me dude and then say sorry. I'm like no, you can call me dude and that makes me happy because that makes me feel like you see me...I don't want to be seen as someone better than you or knows more than you, because I probably don't. We both know a lot and so it's a partnership." Sofia's intentions to be in partnership resonated with her students. Emilia mentioned how, "She was just in the process, and I never felt like she was in charge of me. She was riding along with me." Similarly, Melody expressed how she felt a sense of agency: "I think sometimes there's cases when you talk to people like your friends and family and they're like oh yeah you should make this choice. For her that's something she definitely did not do and she's still giving me a lot of agency to make my own decisions." As mentioned by the students, Sofia's expression of working in partnership created a brave space, fostering a relational power dynamic where students felt agency and were supported in pursuing life choices and possible selves.

Brave space: Understanding cultural background. Another effective practice was being culturally mindful of students' situations through active listening, which Sofia describes below:

> I'm not going into any session thinking that I know what they need, what they want, what they're trying to do. I'm asking follow up questions and open ended questions...and with a multicultural lens that everybody's identities play a role in their experiences. I know that I don't know everything about every identity and even the ones that I hold I still I'm always constantly like you still don't know it...there's always room to learn.

Instead of engaging in transference, Sofia is cognizant of the intersectionality of experiences that impact students. Emilia notes this as well:

> After I was done with all my academic issues, she asked "but how do you feel with your roommates?" because my roommates my first semester were from China and India, so it was a big change because I come from a very Hispanic community, so I'm not used to it. She asked "in college how is your relationship

[1] All names used in this study are pseudonyms.

> with your parents right now?" They recognized me so much more than a student and knew that my performance in school relies on how I feel going into class and how I feel coming out of class. And also who I'm connecting with outside of class and what's going on at home and the family life.

Emilia touched on how Sofia's understanding of her cultural background situates her learning within a cultural context including her home environment and peer groups. Similarly, Melody also mentioned how Sofia was able to get "an idea of my situation to be able to support me better." An important practice Sofia applied in creating an authentic relationship was not making assumptions about students, but instead assessing where they are in consideration of their cultural backgrounds.

Validation. Another important practice was validating students' strengths, challenges, and feelings towards their professional and personal goals. Sofia applied validation of students' feelings to combat imposter syndrome and support students' confidence in themselves and their identities:

> With imposter syndrome and students telling themselves that they don't belong here, for me it's validating their feelings. Your feelings are valid and they're real and you're not the only one...I think that once I validate their feelings, we go through that conversation of this is not you, this is the institution. It helps them create a new narrative for themselves that they do belong...I'll tell them I know that you're not just a student. You wear other hats, I don't know if you're a daughter or you're a sister or a mom, there's so many hats that our students hold. Building up their confidence and letting them know that their student identity is not a reflection of who they are. Really bringing into light all the strengths that a student brings that sometimes are forgotten.

Sofia connected the internal monologues students have to larger institutional signals and encouraged students to transform the narrative of their position at the university. This validation was important for students to hear, as portrayed in Emilia's quote:

> My first semester was full on imposter syndrome...But I think the biggest thing that she kept telling me was that my journey is not a journey that's going to be like others and that's okay. She would tell me about her non-stereotypical journey to where she is now...and that truly really did help me...and it was something that's funny because I know this. But the thing is it's kind of like when you tickle yourself, you can't feel it within you...but when she would tell me...it's like, you're right, I internalize it.

In validating Emilia's feelings, Sofia embraced being vulnerable enough to share her story and show how the learning pathway for each individual is unique. Melody also expressed how Sofia was adept at validating her feelings towards activities related to her professional goals:

> I think there was an understanding and validating of feelings definitely a lot of the time, because I was telling her all of my uncertainties and doubts regarding a lot of the opportunities that I was looking at... That was something that I think she was really good at handling and understanding. Giving me as much information as possible and really being transparent about that and also being vulnerable about herself and relating to my experiences and telling me straight out "It is okay to feel this way."

Emilia and Melody mention how Sofia validated a sometimes forgotten part of possible selves — the feared selves we are afraid of becoming, or in this case the fear of conforming to the narratives from institutional messages about who belongs and who succeeds. Sofia's validation encompassed validating these fears instead of dismissing them, and also overcoming these fears by drawing on students' strengths and holistic identities.

Supporting social-emotional competencies: Organizational brokering. Organizational brokering was an effective practice Sofia used to support students' social-emotional competency in relationship-skills building with communities. Sofia discussed how she plays the role of an organizational broker: "I'm constantly networking because that is so important so that I can help my students reach their goals." Emilia described how Sofia acted as a broker for her:

> It's going to be my third year so things are kind of more settling into what I want to do for career paths and I just didn't know who to reach out to to help me. She was able to connect me with the career center and their specific times that they have to help us...and then also she connected me to appointments with peer advising for public health...So she was a major segway into all of that, because I wouldn't have even known about them...I joined these little communities and now I have met with both of those communities, the career center and the public health advising, at least two or three times since.

Melody also discussed how Sofia helped connect her to the career center: "...that was something I was super surprised about and didn't know that they did in counseling, helping me check my progress and helping me set up other counseling sessions, like the career center, for example. That was one way she helped me take those next steps to learn more about what I wanted to do." In both instances, Sofia was able to help the students navigate resources within the institution and support them in building relationships with communities related to their professional goals.

Organizational brokering can only be effective if students are comfortable seeking the support they need to reach their goals. Sofia recognized that many students face emotional barriers: "When it comes to reaching out to others, if it's a professional staff, I will ask them, do you feel comfortable asking or reaching out?" Emilia, for instance, did not feel comfortable in the beginning:

> When I grew up, my parents never really encouraged me to ask for help. It's always just authorities, you respect them, you give them your ultimate yes, thank you, bowing down to them in a sense. And you only asked for help if you really needed it. You're gonna try your best yourself. But by her creating a space where you can ask for help, then it got me to walk into the career center meetings saying "I need your help", and this is why I'm here and feeling okay to ask for help.

Similarly, Melody also discussed how her family was hesitant to ask for more help:

> I also talked to her about the cost of adjustment and filing for that and how that works and asking for money when I need it. And she was the one who told me "Yes, you know if you do need it, ask for it and don't be afraid to do that" because I think especially within my family, I already get a lot of financial aid from the government and the school, so they are like "Oh don't push it, don't ask for more security, we're receiving a lot" and I'm already very grateful for that, but there are some situations where you do need additional support. That was something that she told me you have to advocate for yourself.

These accounts reveal how the act of seeking help, a part of the relationships building social-emotional competency, is also a new cultural practice for students whose families elevate respect for authority.

Research question 2: ZPS model impact on professional and personal goals

This section examines how the ZPS model impacts aspects of students' possible selves, specifically their professional and personal goals. Overall, the gains in professional and personal raw scores were varied for all 50 students. The raw score mean for gains in professional goals was .92 (SD = .997, min = -1, max = 4). The raw score mean for gains in personal goals was .18 (SD = 1.17, min = -3, max = 3). Tables 3 and 4 show the regression model estimates with normalized variables in standard deviation units. There was no evidence of collinearity between predictors in the models for professional goals (mean VIF =1.06) and personal goals (mean VIF=1.05).

Model 1 estimates: Professional gain. For every unit increase in the ZPS model (presence of brave space, validation, and social-emotional competencies mentioned in the diary entries), there is an estimated mean increase of .30 units (95% CI [.044, .553]) in professional gain when controlling for whether the student met with the same person and high school preparation (t = 2.36, df =46, p<.05). The estimated mean increase in professional gain is .44 units (95% CI [.182, .702]) per unit increase in high school preparation when controlling for whether the student met with the same person and ZPS model (t =3.42, df = 46, p<.001). The R^2 for this model is .31, suggesting that 31% of the variation in gains of professional goals can be explained by the ZPS model, meeting with the same person, and high school preparation.

Table 3. *Regression Model for professional gain*

Covariate	Coefficient	Robust standard error	P-value	Confidence Interval
ZPS model	.30	.13	.023	[.044, .553]
Same person	-.14	.25	.571	[-.640, .358]
High school prep	.44	.13	.001	[.182, .702]
intercept	.06	.15	.685	[-.233, .353]

Model 2 estimates: Personal gain. For every unit increase in the ZPS model, there is a predicted mean increase of .49 units (95% CI [.231, .747]) in personal gain when controlling for whether the student met with the same person and high school preparation (t =3.82, df = 45, p<.001). The R^2 for this model is .25, suggesting that 25% of the variation in gains of personal goals can be explained by the ZPS model, meeting with the same person, and high school preparation.

Table 4. *Regression Model for personal gain*

Covariate	Coefficient	Robust standard error	P-value	Confidence Interval
ZPS model	.49	.13	<.001	[.231, .747]
Same person	-.28	.23	.234	[-.739, .185]
High school prep	.11	.12	.358	[-.125, .341]
intercept	.12	.16	.471	[-.210, .447]

Discussion and significance

In sum, the findings reveal the significance of applying a ZPS model to support students from FLM backgrounds in pursuing their possible selves. The model, building on extant literature and empirical data from the present study, is characterized by effective practices of creating an authentic relationship with students (i.e., creation of a brave space and validation) and strengthening students' social-emotional competencies (e.g., relationship skills) in culturally mindful ways. Moreover, the case examples reveal the importance of relational interactions and cultural mindfulness in organizational brokering with students from diverse backgrounds. Results from multiple linear regression models suggest that students, on average, have higher growth towards their professional and personal goals when they are exposed to more ZPS model practices from counselors/advisors. Future research should examine how these interactions impact student experiences across different institutional settings and roles in higher education, including instructors, peers, and family.

Ultimately, this study was completed during a Covid-19 pandemic fraught with uncertainties in professional and personal lives; and yet, during virtual conference meetings with students, counselors and advisors were able to support students' goals. The ZPS model articulated in this study is a testament to the strength and potential of counselors and advisors in bridging the distance between students' current realities and future possibilities. This work is part of a greater reimagining of equity-oriented work in higher education that recognizes the cultural, social, and emotional processes of student learning and development.

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Pandemic Board Game Redesigned: How Learners' Decisions Enable Emergent Learning Possibilities

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Abstract: This paper discusses a study on students' exploring and creating emergent systems using mathematics and science while redesigning the cooperative board game, *Pandemic*. Grade seven students participated in the game redesign project co-developed with a teacher in an art immersion school in Western Canada. Their work was collected through video recordings, photos, and interviews. The analysis shows how the game redesign activities supported the divergence and convergence of ideas and group decision making. It highlights how learners' interests and choices acted as frames that enabled their ongoing inquiry and expanding their use of learning topics in creating a working system.

This paper describes a design-based research project on using a board game redesign approach to learning. It aimed to support students to engage with emergent systems and to imagine and model new possible structures using mathematics and science topics. Relying on a complexity perspective, we follow a notion of learning as an emergent phenomenon that involves expanding capacities to adapt to and participate in novel situations (Davis et al., 2015). Complexity perspectives propose learning designs that attend to creating a balance between setting constraints and stimulating learners' diverse responses. In this paper, we discuss how the board game redesign approach, and the materials and activities involved, not only set some structures, but also enable students' collective decisions that could expand their design space and engagement with math and science topics. Our analysis attends to the critical episodes of divergence and convergence of ideas in the groups and the role of structured and self-imposed constraints in supporting this process, using a frame informed by design and creativity research. The following questions guided our analysis: (1) How do the co-design spaces evolve through the redesign process? (2) How do the project structure and learners' decisions frame their design directions and use of math and science topics in creating their game system?

Perspectives

This study draws on a complexity perspective of knowledge and learning that address the emergent nature of learning and its nestedness (Davis et al., 2015). That is, individual understanding and collective knowledge are emergent learning systems at different but interwoven levels. Complexity views, therefore, seek for the conditions that could stimulate more emergent learning possibilities for learners. They use the notion of enabling constraints to indicate how design for learning should attend to a balance between enabling learners' idiosyncratic responses and setting structures that would limit the vast possibilities of approaching learning topics to support learners' shared goals and language (Davis & Simmt, 2003). Classroom structures that engage learners in design practices have showcased their potential to support collaboration based on their interests and skills toward shared goals (e.g., Kim et al., 2019). Design practices support learners to engage in intentional interactions with their peers, teachers and learning topics, using design materials and their developing artifacts. Approaching learning topics through balanced design practices with structures and openness speaks to the notion of enabling constraints, allowing learners to iteratively challenge their own assumptions of problems at hand and explore possible solutions and thus emergent learning possibilities.

Games have the potential for embodying disciplinary and interdisciplinary knowledge. Some studies have explored how designing board games, as models of systems, could support students' engagement with mathematics and science (Kim & Bastani, 2017; Ke, 2014). The present study was a design iteration of a previous learning design for supporting mathematics learning through collaborative re-design of a board game (Kim et al., 2021). The previous project indicated structuring game design projects as re-designing board games (rather than starting from scratch), in which learners play a common board game and change its elements to create their own games, enabled learners to creatively engage with disciplinary ideas. The common starting point and physical material (e.g., the components from the board game to be redesigned) could function as enabling constraints that help learners develop shared communication channels and collective goals, which supported their collective decision making. In the iterative process of design and getting feedback, learners' evolving decisions shaped and acted as frames that direct their further

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inquiry into design problems and possible solutions. This could stimulate unique paths of using disciplinary knowledge in learners' groups (Bastani & Kim, 2020; Kim et al., 2020).

Research design and data sources

We conducted this design-based research with grade seven students in Fall 2018 and early 2019. It aimed to engage students with mathematics and science through exploring emergent phenomena, in an art-immersion school in Western Canada. The school's approach is to deliver the subject matters not in isolation, but as connected and as the content of the problems that students can creatively engage with. We developed the activities with the math teacher who is also a game designer. The project mainly focused on engaging students with the math topics of numbers, statistics, and probability and the science topics of interactions and ecosystems and human impact. The cooperative board game *Pandemic* (Z-MAN Games, 2007; Figure 1), which models disease spread across the world, was selected as the game to be redesigned. We expected that the theme and the system of this board game could engage students with exploring emergent phenomena, connected to grade 7 math and science topics. Importantly, the game's inherent complexity could also engage learners' diverse interests and stimulate various ideas and viewpoints, as learners explore its multiple components and possibilities of changing them. In the game *Pandemic*, players take different roles and work together to treat infected populations to buy enough time to complete the ultimate objective which is the discovery of the cures. The main stages of the project included playing *Pandemic* and mastering the rules, brainstorming possible new game theme, narrowing down ideas for using math and science with the teacher, and designing and playtesting the game. We collected ethnographic data through field notes and video-recordings of students' in-progress and final designs. We also had a 30-minute interview with each group on their experience with their redesign project.

Figure 1

a) Pandemic board game, Z-MAN Games (Retrieved from http://bitly.ws/ji22)

Analysis

This analysis aims to explore learners' game redesign processes and the underlying elements that stimulated learners' collective idea development and engagement with learning topics, using the data from two groups in this classroom. In framing our analysis of the groups' design practices, we draw on how the design and creativity research view the design practices' value in supporting learning. They include decision making, adapting to evolving goals, and imagining and examining various alternatives. Importantly and in line with the notion of enabling constraints addressed by complexity perspectives (Davis & Simmt, 2003), the design literature signifies how constraints in the process of design could prompt a pathway to creativity and innovation. They include external constraints such as materials and time limitations, and self-imposed constraints that emerge as designers' ideas interact and lead to design decisions. The design process is a continuous space of experimentation and reflection (Schön, 1992). With every decision, designers impose constraints on their work that not only restrain the next actions but also become tools to think with and to explore new possibilities (Biskjaer & Halskov, 2014).

Divergence and convergence of ideas in the transformation of the design space

Exploring the design process, scholars point to the cycles of divergent thinking, i.e., exploring various possibilities, and convergent thinking, i.e., choosing from alternatives to come to a more focused understanding of a problem or arriving at a solution. Our analytic frame (Figure 2) attends to divergence and convergence of ideas that happen iteratively in the design process (Norman, 2013) and the role of constraints (Biskjaer & Halskov, 2014) including the activities' structure and learners' self-imposed constraints in transforming the design space. Self-imposed constraints are evolving frames that could open the space for designers' further exploration. Through identifying the critical

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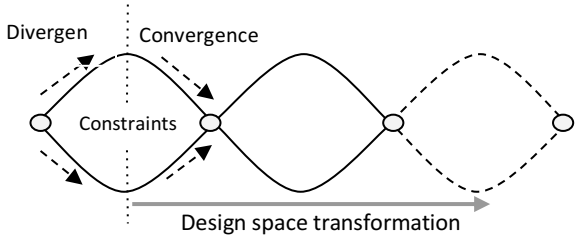
episodes of divergence and convergence of ideas, we investigate how learners' interests and intentional choices enabled them to develop their designs and expand and deepen their use of learning topics.

Figure 2

The analytic framework model adopted from the double diamond model of design (Norman, 2013)



The process of interpreting data

Our coding of data was informed by Barab et al.'s (2001) process for identifying the critical episodes in which learners' ideas and practices evolve, through their interactions with one another, tools and activities. It also attends to the links among these episodes to address the research questions. The analytic frame was used in chunking the data from the groups, identifying the critical episodes and the elements of divergence and convergence of ideas (Table 1). This analysis sought the temporal links among the critical episodes, i.e., how learners' co-designs evolved. It also attended to the students' interim decisions that contributed to developing their designs.

Table 1

An example of the identified critical episodes (Reverse Pandemic)

Episode	Divergence Elements	Supporting Interactions	Convergence Elements	Supporting Interactions
Taking the perspective of bacteria and viruses	Exploring how bacteria and viruses spread and how they act in different environments	Discussing their game story with their science teacher/ using Pandemic to discuss their ideas	Discussing the mechanisms that could strengthen or weaken players (i.e., diseases)/ deciding what diseases they want to use	Researching bacteria and viruses/ drawing diseases' cards/ making parallels between their intended game components and the original game components

Findings

In the following, we discuss the redesign effort of two groups, whose redesigned games were named *Reverse Pandemic* and *Pandemic Theatre Edition*. Elaborating on the identified critical episodes of students' design practices, we address how learners could expand their ideas over time, transform their conceptions of problems and design possibilities, and find opportunities to research on and use learning topics.

Reverse Pandemic: Players acting as viral diseases

The first group developed the idea of reversing the *Pandemic* game story, i.e., creating a cooperative game in which players would act as diseases to overtake the cities and spread around the world. One significant aspect of this group decision was their building on the original game's narrative, and not changing the game's theme completely. The *Pandemic*'s game materials, e.g., the cubes representing viruses, board map, and infection and role cards, mediated the group discussions on their game's aspects and implementing their ideas. Notably, they initially tried to implement their idea of reversing the *Pandemic*'s story by defining opposite functions for the original game's components (e.g., cubes representing cures instead of diseases). This approach might not have been helpful in reversing the dynamics of a game system. For example, in *Pandemic*, the cubes represent the number of infected areas and possible outbreaks. Therefore, simply using them to represent cures would not make meaningful dynamics in the redesigned game. This step was still significant in realizing the need for a deeper exploration of the original game system.

Taking the perspective of bacteria and viruses: Developing the game's backstory and system

The students' focus and practices became more purposeful as they started evaluating the possibilities of implementing their initial ideas while using and creating different game components and rules. A transforming event happened for the group when they shared their ideas with their science teacher. They had a conversation about the theme and rules of *Pandemic,* including the idea of reversing the theme. It started with a question by Jess, one of the group members,

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"how players (diseases) could move ((on the board)) and overcome the cities in their game" and led to elaborating their game backstory and system. Their chosen game theme, as a self-imposed constraint, encouraged them to take the perspective of bacteria and viruses, exploring the mechanisms that players could progress through spreading the diseases. They discussed how bacteria could develop resistance against antibiotics and mutate and evolve. The teacher talked about how diseases spread as the group explained how the original game worked, showing the teacher the original game's elements and their own game ideas. The teacher built on Elaine's discussion on players' (diseases) moving between the cities, using the *Pandemic* game board, and explained how a disease could spread to far away locations due to international travels: "one of the biggest issues with our global community is we travel a lot. An infection that happens in Chicago can easily end up in Jakarta in a day. And then you will have two outbreaks ((pointing to the map))" (Figure 3a) (it should be noted that this project happened before the spread of Covid-19 and the widespread knowledge about pandemics). Taking the diseases' perspective, they then talked about how travelling between cities could advantage players. Discussing the possible defence mechanisms against diseases for cities, they also talked about how making new vaccines could cause widespread and long-term immunity.

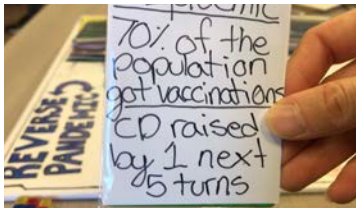
We observed an intentional interaction between the students and teachers mediated by the game materials, e.g., the board map, which supported the integration of learning topics. Their design space with the goal of reversing the theme of *Pandemic*, therefore, changed to include more scientific exploration. Taking viruses' perspective supported their design of game components in a connected way (e.g., how players -- diseases -- could take advantage of moving between cities, and, at the same time, how it could be disrupted by other mechanisms such as vaccination). After these discussions, they did research on different viruses and bacteria and decided which one to use in their game. They worked on their idea of overcoming the cities based on their protection level and developed their player cards (i.e., diseases cards- Figure 3b), their infection cards, and the rules of spreading among the cities.

Numbers, percentages and probability as a tool in materializing ideas

The group found that to reverse the *Pandemic*'s story, they needed to understand this game's system deeply. They evaluated how infection cards, which determined the cities to be infected based on designed probabilities, work and how epidemic cards trigger an outbreak. Put differently, their choice of reversing the *Pandemic*'s story became about reversing the logic of the game, rather than reversing the role of the elements in the game. This self-imposed constraint involved exploring new possibilities of using math in creating a playable game. This exploration converged into using numbers to compare players' power (disease spread) against cities' defence (CD) in their own game. They also designed vaccination cards (Figure 3c), using probability (one out of ten players' cards were vaccination cards), which made cities' defence dynamic: "The city defence changes when 70 percent of the population get vaccination" (Jess).

Figure 3

a) discussing emergent outbreaks in distant location, b) player(diseases) cards (c) vaccination cards

(a) (b) (c) 

Incorporating the feature of their interest into the game

The group decided to have six players (diseases) to differentiate their game from *Pandemic* that has four diseases. They, then, needed to categorize the cities differently as hotbeds for the six different diseases. Grouping the cities, they also engaged with the geographical aspect of *Pandemic*, locating the cities on the map, discussing how to scale down the map and create one for their own game. After exploring how to have a 6-player game, their ideas, then, converged into drawing their own map. This became a challenge of how to connect the cities based on their game goal and designed system. They, therefore, faced a "graph" problem in creating their cities' network (Figure 4a).

Encountering complexities in balancing the game

Having a draft in time, the group could playtest their game. During playtesting (Figure 4b), they found that in their design, diseases (players) couldn't win. They re-evaluated *Pandemic* and noticed how the Event cards, which would give players random advantages, created a power balance (e.g., the ability to predict which cities will be infected next).

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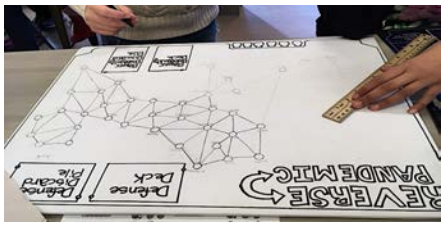
They had created vaccination cards that would give advantage to the cities against players (diseases), but they hadn't used enough mechanisms to give players random advantages. They then designed their own event cards that would randomly allow players (diseases) to make "virus bases" in other countries to travel between them and spread. The group's intention of having a balanced and playable game, therefore, led to make a better sense of the interconnection of different elements in the original game and incorporate their understanding in their own designs, in a way that was meaningful to their redesigned game's narrative. Similar to what Kim et al. (2019) argued, as the students shared their work and confronted their own designs with their applications in the world, they could experience the problems in context and attend to further possibilities. Their more complex understanding was specifically supported through the exchange of group members' viewpoints on different aspects of their game, e.g., how to create a balance, how to modify the graph on their board according to their game goal, and how to make their game meaningfully more complex.

Figure 4

(a) Designing the board, deciding how to connect the cities b) playtesting their game

(a)  (b)

Pandemic Theatre Edition: Imagining a world balanced through science and art

The other group, *Pandemic Theatre Edition*, initially thought of the game theme of eradicating diseases, similar to *Pandemic* but using different mechanisms. After a few sessions of playing the original game, the teacher asked the students to specify their main ideas and the math and science topics they aim to use. As the students mentioned, this encouraged all the group members to put their ideas together, revisit their initial decisions. They chose to develop a new backstory about making a balance in the world in terms of people's happiness, connecting it to climate conditions. Their game backstory included hot and cold places impacted by climate change and areas with sad and "overly happy" people who would destroy the environment. They decided to have research stations, which could help people in hot and cold areas, and theaters, which could balance people's mood. It was notable how they separated the regions impacted by climate change and the regions that worsen the environmental conditions, and how they considered the role of both science and art in creating a balanced world.

Using Pandemic's components to create a form for their game and enact its story

Focusing on how to enact their game backstory, they evaluated how they could use or modify *Pandemic*'s components in their own game. Their ideas converged into using the cubes (representing diseases in the original game) as symbols of the populations moving among the cities. After considering possible geographical scopes for their game, using *Pandemic*'s board, they decided to use the map of the whole world and to not limit their scope. They also modified the infection deck in *Pandemic*, which added cubes to the board, to tell players how to move people between areas to make the intended balance in their game world. In moving people, they used the concept of percentages. Each player needed to calculate a specific percentage of the cities' total population to determine the number of people to be moved. They also talked about how their game represented the concept of negative numbers in a way, as players needed to move people between the cities with opposite conditions. Their developing game theme also allowed them to connect their game more to the science topics of interactions and ecosystem in a symbolic way. For example, they created a "world climate health meter" for the environmental condition. As the condition gets worse, moving between cities becomes more difficult: "when the world health meter gets to like a certain point, … you can no longer fly unless it's a shuttle flight at the research stations" (Ethan).

The group also decided to have different roles for players for creating the intended balance in the world, e.g., a director to "move people on their turn" and an actress to "cure depressed people", and an environmentalist who could "discard a card in research stations or theatre (and) move the climate health meter up." They also discussed these roles' gender and power, questioning perceived boundaries around gender roles. This led to an emergent discussion on politics and how gender played a role in the Clinton-Trump battle, referring to the 2016 US presidential elections. Such interactions suggest that the human aspect of the game theme provided the space

for the students to relate more with the task. In modeling their imagined world, symbolic representations of human actors became a venue for learners to express their perspectives as if they saw themselves in relation to others.

Engaging with complexities in materializing their imagined world

The group's decision on using the whole world as their game scope was an important self-imposed constraint that needed them to specify "too hot" and "too cold" areas and the overall "happiness" of people living in different cities and countries. Creating the actual game elements, then, needed them to explore deeper their idea of imbalances in their game world and the possibility of categorizing the countries based on opposing conditions. This encountered complexity encouraged the students' exchanging their viewpoints, exemplified in the following:

1. Eva: Oops! People in California are sad ((talking about their initial categorization)).
2. Ema: Why? It's so nice out there. There's Disneyland there!
3. Ethan: Yeah! No, the happy people are in California ((pointing to the map to show it))
4. Eva: Russia is sad.
5. Jacob (from another group): Russia is not that sad.
6. Ethan: It is sad in our game. Although if you say Russia is sad out of nowhere then you are kind of a hatist.

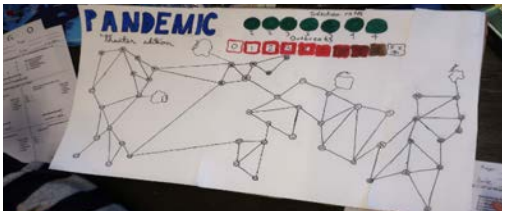
The group also discussed a possible destructive human impact on the environment in the areas where people are "overly happy" because they would not care enough about the impact of their actions on the environment. The decision of having a broad geographical scope for their game did not seem to be significant at the time. It, however, became decisive when interacted with the goal of designing a game with multiple interconnected elements. The group members engaged with complex issues that challenged their simplistic assumptions (e.g., with regards to "sadness" or "happiness" of different regions). Ethan's last utterance (Turn 6) presents a dilemmatic situation for him: although he implied that they would need to make simplifying decisions in modeling their game story, he challenged groundless assumptions. The group's emergent discussions also showcase how addressing a seemingly scientific issue, i.e., climate change in their game, entails attending to social and political factors. This signifies the complexity of the problem the students were engaged with in the context of designing a game system.

Envisioning and moving towards further developments in their game mechanics

Developing their game (Figure 5), the group thought of other design possibilities that could facilitate moving between cities and create "a new way for interaction" (Ethan). Although they could not use all these components in their final game, it was notable how their design process enabled them to expand their view of what would be possible in terms of game dynamics (and the supporting mechanics) and their use of learning topics.

Figure 5

a) The Pandemic Theatre Edition game board, b) Final role cards

(a) 

(b)

Adding chaos and an element of luck. One of these design ideas was adding "immigration cards" to the game to specify what cities players should move between. This might not be in line with what players need in terms of moving people on the board and could add an element of "randomness" and "chaos" as "things would be moving across the board" (Ethan). The group started by evaluating the mechanics of *Pandemic* and explored the possibilities of transforming their initial design to fit their complex backstory and make their game playable and more meaningful.

Using more science. The group used interactions and ecosystems through their "world health meter" marker on their board: as the environmental conditions get worse in the world, going forward would be more challenging for players. However, as Ema reflected, a deeper connection to science was missing. They aimed to use the heat and temperature topic, but it became limited to specifying hot and cold regions. Although it could be a good start, they envisioned possibilities of better connections between their game system and the learning topic.

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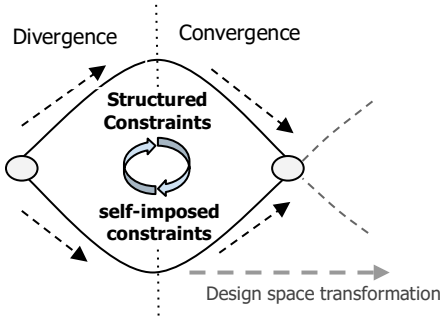
Discussion: the groups' evolving designs and the role of constraints

Our analysis explored the divergence and convergence of ideas and the supporting settings in which learners' design goals and conceptions of solutions evolved (Biskjaer & Halskov, 2014). Here we discuss how the game redesign's structured constraints and the emergent constraints from the groups' interests and decisions enabled them to expand their use of learning topics, adopt new goals, and progress in their design. It also highlights a continuity between structured constraints and learners' self-imposed constraints emerging through the process (Figure 6).

Figure 6

Structured and self-imposed constraints in an evolving design



Structured constraints and tentative boundaries: Foundations for an open-ended task

The project stages aimed to provide a structure within which student groups could develop common languages and collective purposes as underpinnings of group interactivity and idea exchange (Davis & Simmt, 2003). The project structure, mainly starting from a selected common game and the groups' goal of redesigning it, acted as constraints for the broad range of possible design approaches the groups could take at the starting point. In the following, we discuss these structured constraints and how they could enable the groups' focus and progress in their designs.

Playing the original game to decode and destruct what is at hand. The groups started with playing *Pandemic* and, as they engaged with their designs, they needed to further decode this game's system. This, in turn, supported their idea development and decision making as they progressed in their design. The shared understanding of what is at hand and the agency to restructure it could stimulate their imagining of possibilities within the frame of the task. As the teacher put it, there is a mutual relationship between creation and destruction of what already exists, which could be supported in this game redesign project.

Using the original game's components as tools for communication and materializing ideas. The group discussions showed the original game's components acted as tools for students to interact and come up with the elements that would enact their game story. Notably, this supported the groups' focus on the core elements of their own design. The groups had the opportunity of modifying the existing components, i.e., using what already existed in a way that would fit their game (e.g., *Reverse Pandemic*'s use of a similar map as *Pandemic*), while creating what they needed for their unique game (e.g., changing the cities' grouping to have a 6-player game). This signifies an enabling aspect of redesign and its involved constraints, compared to designing from scratch where the broad scope might hinder the groups' focus and translating their ideas into sharable artifacts (Kim & Bastani, 2017).

Attending to project goals and deadlines: Staying within the boundaries of the project. The project had goals and limitations which set overall boundaries for the groups' work (Davis et al., 2015). They mainly included incorporating math and science topics in their redesigned game, the project deadline, and having a shareable game to be played with other groups and students. This overall framework supported students' shared understanding of expectations (Davis & Simmt, 2003), the convergence of ideas in groups, and the groups' making sense of other redesigned games' goals and systems. On the other hand, there were variations in how the groups approached these constraints. For example, the goal of having a balanced game by the deadline encouraged the group *Reverse Pandemic* to have early game drafts, which they could test and get feedback from. This is while the group *Pandemic Theatre edition* focused more on developing their game backstory making it more complex and meaningful, but less on playtesting before the deadline. We observed the important role of the groups' interim decisions as self-imposed constraints in shaping their emergent design process (Biskjaer & Halskov, 2014), which we discuss next.

A continuity between the structure and what emerges through learners' participation

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The open-ended process of design entails iterative goal setting and designers' revisiting their conceptions of problems and solutions, as designers get feedback from their prototypes (Norman, 2013). This could create the setting for learners to adopt intentions in approaching the problems and in using learning topics. The critical episodes of the groups' design practices showed how as learners participated in this design project, structured as redesigning a particular board game, they engaged in intentional interactions with their peers, teachers and learning topics, using design materials and their developing artifacts. It showcased an interconnection and continuity between structured constraints and learners' self-imposed constraints emerging through the process.

Learners' expanding and deepening the use of learning topics building on their design decisions. The groups' interim design decisions were self-imposed constraints, which acted as dynamic frames that not only structured their work but also became tools for idea development (Biskjaer & Halskov, 2014). Students' use of science and math topics emerged and expanded throughout the project. This was intertwined with learners' seeing more possibilities to expand their game backstory and implement their ideas to create a working system. As an example, the group *Reverse Pandemic* incorporated numbers, percentages and probabilities as they went through materializing their ideas and creating a balanced game. Their exploration of the possible mechanisms that could enact their game story helped them make a better sense of the emergent process of disease spread at the global scale.

Engaging with complexities in developing the imagined backstory and turning it into a playable game. The game redesign project was a context for modeling an imagined world developed by students. The groups iteratively developed the backstory of their interest to make it more meaningful. This became a self-imposed frame that triggered their design trajectory. The sophistication of *Pandemic-Theatre Edition*'s backstory encouraged divergent ideas through the design process. This included both adding details to their game story and goal and the design ideas that attended to the possible dynamics and mechanics in their game to enact their story. The groups engaged with emergent discussions on the multiple aspects of their game theme and making a better sense of the complexities involved as they intended to create a modeled world through different signs and symbols.

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The Role of Augmented Reality in Multi-Device Small Group Learning Ecosystems

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Abstract: Augmented reality (AR) has shown benefits for individual learning with single devices and platforms. However, there has been sparse research on the learning effects of more complex technology ecosystems where multiple devices allow for different interactions with the same simulation. This study describes one such multi-device ecosystem where undergraduate students in an astronomy course were presented with a small group problem-solving task where both AR headsets and tablet computers could be used to explore a night sky simulation. We investigated whether students learned the targeted astronomy concepts, and whether the ways the devices were used affected students' learning and their perceptions of the activity. Results indicate an overall learning gain from pre to post, and while participants who used AR did not score higher than students who did not use AR, there was an association between how each device was used and one of the key learning outcomes.

Introduction

Augmented reality (AR) describes a genre of technologies that blend the virtual world with the real world, often through dynamic overlays of "context sensitive virtual information" (Klopfer & Squire, 2008, p. 205). A number of devices have been used to achieve AR, including camera-based applications on mobile devices and immersive headsets. Studies of the efficacy of AR technologies in education have shown benefits on assessments of individual learning outcomes in a range of content areas (Chen et al., 2017; Garzón & Acevedo, 2019; Ibáñez & Delgado-Kloos, 2017; Scavarelli et al., 2021). Many researchers have cited the affordances AR has for enhancing situated action—providing context-responsive visualizations that focus attention and alter a person's perspective in ways that promote learning (Dunleavy et al., 2009; Wu et al., 2013). Radu (2014) notes the potential of AR to leverage people's natural capacity for working with spatial information, and several others have pointed to the ability to create a more personalized learning experience given what the system knows about the individual learner and what data can be collected about their learning behaviors (Dunleavy & Dede, 2014; Huang et al., 2016).

Although a range of AR applications have shown benefits for individual learning with single devices and platforms, we know that learning in the future will increasingly take place in more complex spaces where there are multiple people, multiple devices, and multiple modalities with which to interact. The types of learning challenges that students will encounter in these spaces will require them to work with and reconcile multiple representations (White & Pea, 2011). There has been some research on face-to-face multi-user technologies such as large multi-touch display surfaces that have been shown to be effective for facilitating collaborative learning (e.g., Mercier & Higgins, 2013). Likewise, there have been a handful of studies on multi-user "mixed reality" environments (e.g., Kim et al., 2021; Lui & Slotta, 2014). To our knowledge, however, there has been little if any research on the learning effects of technology ecosystems where multiple devices allow for different perspectives and different interactions with the same phenomenon or simulation.

There are important and unresolved design questions concerning how to coordinate multiple devices to both support synergistic interactions between groups of students and ensure that individuals in those groups come away with robust understandings and the ability to flexibly apply their knowledge to new contexts. In particular, there are questions specifically about immersive technologies such as AR and the role that it can and should play in these layered ecosystems. In these more complex configurations, the question is more than whether or not someone uses AR, but rather how they are using it, for what purpose, and with whom? This opens up additional questions about how to assess the impact of AR integration into the learning process. These implementations must take a multidimensional assessment approach, examining learning in the context of users' perceptions of the technologies, tasks, and group interactions. While there has been some early work attempting to explore these dynamics (Bork et al., 2021; Radu & Schneider, 2019), the mixed results from these studies motivates the need for additional research.

The current study explores the issue of learning effects in a multi-device ecosystem in the context of undergraduate astronomy courses. Astronomy is a well-suited content area for this investigation because it is a domain where students are frequently asked to reconcile multiple spatial perspectives to explain complex

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phenomena such as the causes of seasons (Plummer & Maynard, 2014). The specific research questions for this study are:

RQ1. To what extent did students learn the target astronomy skills and concepts while working in a multi-device (AR and tablet computers) small group ecosystem?

RQ2. How are learning outcomes and perceptions of/attitudes toward the learning activity different between students who used the AR device and those who did not?

RQ3. How did the ways that individuals used the devices affect learning outcomes and their perceptions of/attitudes toward the learning activity?

Methods

Participants and Study Design

The participants were 77 students recruited from an introductory astronomy course at a university located in the mid-western United States. All participants in the study consented to have their classroom activity data collected as part of this research. The study took place during participants' 50 mins weekly lab session for a consecutive three-week period during the Fall 2021 semester. In Week 1, the research team introduced the simulation software and let students explore it using both AR and tablet computers that were provided to them. This exploration was guided with a task sheet that highlighted the functionality that participants would be asked to use in the upcoming weeks. In Week 2, students worked on a seasons lab which was part of the students' regular course material. Students also had the opportunity to use our software and devices while they were working on the lab tasks in Week 2 of the study. The purpose of these first two weeks was to let students become familiar with our software and devices; no data from these weeks were used in the analysis described in this paper. In Week 3, the students engaged in a multi-device small group learning task designed by the research team called "Lost at Sea." During this week, students were randomly assigned to groups of three to four such that they could work on the task collaboratively.

There were a total of 8 lab sessions and each session had three to four groups (22 groups in total). Groups had the entire 50 mins of the session to work on the task together. One AR device (the Microsoft HoloLens 2) and two tablet computers were provided to each group. The research team encouraged the groups to use both devices while they explored the simulation in the first two weeks and in the introduction to the Lost at Sea task, but once the students started working on the task independently, they were able to make their own choices about which devices to use and when. All student interactions on the Lost at Sea task were video recorded using a tripod-mounted camera, and screen captures were taken from all the devices including AR. Students completed pre and post learning assessments as well as an individual post questionnaire administered at the end of the session.

Multi-Device Ecosystem Design

The digital sky simulation software utilized in this analysis was the product of multiple co-design cycles between the research team and collaborating astronomy educators. The system provides users with a stellar catalogue that can be explored across both space (location on Earth) and time. In addition, the system is networked between tablet and AR users, allowing all group members to annotate the night sky (e.g., sketching lines), highlight specific constellations of interest, share location information, and share their night sky perspectives collaboratively as they work. Interaction on the tablets is touch-based, while interacting in AR leverages hand and gesture detection to allow the user to tap interface items, pinch holograms to reposition them, and tap their index and thumb together to select distant objects such as stars.

Figure 1 shows a group accessing the three simulation representations available in the system, all accessible in both the tablet and AR platforms. The system was designed so that the interface was as consistent as possible across AR and tablets to reduce the need to "re-learn" the software when entering AR (see blue input and info panels in Figure 1). "Horizon view" (top-right) provides the user with a first-person view of the sky as if standing on Earth. "Star view" (bottom-right) removes the horizon limitations from the perspective, giving the user access to the full celestial sphere. "Earth view" (bottom-left) places the user in orbit above the Earth with the ability to place location pins with which to change their position on the Earth or confer with other users about potential sky viewing locations. All group software interactions (interface manipulations, view changes, annotations) were written to log files for later analysis.

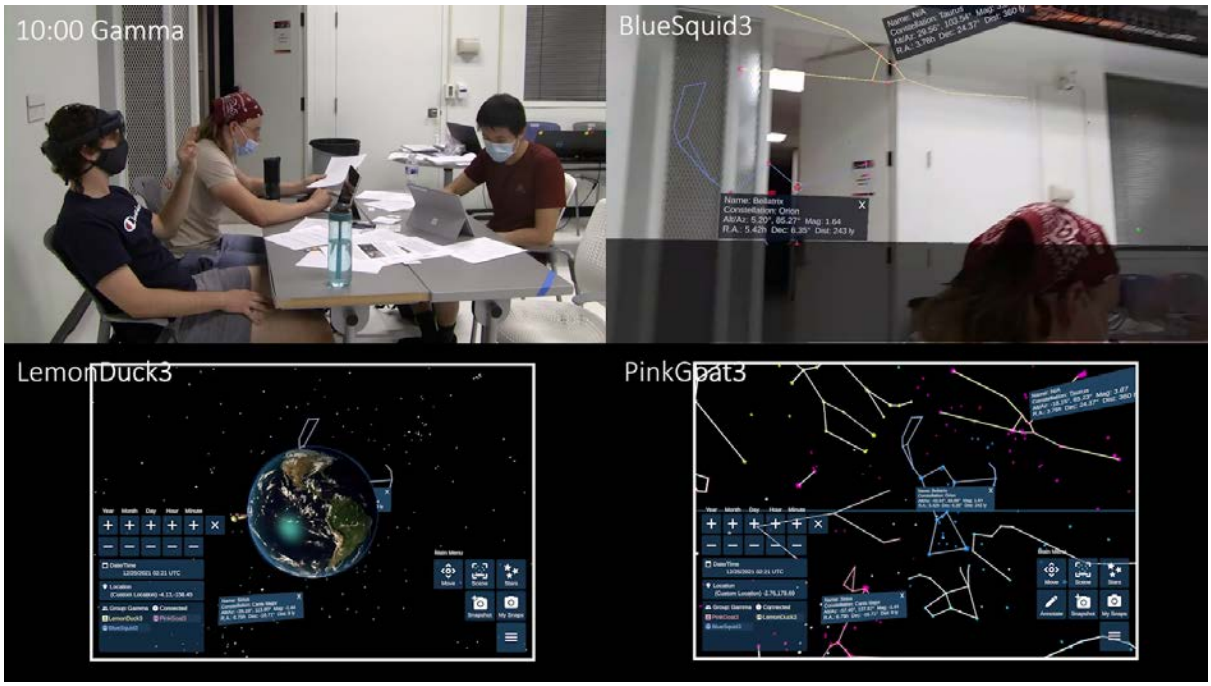
Task Design

A multi-part problem solving narrative was created for students to address in the "Lost at Sea" task. The goal was to promote authentic problem solving and in-depth utilization of the simulation. The narrative describes a crewed space capsule that has splashed down at night at an unknown location. The simulation contains a selection of

specially bookmarked locations with no associated latitude or longitude data, and students are tasked with using their night sky knowledge to determine the latitude and longitude of their capsule splash-down site. There are three parts to the task: Subtask 1 has the group locating stars or reference constellations to determine what hemisphere they are located in; Subtask 2 then asks the group to identify constellations that can serve as reference points for North, South, East, and West; finally, Subtask 3 asks them to formally calculate their latitude and longitude. The ability to use night sky data to determine the latitude and longitude is the overarching learning goal for this activity. Supporting task documents outlining the task goals, as well as supplemental information on the process of latitude and longitude calculation, are accessible to the group. What makes longitude calculations especially challenging is that the supporting instructions reference the most common process of leveraging the position of the sun, but groups must transform that knowledge to calculate longitude using the night sky instead.

Figure 1

Composite screenshot of the multi-device learning ecosystem showing the three views of the simulation: Top right (AR in Horizon view), bottom right (Tablet in Star view), and bottom left (Tablet in Earth view).



Measures

We conducted two paper-based assessments: pre and post learning assessments and post questionnaires about perceptions and attitudes. Pre and post learning assessments were designed to measure whether students' knowledge of how to calculate latitude and longitude changed based on their interactions with the multi-device learning ecosystem described above. Both learning outcomes entail a multi-step process, and a short open response prompt allowed the research team to evaluate the completeness and accuracy of students' understanding of this process. The prompts in both the pre and post learning assessments were the same: "Write as much as you know about the steps for calculating latitude/longitude based on the stars visible in a given location." To assess students' responses, two researchers (1st and 2nd author) looked through all students' answers together and scored them based on a rubric developed during pilot testing of the multi-device learning ecosystem (Kim et al., 2021). If students' answers did not contain any of the key astronomy concepts or they did not respond, we scored them as 0. If students' answers only contained basic concepts, then we scored them as 1 (e.g., we need to find a certain star's height to calculate latitude; calculating longitude is related to the time and location). If students' answers contained all desired astronomy concepts, then we scored them as 2 (e.g., we need to find Polaris and measure its height from the horizon, and it is the latitude for Northern hemisphere; we need to find when a certain star is at the highest point in both Greenwich and crash site to find the time difference then multiply it by 15 to calculate longitude). The post questionnaire consisted of five-point Likert scale items asking how they felt about their perceptions of and attitudes toward the multi-device group collaborative learning activity: "While working with your group, how often did you rely on your group members for help on a task or concept?", "While working in

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your group, how often did your group members rely on you for help with a task or concept?", "While working in your group, did collaborations occur frequently between students using AR and students using tablets?".

In addition, open-ended questionnaires asked participants what tasks they completed while they were using each device. The first and second authors also classified these open-ended post-questionnaire items based on the coding scheme detailed in Table 1. The coding scheme was applied for both types of device-use (tablet and AR), but for tablets only level 2 and 3 were employed, because all students used the tablets at least once for exploring or measuring.

Table 1
Classifying how students used technology

Level		Description	Example
0	Not used	Student did not use the device at all.	I didn't use AR this week.
1	Adjust to the technology	A student used the device but adjusted to the technology itself rather than using it for problem-solving.	Mostly focused on understanding AR.
2	Exploring	A student used the device to explore the night sky and clicked on some stars and constellations.	I selected a few constellations in the AR.
3	Measuring	A student used the device to calculate or measure for the task completion (e.g., location change, tracking time, etc.).	I used the tablet to change locations, set the time, and find constellations.

Results

Our first research question asks whether students learned the targeted astronomy content (calculating longitude and latitude) while they worked on the multi-device small group activity. Wilcoxon signed rank test (paired) was conducted on the students' pre and post learning assessment scores. The result shows that the pre assessment median score is significantly different from the post assessment median score for both latitude ($p < 0.001$, effect size $r = 0.56$) and longitude ($p < 0.001$, effect size $r = 0.54$). Table 2 shows that for both latitude and longitude, the number of students with 0 points decreased and the number of students with 1 and 2 points increased on the post-assessment. Since longitude is a more complex calculation, it is not surprising that scores for this measure were lower than for latitude.

Table 2
Pre-assessment and post-assessment score distribution

	Latitude		Longitude	
Score	Pre	Post	Pre	Post
0	59	31	74	48
1	12	17	3	21
2	6	29	0	8
Total Participants	77	77	77	77

Our second research question asks whether there is a difference between students who used AR devices and students who did not in terms of learning outcomes and perceptions of/attitudes toward the learning activity. First, we conducted the Mann-Whitney U test to measure the learning outcomes. The result shows that whether or not students use AR during the lab session did not affect either of the learning outcomes (e.g., latitude: $p = 0.82$, longitude: $p = 0.32$). Combining this with Wilcoxon signed rank test result (research question 1), we can conclude that students learned desired content regardless of their use of the AR devices. We did not conduct the same measurement for the tablet since all the students used tablets. In addition, we conducted a One-way ANOVA to measure perceptions of the learning activity. The result also revealed that whether students used AR devices or not does not impact these perceptions (e.g., Individual reliance on group: $p = 0.43$, Group reliance on individual: $p = 0.39$, Frequency of collaboration: $p = 0.74$).

Our last research question asks how the way in which individuals used each device affected learning outcomes and their perceptions of the learning activity. First, we conducted an Ordinal Logistic Regression to measure the relationship between how students used each device and learning outcomes. The estimated model shows that:

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For latitude

$$\text{Logit}(P(Y \leqq 1)) = 2.67 - 0.29 * \text{AR usage} - 0.95 * \text{Tablet usage}$$
$$\text{Logit}(P(Y \leqq 2)) = 3.65 - 0.29 * \text{AR usage} - 0.95 * \text{Tablet usage}$$

For longitude

$$\text{Logit}(P(Y \leqq 1)) = 0.14 - 0.12 * \text{AR usage} - (-0.21) * \text{Tablet usage}$$
$$\text{Logit}(P(Y \leqq 2)) = 3.65 - 0.12 * \text{AR usage} - (-0.21) * \text{Tablet usage}$$

Based on the model, the odds ratios are presented in Table 3. For *latitude*, for every one unit increase in students' AR usage (i.e., Adjust to the technology → exploring), the odds of being more likely to get a higher score (i.e., 1 or 2 versus 0) is multiplied 1.33 times (i.e., increases 33%), holding constant all other variables. For students who used tablets for measuring, the odds of being more likely to get a higher score (i.e., 1 or 2 versus 0) is 2.60 times that of students who used tablets for exploring, holding constant all other variables. For *longitude*, for every one unit increase in students' AR usage, the odds of being more likely to get a higher score is multiplied 1.13 times, holding constant all other variables. For students who used tablets for measuring, the odds of getting a higher score (i.e., 1 or 2 versus 0) is 19% lower [i.e., (1 - 0.81) * 100%] than the students who used tablets for exploring, holding constant all other variables.

Table 3
Odds ratios for each learning outcome

Latitude			
	OR	2.5%	97.5%
AR usage	1.33	0.88	2.03
Tablet usage	2.60	0.89	8.10
Longitude			
	OR	2.5%	97.5%
AR usage	1.13	0.73	1.78
Tablet usage	0.81	0.28	2.47

Furthermore, we conducted a Two-way ANOVA to measure the relationship between how students used each device and their perceptions of the activity (see Table 4). Results revealed that there is a significant difference in the extent to which they felt that they relied on their group members based on how the students used the tablet computers ($F = 3.92$, $p = 0.05$). How they used AR also has a marginally significant effect on students' perceived group reliability ($F = 2.23$, $p = 0.08$), so we decided to look more deeply using the Tukey post hoc test to see if there are any significant pairwise differences. There is a marginally significant pairwise difference between 3 (measuring) and 1 (adjusting to the tech), ($p = 0.06$). These findings indicate that the way students used tablets influenced students' perceived dependency towards the group, and there is a pairwise difference when students used AR as a measuring technology compared to when students used AR simply to acclimate to using the technology itself on the students' perceived dependency towards the group. This means that the students who used AR for measuring felt less dependency towards the group compared to the students who used AR solely to learn how to use the technology. There were no significant differences for other perception questions yielded by different types of technology usage (see Table 4).

Table 4
How different usage of each technology affects students' perceptions of the learning activity
(* indicates $p < .05$)

Two-way ANOVA					
Individual reliance on group	df	Sum sq	Mean sq	F	p
AR usage	3	4.57	1.52	2.23	0.08
Tablet usage	1	2.64	2.64	3.94	0.05*
Residuals	72	48.32	0.67		
Group reliance on individual	df	Sum sq	Mean sq	F	p
AR usage	3	0.46	0.15	0.24	0.87
Tablet usage	1	0.00	0.00	0.00	0.98
Residuals	72	45.34	0.63		
Frequency of collaboration	df	Sum sq	Mean sq	F	p
AR usage	3	3.00	1.00	0.93	0.43
Tablet usage	1	0.47	0.47	0.44	0.51

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Residuals	72	77.77	1.08	

Tukey's Honestly-Significant-Difference (TukeyHSD) Test for AR Usage and Individual Reliance on Group

AR usage	diff	lwr	upr	p adj
1 - 0	0.74	-0.17	1.64	0.15
2 - 0	0.11	-0.51	0.74	0.97
3 - 0	-0.15	-0.86	0.55	0.94
2 - 1	-0.63	-1.48	0.23	0.22
3 - 1	-0.89	-1.80	0.03	0.06
3 - 2	-0.26	-0.90	0.37	0.70

Discussion

The significant pre to post learning gains measured here suggest that productive learning can occur when students engage with problem-solving tasks within a multi-device small group ecosystem. In and of itself, this is a meaningful result, showing that the combination of AR and tablet technology integrated through a multi-part problem solving task did not detract from, and may have benefitted, the core instructional goals of the implementation. Interestingly, the learning gains experienced as a result of engaging with the multi-device ecosystem was not affected by whether or not a participant used the AR headset. One possible interpretation is that the learning effects of this intervention stem from the overall ecosystem and not from a specific device; a participant does not necessarily need to put on an AR headset themselves to receive the benefit of someone in the group having and sharing that perspective. Likewise, participants' perceptions of whether they relied on the other members of the group and whether the group relied on them were not affected by AR usage. This again suggests that participants felt that they were interacting with a dynamic system of people and technology as opposed to a single device.

In general, it was clear from this analysis that simply accounting for whether students used the AR device or not does not provide a complete picture of how the technology influences learning and perceptions of the activity. When we examined *how* the technology was being used, we began to see a more nuanced relationship between AR usage and performance on the problem-solving tasks. Specifically, the categorization of usage into exploring and measuring behaviors proved to be a useful lens for analysis. We discuss these results in terms of our two primary learning outcomes: calculating *latitude* and calculating *longitude*. We are keeping our discussion of these outcomes separate because the results were slightly different, and because the tasks themselves present different levels of challenges, as described below.

When examining student learning performance around the calculation of *latitude*, while the AR usage levels showed some benefit to the likelihood of an increased assessment score, tablet users showed substantially higher likelihood when engaging in tasks related to measuring as opposed to exploring. These relationships are potentially due to the affordances of the AR and tablet technologies, highlighting differences in the user interface actions required for exploration or measurement. Exploration interactions (such as panning the sky to locate a star) in the tablet required the use of arrow key touch buttons, while within AR a user needs no interface interactions (simply rotating their head and body) to modify their view. Therefore, it is much more natural and easier to explore and find constellations in the night sky with the AR environment. In contrast, measuring interactions (changing time, drawing annotations) use similar combinations of buttons (touch or holographic) and selection actions to complete. The condensed layout and faster response of the tablet interface (as opposed to "pressing" a holographic button) may have been a contributing factor in facilitating the likelihood of higher knowledge scores for the tablet users.

With the calculation of *longitude*, we see again that moving up levels of AR usage still shows a positive relationship with higher level post assessment scores although it slightly decreased compared to the latitude learning outcome. The result for tablet usage here is reversed, with tablet users engaging in exploration showing increased likelihood of higher assessment scores when compared to those who engaged in measuring. As we mentioned in the Task Design section of the paper, the longitude task was intentionally designed to be more difficult to solve since it requires students to do a higher-level calculation and transfer knowledge from a different scenario. Here the complexity of the longitude task potentially plays a large factor. To calculate longitude, a group needs to engage in a series of alternating exploration and measurement/manipulation behaviors, reducing the likelihood of one device type dominating the other due to an interface affordance. Although our RQ1 finding verified there is a pre to post increase on the longitude measure, it is also true that many of the students still remained at 0 or 1. This motivates us to investigate students' higher-level/complex learning outcomes by analyzing more diverse data (e.g., students' group discourse, log data, etc.) beyond their self-reporting.

When examining student perceptions of the activity, we see a significant relationship between their ratings of how often they felt they relied on the group based on their level of tablet usage. In other words, if the

students used tablets at a higher level (e.g., measuring), they perceived they were more reliant on their group members. This may mean that students tried to solve problems by interacting with group members rather than solving everything by themselves when trying to calculate or measure something. For example, in order to calculate longitude, information on two particular locations is required at the same time. To do this, a student using a tablet at a higher level may have sent other students to each of those two locations to find information. In addition, the notable pairwise difference for perceived reliance on the group in AR between level 3 (measuring) and level 1 (simply adjusting to the AR technology) may indicate that if students used AR for measuring, they did not think they relied on the group compared to when students use AR simply to get familiar with it. This makes sense because if students are using AR to get familiar with it, they are likely to ask group members some questions about how to use the device, while if students are using AR for measurement, they are likely more focused on the task and less in need of relying on their group.

Taken together, these results contribute to an increased understanding of how groups can begin to engage in a complex problem solving task with the support of AR technologies. The analysis performed here provides insight into the role of user perceptions of technology and group interactions and the relationship of these perceptions with learning outcomes. Moving forward, it is clear that effective designs that incorporate AR into small group learning environments alongside other technologies must be cognizant of the affordances attributed to each platform, and the role they can play in facilitating specific patterns of interaction and measurements of learning. In the current study, we primarily focused on the students' self-reports of their usage of the technology. Furthermore, this study was conducted during existing university class sessions, not in a controlled experimental environment. As to keep a classroom atmosphere, we wanted to give students autonomy over which device to use and how much to use, rather than force them to use all devices evenly. Therefore, this paper mostly focuses on the effectiveness of a multi-device learning ecosystem as a whole, and how the ecosystem should be designed based on the students' usage of each device. To have a more detailed understanding of how the students' different device usage affected their learning and what are the educational effectiveness of individual device usage, our future research will include discourse analysis (e.g., topic modeling and association rule mining) along with log data analysis. We will investigate how the students' discourse topics vary when they are using different devices, how those different discourse topics are associated, and if there are any relationships between the topics and certain types of student-software interactions.

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Leveraging Students to Generate Skill Tags that Inform Learning Analytics

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Abstract: Generating skill taggings for learning activities is a task typically performed by instructors and domain experts, which can be challenging to scale due to the required expertise. However, these skill tags are used by many learning analytic platforms. In this work, we investigate the feasibility of leveraging students to generate skill tags in an online learning setting. Across four instances of two online courses in chemistry and programming, we embedded an optional and low-stake activity, where students were asked to propose three skill tags to a given problem in the course domain. We found that 12% of the student-generated skill tags matched expert-generated ones used in the courses while 54% of them were unusable even with revisions. Our results suggest that students are willing to engage with an optional skill tagging activity; however such interventions should be accompanied by scaffolding the process for students to yield higher quality responses.

Introduction

Educational technologies, such as intelligent tutoring systems and digital learning platforms, often employ a mapping of skills to assessment items in order to measure student performance and guide them in the learning process (Bier et al., 2014). These skills treat student knowledge as "an acquired unit of cognitive function or structure that can be inferred from performance on a set of related tasks" (Koedinger et al., 2012). Typically the skills mapped to assessments in these technologies are at a fine granularity intended to measure the low level concepts assessed by a given activity, compared to the higher level skills often found in summative assessments that are often at the standard or learning objective level (Guilbert, 2002). This skill mapping is intended to capture the student's underlying cognitive process and is vital to many core functionalities of educational software, enabling features such as adaptive feedback and hints (Moore & Stamper, 2019).

While having these skills allows for student modeling and can assist in analytical pipelines like open learner models or learning dashboards, developing the mapping of skills to assessments poses several challenges. Traditionally an expert is employed to create the mapping of skills to an assessment, potentially with assistance from an instructional designer or learning engineer (Koedinger & McLaughlin, 2010). This process can be arduous and often requires methods such as think-alouds to elicit the skills from the expert while avoiding pitfalls such as expert blindspot (Nathan et al., 2001). As a result, scaling this process is challenging due to the time constraints, resources for eliciting the skills, and recruiting the domain experts to assist with skill tagging (Matsuda et al., 2015).

Attempts have been made to scale this process, as several studies have turned to crowdsourcing to recruit a pool of humans to skill tag assessments (Moore et al., 2020a, Moore et al., 2020b). While there was surface level success with this pool of human judgement, prior knowledge of the domain is often required to properly generate and map skills to assessments (Koedinger & McLaughlin, 2010). Enlisting students, who have varying domain knowledge and have been successful in related tasks, may offer a viable solution to this problem (Williams et al., 2016).

To explore how we could potentially engage and scale a group of humans in the skill tagging process, we sought to test a novel solution that utilized a more knowledgeable base. To utilize students in generating skill tags, we deployed a completely optional activity where students could input three skills, via free-text boxes, needed to solve a problem in the context of four undergraduate online courses. This study contributes new knowledge about student participation with optional tasks in an online course, particularly one involving skill tagging. It also supports how student performance correlates with the quality of their skill tags. The results provide insights into the feasibility of leveraging students to skill tag problems and challenge us to further investigate how we can deploy interventions that leverage student knowledge to develop stronger learning analytics.

Theoretical framework

A skill refers to a granular piece of knowledge that is required to solve a particular problem in a digital learning environment (Koedinger et al., 2012). These skills power a plethora of learning analytic resources: learning curves, open learner models, adaptivity, and many more (Stamper & Koedinger, 2011). Findings have demonstrated that

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digital learning environments that leverage this skill-powered adaptivity, such as cognitive tutors, can help students reach mastery in 26% less time compared to traditional classroom instruction (Koedinger et al., 2012). These systems and the advances they bring all rely on having accurate skill tags, meaning they are written at the correct level of specificity and model part of the knowledge required to solve the problem.

Skills used for these learning analytics systems are more fine-grained than learning objectives or common core standards that typically get mapped to sections or pages of a given course that encompass multiple skills (Badawy et al., 2016). For instance, a learning objective for an algebra course might be "Graph linear and quadratic functions and show intercepts, maxima, and minima". Learning objectives in contrast are fairly broad and encompass several larger concepts that could further be broken down. On the other hand, skills refer to a specific semi-granular subject area associated with a learning resource (Razzaq et al., 2007). An example of a skill tagged to a problem in an algebra course might be "Identify the slope from an equation in the form of y=mx+b". While the skill involves knowing other concepts such as slope-intercept form and arithmetic operations, it is specific enough to be assessed by a single problem and can be encompassed by the larger learning objectives for the course. Note, skills should be relevant to both the problem and the context of the course. For example, while knowing what "+" and "=" mean in the problem is required, a problem in an algebra course would not necessarily be assessing students for that knowledge.

Traditionally, generating and mapping skills to assessments is done by experts that are familiar with the process of skill tagging, their required granularity, and with knowledge of the given domain (Koedinger & McLaughlin, 2010). Frequently when an expert instructor is utilized to create skill mappings, a cognitive task analysis (CTA) or think aloud is conducted (Chipman et al., 2000). In CTA, an expert is interviewed and performs a series of tasks while articulating their thought process, which are intended to specify the cognitive processes associated with task performance. During this process, the interviewer records the skills being articulated by the experts. Studies have shown this leads to effective instructional designs and an accurate skill mapping, but requires substantial human efforts (Lee, 2004). These methods are done so the domain expert involved can potentially overcome expert blind spot, where the explicit steps taken to solve a problem can get grouped together when it becomes second-nature (Nathan et al., 2001). This can impede the skill tagging process, as the expert might otherwise overlook a skill that is innate to them, but one that is critically assessed by the given problem.

Compared to experts, students' knowledge of a domain can be classified towards novice, which may help them avoid some of the pitfalls of expert blind spot, as they can leverage the knowledge of their own previous misconceptions in the learning process (Edens & Potter, 2008). The same CTA methods have been leveraged on novices such as workers on a crowdsourcing platform to provide knowledge components for problems in the domain of geometry and college-level English writing (Moore et al., 2020a). This study had crowd workers complete several assessments and then prompted them to provide the skills, via free-text boxes in a survey, they needed to solve the last problem they completed. They found that roughly half of the skills generated by experts and previously used for the problems in both domains were able to be matched by the skills generated by the participants. While crowdsourcing skills demonstrated baseline success by matching some of the expert skills, the specificity of the skills was not at the appropriate level of detail, perhaps in part due to the lack of domain knowledge of the crowdworkers.

In the present work, we propose utilizing students to help skill tag problems, to create and scale high quality skill mappings that are at the correct level of detail to be utilized by learning analytic systems. As a first step towards this, we must first investigate if students can successfully provide accurate skill tags. To test this, we present students with an optional skill tagging activity embedded in their online coursework. We then utilize a 4-item rubric to assess the quality of students' skill tags and analyze how they relate to both expert-generated ones and the students' performance in the course. The two specific research questions we address are: (1) How accurately can students generate skill tags that domain experts have identified? and (2) How does the accuracy of students' skill tags relate to their participation and performance in the course?

Methods

Learning platform

The present study takes place in a digital courseware platform known as the Open Learning Initiative (OLI). OLI is an open-ended learning environment that offers courses from a variety of domains (such as chemistry, biology, statistics, economics, etc.) and consists of interactive activities and diverse multimedia content (Bier et al., 2019). OLI activities are presented in two distinct categories: low-stakes/formative, providing students with feedback, or high-stakes/summative, used to evaluate student learning at the end of a structured unit. The low-stakes formative assessments in the system are all optional, allowing the students to scroll by them and focus purely on the instructional content. These assessments consist of a variety of question types such as multiple-choice questions, short answer, and dropdown style questions. Each question in OLI is broken down into one or more problem steps,

where each step corresponds to an opportunity for student input. For instance, if a question asks a student to set the value of three dropdown boxes, then it consists of three unique steps that each have their own set of feedback and correct or incorrect responses. This distinction between a problem and its steps is important, since students may work on a problem, but not complete all of the steps due to reasons such as not knowing the answer to some of them, wanting to skip them to save time, or getting distracted (Chen et al., 2018).

Study context & students

For this study, we used data collected from four instances of two different introductory courses, one in chemistry and the other in Python programming. The two instances of the introductory chemistry course were taught at a community college in the western United States. This course provides students with fundamental knowledge of chemistry concepts, preparing them for future biology and chemistry courses. The course is generally geared towards freshman and sophomore undergraduates from varying degree backgrounds, with a majority of the students pursuing a chemistry-related degree. Our data comes from the fall semester of 2020, when the introductory chemistry course was offered in the OLI system.

The OLI content the students used for these two instances of the chemistry course in this study covers the topic of elements and compounds and consists of thirteen separate modules. Each module consists of several topic headers, containing paragraphs of instructional text and low-stakes activities embedded throughout. There are a total of 33 low-stakes and completely optional activities embedded throughout the thirteen modules of the course, not including the skill tagging activity used for this study. These activities include multiple-choice questions, selecting the correct option from a dropdown, drag-and-drop exercises, and submitting a short answer to compare against an expert response. Each of these activities is broken down into steps, depending on the components of the activity, for a total of 178 unique steps. For instance, if a problem has three fill-in-the-blank boxes, then that problem would consist of three unique steps. Every activity and their steps provide students with feedback after they have been answered. Additionally, students have unlimited attempts to answer these questions, so they can continue until they are correct or choose to advance, regardless of a correct or incorrect response.

The two instances of the introductory Python programming course were taught at an R1 university in the northeastern United States. This course provides students with knowledge on introductory concepts in the Python programming language, preparing them for their future coursework in computer science. This course was taught to incoming master's students in a human-computer interaction program who indicated by self-report they did have a sufficient understanding of programming concepts. The collected data we used comes from the summer semesters of 2020 and 2021, when the course was offered in the OLI system. The OLI content in the two instances of the programming course covers the topic of iteration and consists of twelve separate modules. There are a total of 41 low-stakes and completely optional activities embedded throughout the twelve modules of the course. Each of these activities is broken down into steps, depending on the activity, for a total of 113 unique steps.

While the four course instances were taught in different semesters by different instructors, students were provided with the same set of instructions regarding the use of the OLI materials. They were not required to answer the questions found throughout the OLI modules or even access them. Students were provided with an "Introduction to OLI" module, which is an overview of how to effectively make use of the system and the concepts that will be covered in the course. All the instructional materials in OLI were optional to the students; there was no requirement for them to access or complete the materials. However, students were assessed on the concepts covered by the OLI materials, so it was beneficial for the students to utilize them. A further breakdown of the course offerings, including the anonymized instructor, semester, and number of students that accessed the course materials can be found in Table 1.

Table 1, The four course instances used in this study

Course	Semester	Instructor	Student Count	Number of Activities
chem 1a	fall 2020	t1	23	33
chem 1b	fall 2020	t2	26	33
programming 1a	summer 2020	t3	33	41
programming 1b	summer 2021	t4	30	41

Data collection

We focus on an activity we added to this course that involves the students generating three skills that they believe are required to solve a particular problem in the course[1]. In the chemistry course, this activity is found in the ninth module of the OLI content for this section of the course. This module provides several paragraphs of instructional text, two worked examples, and several low-stakes multiple-choice questions on the topic of nomenclature for

ionic compounds with polyatomic ions, along with this single activity. In the programming course, this activity is found in the fourth module of the OLI course. This module covers the concept of python for-loops, consisting of several paragraphs of instructional text, multiple-choice questions, and two small programming exercises. In both courses, the activity is presented in the same low-stakes and optional format as the other activities found prior in the course. This task that prompts students to generate the three skills can be found in Figure 1. In the activity, students are prompted to generate three skills that are needed to solve the problem stated above this task. The students input the text in three different free-text boxes. The instructions for the task are minimal to encourage student participation, as lengthier text might deter students (Schmidt-Weigand et al., 2010). We also provide them with a domain contextual example of what a skill might look like for a different, non-related, problem in[1] the course. Aside from that, no training or scaffolding was provided to the students to help them generate three skills for the question. We intentionally wanted to keep this low-stakes and optional, to examine the students' participation with the task and the quality of their contribution.

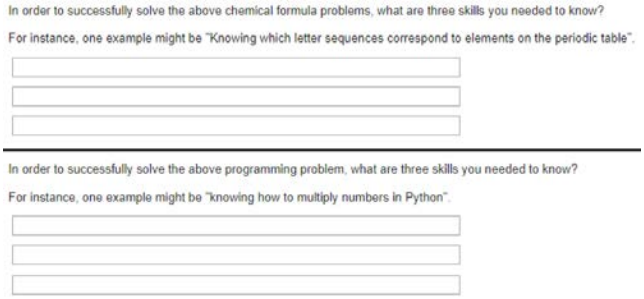

Figure 1. The self-explanation activity and accompanying question presented to the students.

Dataset

Student data was collected from their interactions with the 33 activities found in the chemistry course and the 41 activities in the programming course, in addition to the skill generation task. Since the skill generation task is our outcome, we focus our analysis on the other activities that the students completed in the courses, which consisted of a total of 178 unique steps in the chemistry courses and 113 unique steps in the programming ones. On average, an activity in the course consists of 3 unique steps, such as a single activity having the student select from three different dropdown menus. All of the activities found in the OLI course were completely optional; students could do as much or as little as they desired. For instance, sometimes a student would begin working on an activity, but did not complete all of the parts in it. As a result, the system logs them having worked on that activity and also provides the exact number of steps that they completed. For this data set in particular, it is more common for students to fully complete an activity if they start it, i.e., they will attempt all of the steps of a problem.

Our data also consists of three metrics related to student performance on the activities. When a student works on a step for a given activity, OLI records if their first attempt at that step was correct or not. A first attempt at a problem can be a strong indicator of a student's current understanding of the concepts being assessed (Corbett & Anderson, 1994). Relatedly, the total number of incorrect attempts made at a given step and the total number of correct attempts are recorded. These numbers can potentially exceed the total step count, as a student could correctly answer a question, then select an incorrect answer to see the feedback, then select the correct response once again, registering two correct and one incorrect attempt for that step.

Analysis

In order to assess the quality of the three student-generated skills, we had two item-raters evaluate each skill to determine how much it fit the problem, if it was at the appropriate granularity, and its match to the three skills previously assigned to it by other domain experts. Both raters had content-area expertise, ample experience in skill tagging, and experience applying coding schemes to student data. After familiarizing themselves with the OLI course module once again, they were instructed to go through each skill one at a time and place it into one of four categories. The inter-rater reliability was calculated, and the Cronbach's alpha value was .94, as the raters only disagreed on the categorization of a few skills. These discordant skills were discussed among the two raters until they reached a consensus on the categorization of them using the coding categories. Each of these categories was assigned to a numerical ranking (1-4) that also represented the goodness of the student-contributed skill. In this instance, a ranking of 1 was the best and indicated that the student-generated skill matched the expert-

[1] The full content of this activity is included in https://github.com/StevenJamesMoore/ICLS2022/blob/main/learnersourcing_activities.pdf

generated skill. A ranking of 4 was the worst and indicated that the student-generated skill was not relevant to the problem and therefore it did not match. A full description of the four categories can be seen in Table 2. These four categorizations are based evaluation rubrics from previous studies for assessing math problem solving skills and evaluating knowledge concept maps from novices and experts (Egodawatte, 2010; Kim, 2015).

Table 2. The four categories the student-generated skills were placed into along with an example student-generated skill from the chemistry course.

Category	Rank	Description	Examples
Expert Match	1	The skill matches one of the three skills originally tagged to the problem by an expert.	"Combine ions in the smallest ratio"
Match, Not Granular	2	The skill is very similar to one of the three expert-generated ones, however it could be more specific.	"Know charges on polyatomic ions"
Problem Relevant	3	The skill is technically utilized in the problem, but it is not necessarily what is being assessed given the context.	"Write the formula that reflects this ratio"
No Match	4	The skill is not relevant to the problem, it is not being utilized or assessed by it at all.	"Knowing nomenclature"

The two problems used in each of the courses were selected due to previous student data collected during their use indicating that students tend to struggle on both of them, with 40% of students getting an incorrect answer on their first attempt. Additionally, they each had three skills previously assigned to them by domain experts upon the creation of the courses. Our two item-raters verified that these three skills were appropriate for the problems and at the correct granularity for what was being assessed. While having experts evaluate student-generated skills is not scalable, in the scope of this study, we want to first investigate the feasibility of having students generate such skills. To assess the quality of these student-generated skills, we need to compare their outputs to that of experts that typically do this task. A list of the three skills tagged to each problem can be found in Table 3.

Table 3. Three expert-generated skills for chemistry (left) and programming (right)

Expert Skills - Chemistry	Expert Skills - Programming
1. Identify the cation and anion and their charges	1. Iteration over a value using the range() function
2. Write chemical formulas for ionic compounds that contain polyatomic ions	2. Utilizing a print statement in conjunction with numerical statements
3. Combine the ions in the smallest whole number ratio	3. Modify an existing program to fit a new set of instructions

Results

The student-generated skills were evaluated by experts to determine their quality. Then we analyzed how the student interactions in the course correlated with both student participation on the task and the quality of their contribution. We leveraged measures of central tendency to report the varying categories of the student-generated skills. Then we investigated the different patterns of student participation and performance in the course by looking at their interactions with the varying low-stakes activities and their steps embedded throughout the course. A Bonferroni correction was applied to post hoc analyses that follow (Armstrong, 2014).

Students generating accurate skill tags

Across all four course instances used in this study, a total of 112 students accessed the OLI course. Among those 112 students, 64 of them completed the optional skill generation task where they generated three skills for the presented problem. To assess the quality of these student-generated skills, we had two expert item-raters evaluate all 192 of their contributions. The raters checked if the student-generated skills matched an expert-generated one, indicating that they were accurate, meaning they are written at the correct level of specificity and model part of the knowledge required to solve the problem. This evaluation revealed that 23 (11.98%) of the contributed skills matched an expert-provided item and 65 (33.85%) matched a skill, but needed to be refined for further granularity. Table 4 shows the further breakdown of the item-rater categorizations of the 192 student-generated skills into the four different categories. Over half (54.17%) of the student-generated skills fell into the bottom two categories, which indicates that even with revision they are not usable or particularly useful. All of the skills labeled as the fourth ranking, "No Match", were one word or nonsensical responses by the students for the activity.

Table 4. The count of the four ranking categories assigned to skills in each of the courses.

Course	Student-generated Skill Count	Expert Match	Match, Not Granular	Problem Relevant	No Match
chem 1a	36	7	15	6	9
chem 1b	54	13	24	14	3
programming 1a	54	1	14	29	10
programming 1b	48	2	12	24	10
Totals (%)	192	23 (11.98%)	65 (33.85%)	72 (37.50%)	32 (16.67%)

Each of the activities in the two course domains had three skills tagged to it by domain experts, previously shown in Table 3. Student-generated skills from the chemistry courses were able to match all three of the expert skills for the problem, while only two of three expert skills were matched by students in the programming course. Table 5 shows an example of a student-generated skill from both domains that was categorized as an expert match by the two item-raters.

Table 5. An example of a student-generated skill that matches one of the chemistry expert skills (left) and one of the programming expert skills (right)

Expert Skill - Chemistry	Expert Skill - Programming
Identifying the cation and anion and their charges	Knowing how to use a print statement in conjunction with numerical statements
Student Skill - Chemistry	**Student Skill - Programming**
Identifying the cation, anion, and the charges	Knowing how to manipulate equation to have odd numbers printed instead of even numbers

Student participation and performance

In total, of the 112 students that were part of four instances of the courses, 19 of them did not access any of the course materials in the given modules. A total of 49 students were enrolled in the two chemistry courses, where 38 students accessed the materials, and 30 students did the skill generation activity. The chemistry course consists of a total of 33 optional low-stakes activities, not including the skill generation one, and on average the students completed 26.38 of the 33 (79.93%) activities. The two programming courses had 63 students enrolled in the courses, where 59 students accessed the materials, and 34 students did the generation activity. The programming course consists of 41 optional activities, not including the skill generation one, and on average students completed 30.48 of the 41 (74.34%) activities.

To determine which features of student interaction in the course were indicative of their participation in the skill generation activity, we performed a series of unpaired t-tests on their behavior with the other low-stakes activities found in the courses. This revealed a significant difference between the student participation with the other activities in both the chemistry and programming course and their participation in the skill generation task. An unpaired t-test showed there was a significant difference in the number of activity steps completed by students in the chemistry course who did the skill generation tasks $(M = 164.57, SD = 20.11)$ and those that did not do the task $(M = 39.47, SD = 52.45), t(47) = 11.819, p < .0001$. A similar result was found for the programming course, with students doing the skill generation task $(M = 111.03, SD = 18.41)$ and those that did not do the task $(M = 54.00, SD = 40.27), t(61) = 7.699, p < .0001$. Students who did the skill generation task were also more likely to complete all of the steps present in the activities embedded throughout the course. Similar significant results were observed for the number of activities done by a student and their participation for the skill generation task in the chemistry course, $t(47) = 11.483, p < .0001$ and the programming course $t(61) = 6.299, p < .0001$. This result supports the previous one, as the activities found throughout the course are composed of multiple steps and a subset of students completed all the 33 or 41 low-stakes activities respectively.

We then investigated whether student interactions with the other low-stakes activities in the course correlated with the quality of their generated skill contribution, to see how we might predict or promote better skills from the students. While there was a significant difference found between student participation in the skill generation task and participation in the other low-stakes activities throughout the course, it was not found to significantly correlate with the quality of the student contribution in the chemistry course $(\rho = 0.18, p = 0.333)$ or programming course $(\rho = 0.18, p = 0.303)$. Additionally, student performance on the activities as measured by their first attempt correct on the problems was not significantly correlated with the quality, measured by item-raters categorization, of their skill contributions for the chemistry course $(\rho = 0.29, p = 0.119)$ or programming course $(\rho = 0.09, p = 0.615)$.

Discussion

In this research, we investigated how we might enlist students working through online courses to assist in the skill tagging process. We found that even with the task being optional and only providing brief instructions with no scaffolding, some students were able to generate skills that matched experts, ones that could be utilized without any modifications. However, a majority of the generated skills were not sufficiently detailed, and even with revision, they would not be suited for use. The students who chose to participate in the task typically completed all of the other optional activities found in the course. In exploring what features of student interaction in the course correlated the quality of the skills they generated, we did not find any significant correlations with their performance on the other low-stakes activities. These findings suggest that students can generate and tag expert-level skills to problems from an optional and low-stakes activity within an online learning environment, but they might need more scaffolding to consistently do it.

Evaluation of the 192 student-generated skills indicated that, while not the majority, students across both course domains generated skills that matched all three expert ones in chemistry and two out of the three for programming. Students in all four course instances generated many skills that were categorized as a match but needed a bit more granularity to directly match an expert-generated skill. While these levels of skills cannot be as readily used as the direct match ones, they could still serve as an initial baseline to feed into a learning analytics system. We are hopeful that through more instruction or guidance, we can increase the quality of the student contributions by having them think deeply about the granular details of the skills they use to answer the activities.

With all the low-stakes activities embedded throughout the course being completely optional, including the skill generation one, there was still a high amount of overall participation from the students. This was particularly surprising for an optional activity, which generally has lower participation rates due to the lesser perceived value students see in completion of the activity (Farasat et al., 2017). While past skill generation methods have relied on experts (e.g., Koedinger & McLaughlin, 2010), our study presented the task as a low-stakes activity, seemingly fitting in among the fill-in-the-blank and drag-and-drop activities found on the other modules of course content. Leveraging just the native features of the system, in this case free-text boxes for short answer questions, we were able to provide students with the skill generation task seamlessly and without requiring them to utilize yet another platform. It is likely participation would be even greater if the task was required by students or embedded into a high-stakes assessment, such as a quiz question. However, this approach would introduce another series of potential complications, such as requiring it to be graded and potentially introducing an abundance of unacceptable questions contributed by students that do not wish to do the activity but are forced to in the context.

Our contributions should be interpreted against the following limitations. First, our study was conducted across two domains, chemistry, and programming. As skill tagging is directly influenced by the domain of the problems, this may impact the generalizability of the results. Second, students from each domain skill tagged a single problem in each instance of the course. Similar to the domain, the content of the problem is directly related to skills it assesses, so our results might differ depending on the problem or domain. Finally, we did not heavily investigate the background of the students doing the task. It is possible that some students were more familiar with the concepts of skill tagging or articulating this process more than others.

Conclusion

This research demonstrates a first attempt at directly engaging students in the processes of skill tagging problems across the domains of chemistry and programming. Our results highlight how student behaviors regarding their completion of activities in the course are indicative of their participation on the optional skill tagging task. Requiring the student to do the activity, such as putting it in a high-stakes assessment or having students use another system, is not necessarily required for contributions, some of which are evaluated as being on par with expert ones. Although rare, students can provide expert-level skills, without detailed instructions, prior training, or scaffolding. However, most of the skills students generated would not be usable, even with revision. As a result, we do not recommend enlisting students in the skill tagging process through this mechanism, as they might require training or better scaffolding to submit usable skills. This research demonstrates an attempt to help scale online learning analytics and improve educational resources, by leveraging the students in a course. This work opens further opportunities for both engaging students in the process of skill tagging and promoting their behavior that leads to a higher quality contribution for future tasks. Future research should consider expanding domains and experimenting with different amounts of training or scaffolding for the task.

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A model for shared epistemic agency

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Abstract: Based on seven ethnographic cases of student group projects, this paper describes knowledge creation enacted in assessment tasks in undergraduate units of study, gathered into a model of shared epistemic agency. Key characteristics, including initial framing and ways of creating and using objects, traced between teams indicated patterns of knowledge creation. Some individual students created substantial artefacts based on shared conceptual development. The infrastructure that students created to support their collaboration is integrated within the model. The elements of the model and their connection to types of knowledge creation suggest design principles for similar activities, and avenues for future research.

Introduction

Skills for complex problem-solving are an identified priority for tertiary education, but the processes by which students practice and acquire those skills are under-researched (Graesser et al., 2018). Designers should consider how to support students in developing epistemic fluency, the ability to effectively work with knowledge, and agency in that work: in using tools, resources and processes (Markauskaite & Goodyear, 2017). However, pedagogies that actively support object-centred knowledge creation are in need of further development (Damşa & Muukkonen, 2020). How students exercise epistemic fluency in 'mundane' (action-by-action) ways, a key source of understanding, has not been the subject of much detailed investigation: for example, two empirical studies of student knowledge creation (Damşa et al., 2010; Muukkonen et al., 2010) took snapshots of projects at stages of their work using interviews and collected objects, rather than observing the projects in full.

This study followed day-to-day activities of work within university student group projects, asking the question, 'How do students exercise epistemic agency?' From the ethnographic, case-based study of group projects in university courses, a comparison of cases produced patterns and key elements of their collaborative spaces. This resulted in a model (Figure 2) towards understanding sociomateriality in the exercise of shared epistemic agency: how collaborative processes, objects and material infrastructure are used to create knowledge. It combines epistemic with practical infrastructure to describe the inter-related parts of a group project.

Literature

The model of shared epistemic agency derived from the analysis of cases relates together the concepts, briefly outlined here, of dispositions, knowledge creation, shared epistemic agency, objects and infrastructure invoking distributed cognition.

The early formation of group projects are related to *dispositions*, which combine a sensitivity to the occasion, inclination to act and ability to apply skills and knowledge appropriately (Perkins et al., 1993). The way that a student frames the task and subsequently acts is influenced by previous experience as well as perceived future utility. If the situation is seen as familiar or novel, or could relate directly to a future career goal, for example, it will affect motivation and a decision on whether old or new ways of working are required. The framing of a task is the outcome to the question of "What is going on here?" (Goffman, 1974, p. 8). Framing can happen at the level of the whole project or in terms of personal long-term goals, and it also happens at the moment-to-moment level (Goffman, 1974; Scherr & Hammer, 2009), when students decide to pursue an idea or consider how to set up their communications.

The *knowledge creation* metaphor (Paavola & Hakkarainen, 2005) underpins the analysis of cases. In this view, learning is social and centered on the use and creation of "common objects of activity" (Paavola & Hakkarainen, 2005, p. 536), which include both material artefacts and concepts. The production of knowledge through objects results in a "public life" (Bereiter & Scardamalia, 2014, p. 35) that makes them available for review, interrogation, adaptation and extension by others. In the context of a collaborative project, shared objects are key to productive knowledge creation, placing ideas, discussion topics, resources and record of progress within the gaze and activity of group members.

Shared epistemic agency is where disposition meets knowledge creation in group actions. It is conscious collaborative work with knowledge towards a shared goal in a particular situation (Damşa et al., 2010; Scardamalia & Bereiter, 2006). Similarly to Perkins et al.'s (1993) dispositions above, agency involves reference to past experience, present evaluation and projecting towards an imagined future (Emirbayer & Mische, 1998). The situatedness is important: agency may be enacted differently depending on circumstances. Perceived

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relevance and challenge appropriate to abilities, for example, will influence how students apply effort to a task and shape their work with knowledge.

Objects can be both instantiated in artefacts as well as conceptual and are the focus of work in knowledge creation. The two types of objects relevant to this paper are *epistemic objects* and *technical objects*. Epistemic or knowledge objects are the produce of knowledge creation: their shape and content are unclear at first but emerge through making sense of, combining and representing ideas in activity (Engeström & Blackler, 2005; Knorr Cetina, 2001). An epistemic object holds contested and negotiated knowledge and can be a thinking tool towards a final product, or the emergent final product itself (Ewenstein & Whyte, 2009; Muukkonen et al., 2010). Technical objects (Ewenstein & Whyte, 2009) are used in collaboration but are generally accepted at face value rather than interrogated or changed. Examples might be the periodic table or a journal article. There may be some interpretation involved, but technical objects are used as referenced resources rather than the focus of work. There is some fluidity between types of objects in particular circumstances (Nicolini et al., 2011). An epistemic object may, once work is completed, be treated as a technical object, accepted in its final form, e.g. an earlier-created diagram may become an illustration within a report. Instructions for a task may temporarily be interrogated in detail, becoming for a while an epistemic object as students make sense of what is being asked of them.

Infrastructure to support collaborative work is an assembly of tools and processes worked out by the group to support their goals, accommodating to, or adapting, available tools (Damşa et al., 2019). The theory of distributed cognition extends knowledge work into the surrounding environment and social interactions (Hollan et al., 2000): in thinking through problems and their solutions, people use tools to inscribe, hold, discuss and remix ideas within physical and online spaces. The framework for distributed cognition for teamwork (DiCoT, Furniss & Blandford, 2006) outlines areas of focus useful for thinking about how knowledge work is done by groups. These include: an *information hub*, a shared place for relevant knowledge, communication and resources; *situation awareness* or visibility of progress, the ability to know how, and how well, a team project has advanced; and a *horizon of observation*, that is, the ability to see the current actions of team members. An information hub relies on team members adding relevant content to a shared repository. A way of thinking about how this information hub is developed comes from a piece by Perkins (1994). In writing about an ongoing dialogue between three academics, he described the way they, over repeated occasions, tossed ideas onto a *heap* of shared concepts that were retrieved and mixed, stirred or re-ordered in later discussions. The heap lies "anywhere that information can reside in the immediate environment – in your and others' working memories, notepads, blackboards, and so on" (Perkins, 1994, p. 90). This term referring to a purposeful if rather ad-hoc and semi-structured way of building and refining a shared set of concepts is an off-beat but evocative metaphor for a basis for knowledge creation.

Method

This study employs a sociomaterial perspective, which involves "a stronger focus on people, routines, and situated activity" (Johri, 2011, p. 209). To investigate the activity of student groups in detail, I took an ethnographic case-based approach, videoing in-person meetings and accessing online spaces used by groups. In transcribing activities, I took note of dialogue, physical gestures and actions in person and online. I observed how objects were used and created.

Cases and data collection

Selection criteria for cases included: an undergraduate task that had some level of complexity and open-ness in its solution, that is, students had a degree of control over what they produced and how they produced it; and collaboration within a small group (3-6 members). Ethics approval was received for the study.

Volunteer groups were recruited from two courses: four groups from education (first-year level) and three groups from engineering (second-year level). The number of group members ranging from three to five, to a total of 27 participants. Recordings added up to 36 hours, covering 29 meetings.

In the education task, students were asked to identify their own driving question on a relevant topic, create a media artefact in response and present that in class. In the engineering task, groups were required to identify one element of a larger given project and formulate a plan for executing their part of that project, creating a project plan and a class presentation. There were several overarching project scenarios to choose from. The education project included instructions to set up a shared online workspace and included a mind-mapping exercise at its start. The engineering students were not given instructions or tips on how to organize their collaborative work. The education task ran for approximately four weeks and was worth 30% of the total grade. The engineering task took most of the semester at 10 weeks and its components added up to 85% of the final grade.

For clarity of association in this paper, I have named groups using Edu/Eng to indicate the relevant course, a letter to distinguish between groups, and added a number for the type of knowledge creation allocated after

analysis. For example, 'EngB1' is an engineering group classified as the first knowledge creation type of 'divided work.'

Analysis

I used discourse analysis of multimodal transcripts of student interactions, analyzing actions, concepts, talk and object use in context, to trace how students made meaning of the task and their subsequent actions.

I produced detailed diagrams that traced and connected conceptual development, group members and object use and creation over the duration of each project. See Figure 1 for an excerpt of such a diagram.

I wrote project narratives based on the dimensions of framing and setup of the project and infrastructure for collaboration and knowledge creation. Putting each case narrative into the same structure enabled comparison across cases, summarized in Table 1. Within that structure, I analyzed specific episodes in detail, describing interactions using objects and the physical environment.

Findings

This paper concentrates on comparison of cases and the resultant patterns of collaboration, and here I present a summary of part of the results from the study. Data informed a detailed description of the framing and evident dispositions of the groups, the material infrastructure used for collaboration and their use of objects in knowledge work.

Framing and definition of the problem

Through diagrams of each project from start to finish, as well as coding the types of interactions and their use of shared objects, it was clear that the pattern for collaboration for each of the groups was established very early in the project. A higher density and complexity in the lines connecting objects, actors and concepts indicated higher levels of knowledge creation. I analyzed the set-up of projects in terms of framing and disposition: how the groups understood the task and what it was asking of them. The groups that recognized from the start a problem to be investigated and discussed it together tended to follow through with shared conceptual development and object-centered work. An exception to this was the EduB2 group, which had intended to pool research results but did not follow through. The EngC3 group showed high levels of conceptual development between two of its members, but the remaining two members working somewhat on the periphery on allocated tasks.

In all of the cases, students periodically placed their work in terms of future careers: what the engineering students understood to be a 'professional' report or software; the education students relating their project work to experiences in school and how they would use curriculum as teachers.

Patterns of knowledge creation

I analyzed each case across dimensions of shared conceptual development, collaborative infrastructure and use of objects (see Table 1). Commonalities between cases allowed me to classify them under three types of knowledge creation: 1) divided work; 2) shared conceptual development; and 3) shared conceptual development plus artefacts created by individuals. All groups had some degree of knowledge creation, that is, shared conceptual development centered on objects, but to varied depth and extent.

Two groups, EduC1 and EngB1, in their first meetings decided to basically divide work and assemble individual sections and continued in that pattern for the project, so formed the first category of divided work. These groups had few examples of shared conceptual development, either online or in person. They did not establish much in the way of an information hub or artefact repository and there was a lack of clarity as to group and individual progress. They did not know what each member had completed, although EduC1's online artefact, which was a timeline that they worked on together, showed eventual progress on the final product. One group member assured the others that they had made good progress but only added limited elements late in the project.

The EduB2 group intended to be collaborative but found it difficult to coordinate work, with a surface approach to their subject. There were no shared resources and the script for their product, a video, was worked out without much exploration of the problem and at the time of recording by the group. To that extent, there was some limited shared conceptual development.

Four groups showed sustained conceptual development around shared and created objects, and so higher levels of knowledge creation. EduA2 and EngA2 worked very much in concert with other group members: in person and online. Their conceptual development mostly occurred through coordinated discussion and simultaneous work on shared artefacts. They best represented the second classification of shared conceptual development.

Table 1
Comparison of cases on dimensions of shared knowledge creation and infrastructure

Case	Initially agreed work pattern	Shared conceptual development		Individuals created synthesizing objects	Shared artefactual repository	Visible progress	Pattern of knowledge creation - [] indicates category
		In person	Online				
EduC1	Divide tasks	limited	limited	somewhat – added separate posts to the timeline	yes, the timeline artefact itself	timeline posts, one obscured their lack of progress	[1] Division of tasks, no extra meetings
EngB1	Divide tasks	very limited	no	somewhat – wrote separate topics	no	no	[1] Division of tasks, no extra meetings
EduA2	Share work, extra meetings	yes – high levels	yes – high levels	no	yes, many notes and posts	yes	[2] Deeply collaborative, connected to future profession
EduB2	All contribute research	very limited	no	no – script created as they recorded	no	progress was slow but visible	[2] Surface approach, produced together
EngA2	Share work, extra meetings	yes	yes	no	yes: shared document for writing	yes	[2] Deeply collaborative, ongoing shared work
EduD3	Share work	yes	yes	yes	yes, posts and interim objects	yes	[3] Group conceptual development, specific production roles
EngC3	One said divide work, one able to persuade to share work.	yes – dyad	no	yes	no, but main dyad shared objects and discussion	mostly yes for main dyad, no for other two students	[3/1] Two students shared epistemic work and allocated tasks to the others.

Individuals' synthesizing objects

The remaining two groups of EduD3 and EngC3 worked together in a similar way to those in the second classification, but also showed an added dimension, leading to the third category of knowledge creation. The added dimension was the creation of substantial objects in artefact form by individuals, based on shared conceptual development.

The EduD3 group decided to make a video and in their first meeting ranged through a variety of ideas in an expansive discussion. Before the next meeting, one student had edited together a sample video and shared that with group members (a in Figure 1). The video elements represented ideas that the group had discussed and were linked by textual interstitials based on spoken and written words from their meeting. The student in an interview afterwards said that it was to progress the work of the group, which seemed to be slow in coming to a decision on what to do. Later in the same project, another student took images, videos and text shared and discussed by group members, and organized them into an illustrated storyboard with accompanying script (b in Figure 1). Again, this served to put concepts into a practical and organized format that allowed the group to finalize the structure of the video.

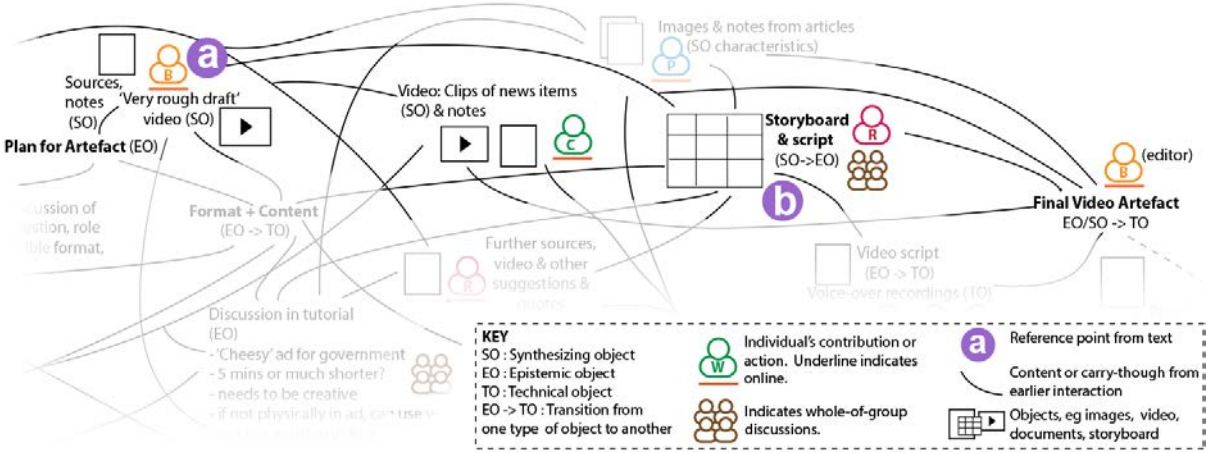
Two members of EngC3, Alex and Cameron, worked closely together on conceptual development for their project, a plan for building houses in a large village. After discussing materials and conditions for the housing with Cameron, Alex brought a paper sketch of a proposed house design to the next meeting. Discussion centered on the sketch, as Alex explained features and Cameron asked questions and suggested modifications. They each drew on the piece of paper as they considered how to lay out houses in clusters with common walls. Alex then brought a digital version of the house sketch to the next session, which the two students refined by searching materials and images online. Alex also started a diagram that planned the locations of houses. The initial layout frustrated Alex, as he likened the grid-like structure to a prison camp. Cameron then repeated an idea from an

earlier meeting related to a circular pattern with a community center, a model of which Alex found in a Google Images search. Alex then worked at home on a new version of the village layout that incorporated both Cameron's ideas as well as new information Alex found about optimal orientation to the sun.

The students who individually created objects in EduD3 and EngC3 did so because they saw a need for them: they were not directed or asked to build them as part of task instructions. The objects were each founded in work that the groups had done – concepts they had discussed and artefacts they had shared – but were shaped by the individual authors, who introduced further perspectives beyond that developed as a group. The objects served to put concepts into a practical form and progress the final product, organizing and expanding upon group ideas.

Figure 1

A segment of EduD3's project diagram, showing the draft video (a) and the storyboard and script (b). Parts are faded to highlight synthesizing objects. Interconnections illustrate the sharing of ideas and artefacts in the building of objects over time.



The (semi-structured) heap of shared knowledge

In the groups with higher levels of shared conceptual development, creating a common repository of knowledge, a type of 'semi-structured heap' of artefacts and concepts laid the foundation for knowledge creation. The heap could be comprised of various items: summaries of articles, images, spoken ideas, example videos, social media posts, budget tables, hand-written notes and diagrams. This provided a common reference and shared concepts and artefacts from which students could subsequently draw and relate to new ideas and resources. The project diagrams used for analysis supported this idea of a knowledge heap, showing, for example, how a concept introduced in an earlier week was reprised and mixed with new ideas in later discussion (see Figure 1 for an example). The building of this set of resources established the materials for the creation of shared epistemic objects, as well as for objects created by individuals. Students in EduC1, EngB1 and EduB2 did not build as much of a base compared to the other groups, had little on which to draw in class discussion and were perceptibly hindered from making progress.

Tools and processes supporting distributed cognition

Usage of tools in an infrastructure for collaboration facilitated a persistent shared set of resources, visibility of progress and a window into team members' activities. One element of infrastructure took the form in EngC3 of the two main collaborators seated next to each other and periodically using screens and paper diagrams to discuss parts of their solution. They had direct sensory inputs into each other's current activity: overlooking each other's computer screen; a frustrated sigh from one would prompt the other to look up and ask about the problem.

The students in EngA2 used a common Google document most of the length of the project, from recording initial ideas and links to resources, through to notes and final composition of the report. Progress in the document was immediately visible to all team members. This had been a new method set up for this project: they reported that they would use the same process for future collaborations.

EduA2 and EduD3 groups were both active on Facebook Group spaces, sharing links, commentary and images. The features of this tool such as a 'thumbs up' and indication that all group members had seen a post also afforded immediate visibility of progress and the activity of members. The EngC3 group used social media more simply as a message board and place to share files. Most of their knowledge work was done in person, which meant that the team members who were not present were necessarily uninformed of progress in the project.

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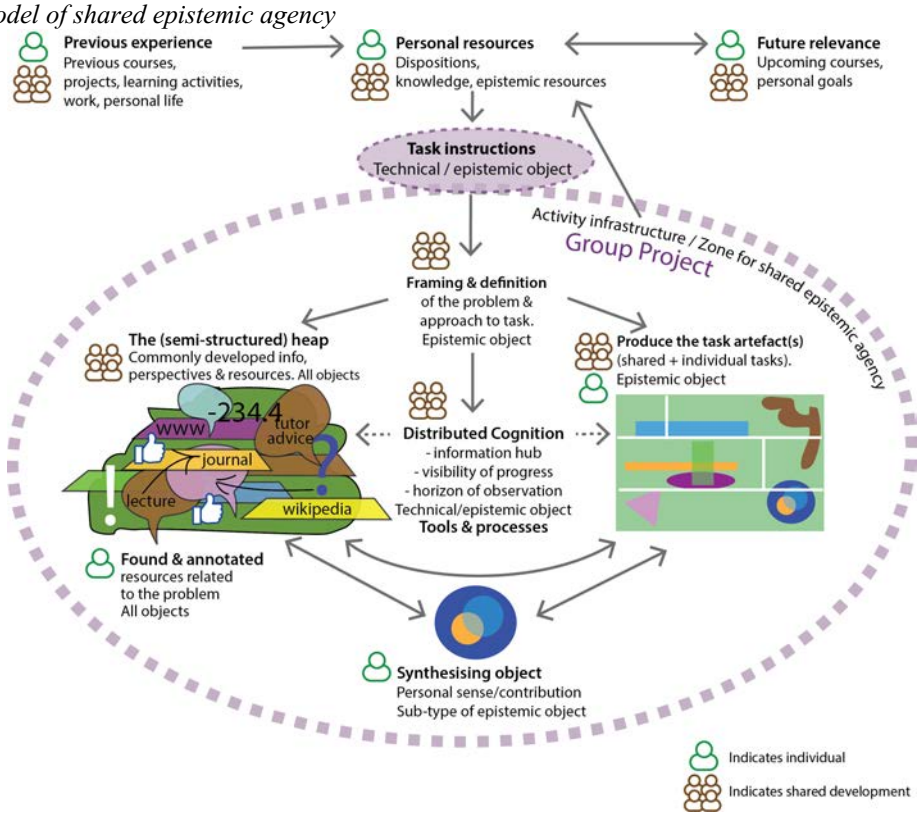
Discussion

The model of shared epistemic agency and activity infrastructure (Figure 2) relationally collates the elements I observed in the cases. The main elements are: 1) framing and definition of the problem, 2) the (semi-structured) heap of shared knowledge, 3) tools and processes supporting distributed cognition, 4) individuals' synthesizing objects and 5) work on the artefact(s) that are the final output of the task. All groups achieved some level of knowledge creation: those that paid attention to and established effective infrastructure across the elements showed higher shared epistemic agency in knowledge creation. A lack in one element tended to indicate less effective knowledge co-creation, with synthesizing objects optional though important contributions.

The epistemic work of groups was bound up in the material ways they worked together, their infrastructure of collaboration, for example, what and how they posted in social media groups, wrote together in a Google doc, shared on paper and on screen in class. Accordingly, knowledge work and infrastructure are intrinsic parts of the same model. In addition, while the final product went from initial ideas to practical construction, projects did not go through distinct phases: there were periods of making sense of the task, researching information and building constituent parts of an output along most of the timeline of each project. The model is therefore not linear, but relational, with each element built upon, and feeding into other elements, over time.

Figure 2

Model of shared epistemic agency



Initial *framing and definition* of the project influenced the type of knowledge creation and the infrastructure for activity that the group assembled. The die is cast at the start. Because the tenor of collaboration was set early in each project, the previous experience of collaborative work and related skills would seem to be a large influence on the framing of the task and level of knowledge creation. The context of experience as well as looking towards future use are informed by Perkins et al.'s (1993) dispositions as well as agency defined by Emirbayer & Misch (1998). In their first conversations, groups made decisive judgements of the type of work required as they read instructions for the task.

Student *dispositions* influenced the way they put the task in context and suggested ways of working. The dynamic of group discussion can change that framing, as in the EngC3 group, where they opted for a more collaborative approach, following one member's stated preference for dividing work. The dispositions of the individuals who created synthesizing objects were key to their actions: they saw the situation in a certain way

(sensitivity), elected to act on it (inclination) and brought their abilities to bear on a solution. The experiences during work on the project potentially feed back to the personal resources of students and in turn influence disposition towards, and constituent abilities for, future tasks.

Tools and processes helped improve the conditions for epistemic agency. An effective infrastructure to support distributed cognition that clearly shared ideas and showed progress on the project helped establish a foundation for group members to recognize where they could add value and progress the project. The way communication and collaboration tools were used tended to align with the initial framing of the project, for example, as either needing in-depth collaborative work or as one that could be divided into separate tasks.

Neither wholly the creation of the author nor a group object, the objects created by individuals in EduD3 and EngC3 were interesting phenomena that indicated a new type of epistemic object. The *synthesizing object* created by one team member allowed for expressing individual perspectives and goals in the context of shared conceptual development. While not required in group collaborative work–EduA2 and EngA2 constructed knowledge together effectively without major examples of such objects–it is a useful concept for understanding how individual contributions can translate or transform ideas, separately from but also contingent on group work.

The shape of a shared *semi-structured heap* of knowledge and resources relied on the group recognizing a need for shared conceptual development as well as establishing tools and processes that supported distributed cognition. Work on the task's final product and interim synthesizing objects helped organize, combine and make sense of the resources assembled by the group.

Production of the task artefact(s) in turn was influenced by the ways that the group framed their project, assembled knowledge and organized communications and collaboration. Synthesizing objects, where used, allowed individuals to contribute to the evolving product.

Supporting this activity infrastructure and zone for shared epistemic agency are the various *designed support activities and supplied resources* that a course teacher may provide for the task, although in the end group dynamics may have the stronger influence on the shape of collaboration. A lack in one part of the model can affect the level of epistemic agency and more effective implementation of an element could possibly assist in improving the conditions for knowledge co-creation. For example, sharing online working documents from the beginning may have helped increase shared conceptual development for the EngB1 group who, even when situated in the same physical space, tended to work on separate documents with limited discussion.

Conclusion

The model for epistemic agency in group projects offers a framework for how students work on their group tasks and the elements that they coordinate in that work. The model and the concept of a synthesizing object were derived from seven project cases within two undergraduate courses. Their applicability beyond that setting is an avenue for further research.

Framing plays a large part in how a task is defined and then the type of knowledge creation used in it. Some students will either be already disposed accordingly or agree through the group dynamic to create knowledge collaboratively. Understanding how teams do this effectively can assist in design for knowledge creation. The experiences that come before a project are potentially very influential on how students frame a new task: further research might consider the role of previous experience and expected future utility in framing of tasks, and how to translate this to design at a program level. The practical aspects of collaboration were set up to serve the task as students framed it, however these might be influenced by designed supports. Setting time and tasks for problem exploration, mandating a shared online workspace and suggesting cloud-based collaborative authoring of documents are some of the ways that the principles of distributed cognition can be made explicit for students.

The model pays attention to object use, which can inform design for learning as well as research: who creates or contributes; what previous activities, objects and discussion are included or expanded in the object; how the role of the object changes over time and how it contributes to the overall project. Iteratively tracing modifications that teams and individuals make to objects helps researchers see how students make sense of knowledge in the moment. Understanding the opportunities for contributions and the shapes those contributions potentially take can assist in designing supports and guidance for students.

Epistemic agency can be expressed both collaboratively and individually. The construction of a shared 'heap' of collective resources forms a basis for effective group knowledge work on epistemic objects and provides opportunities for individuals to modify and expand ideas through synthesizing objects. This foundational work in assembling shared resources helps set the conditions for conceptual development.

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Investigating Girls' Perspectives and Knowledge Gaps on Ethics and Fairness in Artificial Intelligence in a Lightweight Workshop

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Abstract: Artificial intelligence (AI) is everywhere, with many children having increased exposure to AI technologies in daily life. We aimed to understand middle school girls' (a group often excluded group in tech) perceptions and knowledge gaps about AI. We created and explored the feasibility of a lightweight (less than 3 hours) educational workshop in which learners considered challenges in their lives and communities and critically considered how existing and future AI could have an impact. After the workshop, learners had nuanced perceptions of AI, understanding AI can both help and harm. We discuss design implications for creating educational experiences in AI and fairness that embolden learners.

Introduction

Youth have regular direct exposure to and face the consequences of Artificial Intelligence (AI), including through their use of social media and smart home technologies. However, unfairness and bias in AI that affects specific users has been well-documented (e.g., O'Neil, 2016, Buolamwini, et al., 2018), including digital assistants' difficulty comprehending or responding to younger users (e.g., Druga et al., 2017) and users with accents (Lima et al., 2019). AI also introduces concerns about families' privacy around data collection (e.g., Lau et al., 2018). Children's frequent interfacing with AI-based technology, and therefore its potential harms, calls for the creation of more learning opportunities for youth to become AI literate and aware of its risks and challenges. This becomes more essential for underserved groups in tech who are more likely to be harmed by biased algorithms. Girls are often a population excluded from tech design and education (Sultan et al., 2018) yet can be greatly impacted by algorithmic bias (e.g., Buolamwini, et al., 2018). It is important to focus on underserved groups in AI education, so they avoid misinformation, have learning resources, and lend insight into a more just future.

Researchers and curriculum developers have recently begun to create learning opportunities to address children's knowledge gaps in AI literacy. However, many focus primarily on the technical aspects, excluding analysis of the ethical implications of this technology. Additionally, learners in this work have often been predominantly male (e.g., Williams et al., 2019; Kahn et al., 2018), leaving researchers and those who develop educational opportunities with a limited understanding of how girls perceive and learn about AI, potentially compounding existing inequities in AI representation. Some research has looked at teaching K-12 AI with a focus on ethics and fairness, including interpreting the agendas of various stakeholders in AI technology design (Payne, 2019; DiPaola et al., 2020; Register & Ko, 2020) and family-based education around exploring, manipulating, and analyzing AI (Chklovski et al., 2019; Druga et al., 2021). Touretzsky et al. (2019) and Long & Magerko (2020) describe ideas that children should learn about AI, including technical aspects and ethics surrounding impacts on humans and society. Ali et al. (2021) explored teaching middle schoolers about generative AI and corresponding ethical considerations, finding it was necessary to take technical, applied, and ethical approaches. We build on prior work by exploring underserved learners' perceptions, opinions, and knowledge gaps around AI technology to leverage in creating learner-centered education, as well as explore a shorter workshop format.

In this work, we focused on middle school girls, with middle school being a prime time to develop STEM identity (Sadler et al., 2012). To explore middle school girls' perceptions, knowledge gaps, and opinions to inform future creation of AI literacy materials, we created a lightweight workshop with content that assumed no prior knowledge in computing and AI, encouraged critical and creative thinking about AI systems and ethics, and supported learners in thinking about training data. The lightweight (under 3 hours) workshop, compared to other programs that are longer and more intensive, was aimed at inclusivity, reducing common barriers to out-of-school time computing participation like time commitment, commute, etc. We aim to expand upon prior work by integrating both technical and ethical aspects of AI, first taking inspiration from Touretzky et al. (2019) and Long & Magerko (2020), in particular, learning from data and nuanced societal impacts. We took an asset- rather than a deficit-based approach (Garoutte & McCarthy-Gilmore, 2014) which involves centering learners' prior knowledge and interests as a base for further learning and engagement (Coleman & Davis, 2020). This approach is particularly appropriate to successfully support girls of diverse backgrounds in learning computing (Scott et al., 2015). To conduct our research, we used a lens of futuring in our activities, which is a method that encourages

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reflection and analysis around technology and problem-solving by speculating about possible future tools (Dunne & Raby, 2013). Through futuring, we also aimed to gain insight into what is motivating and important to learners, building on their existing knowledge. We strive to address the following research questions: (1) What are middle school girls' conceptions of AI and ethical considerations? (2) How do learners apply their knowledge to ideate and critically analyze AI technologies in short workshops? To create effective and empowering educational opportunities for these learners to gain information about both the technical and ethical aspects of AI, it is essential to understand and center their current funds of knowledge. We report findings about middle school girls' understandings of AI and ethics before, during, and after the lightweight workshop, then offer design implications.

Methods

Data collection and participants

This study took place over five months as a standalone workshop module situated within five individual computing camps (labeled Groups A-E), each held over three to five days. We took a design-based, iterative approach between each camp, slightly adjusting or adding activities to improve the workshop. Each program focused on elementary programming within the context of robotics and emphasized power and identity in techmaking. The programs and workshop sessions did not assume any prior experience with computing or AI. After Group C, we added an additional open-ended final project in a 90-minute session held two days after the initial AI and fairness session. We collected ~14 hours of video and interview data overall with the 5 groups.

Participants: Middle school girls (N = 32, see Table 1) were recruited through a robotics-focused organization, "BoltGirls," in the east coast of the US and a general girls organization, "AmazingGirls," in the southwest of the US. Girls recruited from BoltGirls had more prior experience with computing than girls recruited from AmazingGirls. Each camp included participants from either BoltGirls or AmazingGirls.

Data collection: The AI workshop with educational content and activities lasted about an hour and a half in duration for all groups. In our first group (A) we started with one AI-related session, after which we divided the session into two, but due to the drop-in nature of informal learning experiences, some learners only participated in one of the two sessions. Sessions were conducted synchronously online over Zoom (https://zoom.us) and recorded with chat logs saved. We utilized Jamboards for more efficient group work with peers and a common environment for learners and instructors to observe what others were doing during the virtual sessions, and the content of these boards was collected and analyzed. We also collected data on learners' prior knowledge in all groups via warm-up activities; to facilitate data collection, we decided to distribute these questions as a short pre-survey for groups D and E (N = 17), which asked them to give their best definition of AI, give two examples of AI, and their opinion on whether AI is smarter than them. This pre-survey was added for groups D and E as part of our iterative processes, and 3 of the 17 learners opted to answer a subset of the questions. We also invited learners from groups D and E to participate in follow-up semi-structured interviews, and 10 learners agreed. In interviews, we again asked for their best definition of AI and whether AI is smarter than them, and also what fair and unfair technology is, and where they may have gotten inspiration about AI (e.g., in the media or news). In all questions in the pre-survey and follow-up interviews, we also asked about their reasoning for their answers.

Qualitative coding

We conducted thematic analysis using inductive open coding (Corbin & Strauss, 1990) to uncover themes in video recordings, chat logs, survey and interview data, and learning artifacts (Jamboards and slide decks). Two researchers independently developed a list of themes using affinity diagramming (Beyer & Holtzblatt, 1999), with each source of data contributing to a single set of themes. They then met to discuss, combine, and justify themes, before discussing them with the other authors. The thematic analysis was iterative across camps, as additional data was collected. The researchers discussed the themes regularly with each other and the rest of the research team, until the team agreed on the final set of findings. The findings below describe major themes from our study, which address our research questions. The supporting data for each theme is derived from prompts in the learning activities, unless otherwise specified that the insights are from the pre-survey or follow-up interviews.

Learning content and activities

The learning goals for our workshop sessions included understanding AI and supervised machine learning on a high level and recognizing that AI can have nuanced (i.e., both helpful and harmful) societal impacts. Learners started the session by discussing what they thought the word 'bias' meant in a group discussion. We then played a guessing game, where learners guessed if the technology pictured has AI (e.g., personalized recommendations) and what technology does not (e.g., a hairdryer) and explained their reasoning. To understand AI, learners need a

Table 1
Participant demographics.

Group	*N*	Had prior exp	Organization	Ages	Reported race
A	4	2	BoltGirls	12-14	Asian (1), Black (1), white (1), Asian & white (1)
B	3	1	AmazingGirls	12-14	Hispanic/Latina(1), white (1), Hispanic/Latin & white (1)
C	8	6	BoltGirls	11-13	Asian (5), white (3)
D	4	2	AmazingGirls	11-13	Latina/Hispanic (1), white(2), did not say (1)
E	13	10	BoltGirls	12-14	Asian (7), Black (1), Indian American/First Nation (1), white (2), did not say (2)

working definition of an algorithm, which we gave in a short lesson covering how algorithms consist of three parts: an input, steps to change the input, and an output (adapted from Payne, 2019). After iterating our materials, we created an application activity for groups D and E to practice in an activity where they filled out sticky notes for their favorite food (output), with ingredients (input) and preparation or cooking actions (steps to change input).

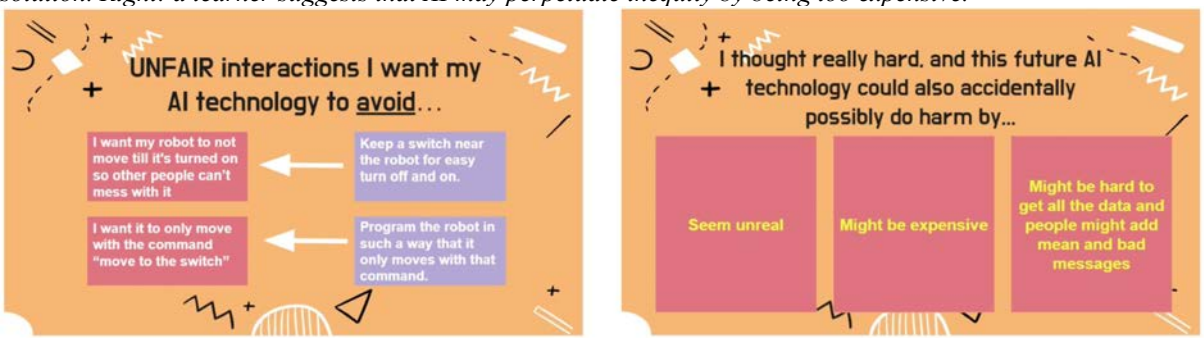
We then shifted over to AI, providing a definition of what AI is and how it relates to algorithms. We centered this lesson on supervised machine learning, emphasizing the concept of training data, since it is a pressing and relevant topic related to power and unfairness (O'Neil, 2016), as well as an important topic to cover in AI education (Touretzsky et al., 2019; Long & Magerko, 2020). Learners then played Google's QuickDraw (quickdraw.withgoogle.com), an interactive, short game leveraged in other AI education programs, e.g., Druga et al., 2021. We opted for this over other tools (e.g., Google's Teachable Machine) to fit within our lightweight workshop. We then discussed why and how the algorithm identifies or misidentifies their drawings, sifting through the data set that other users drew. While most groups concluded that the algorithm may not be able to identify certain drawings because they are not represented in the training data, the instructor made sure to emphasize this point before moving on. The learners then watched a 4-minute video on algorithmic bias stemming from systemic bias in society and data, discussing examples where biased data in AI could do great harm. Learners were then prompted to consider where else harmful effects of algorithmic bias could take place. Learners then took part in two Jamboard group activities and an individual, guided final project, which we go into more detail next.

After the lesson and discussions on AI and bias, we ran several activities designed to encourage learners to critically analyze technologies and apply concepts delivered in the content. We use artifacts generated from these activities as one of our main sources of data, alongside pre-surveys, follow-up interviews, video recordings, and chat logs. In Jamboard activities, the girls contributed to at least one sticky note and discussed the prompt. The facilitator helped with pacing and prompting. If girls did not want to write, they also had the option to type in the Zoom chat or speak, and the facilitator would fill out a sticky note for them.

In Activity 1, *Digital Assistants Help and Harm*, we first asked learners to consider how and who existing digital assistant technology, such as Alexa, Siri, or Google Home, could help and harm. We started by introducing what digital assistants are and brainstorming together what they are capable of. We then provided a Jamboard with prompts. Instructors helped to pace the learners through the Jamboard and offered an example when the learners were stuck, such as accent bias in voice recognition, but aimed not to scaffold too heavily. Jamboard prompts included inquiring what fair and unfair interactions digital assistants could do and who would be affected, as well as which training data to include or exclude for more equitable interactions (see Figure 1). In Activity 2, *Community AI Robot,* learners then considered a challenge in their community that they wanted to solve and were prompted to brainstorm a robot AI that could be a part of the solution. We chose a robot here as part of the prompt due to the context of the computing camps, since robotics were an emphasized theme. Similar to Activity 1, learners then brainstormed who it could benefit or be harmed by their AI robot. They then ideated on which training data they would include or exclude to facilitate fair interactions or avoid unfair interactions.

For groups D and E, we added a final project, which took place two days after the initial workshop session and involved learners brainstorming any futuristic AI technologies to help solve a problem that they are passionate about. On a Jamboard, we started by brainstorming AI technologies and what they can do (e.g., types of personalization, face/screen/object recognition, etc.). Then, learners brainstormed together different challenges in the world, and finally considered how the AI examples they came up with could be applied to support solving some of these challenges. After the group-wide brainstorm, they were given their own slide deck to create a presentation on a futuristic AI technology of their choice. Slide prompts asked learners to define the problem their AI technology could help solve and describe how and who the AI technology could help, what form the AI technology would take (e.g., a robot, website, app, etc.), how the AI could do harm and to whom. They then were further prompted to identify fair and unfair interactions that they wanted their AI technology to have and avoid, as well as what training data they would include or exclude to facilitate or mitigate such interactions (see Figure 1). Learners had opportunities to present their progress throughout the session.

Figure 1
Two screenshots of learners' final projects analyzed in this study. Left: learner suggests a human-in-the-loop solution. Right: a learner suggests that AI may perpetuate inequity by being too expensive.



Findings

(Mis)perceptions of AI: Understanding of AI

We wanted to understand learners' conceptions of AI before engaging in the workshop and consider how they shifted over the course of the experience. We consider a working definition of AI to be along the lines of e.g., 'algorithms that can learn to make meaningful output or decisions.' We observed that almost all 17 learners who took the pre-survey were able to give an example of a technology that uses AI, with 11 giving two. For instance, learners listed digital assistants (i.e., Siri, Google Home, (n = 7), self-driving cars (n = 2), and facial recognition (n = 2) as examples of AI. Some learners (n = 3) were able to give more technical definitions of AI, such as "*something that is developed by humans, to make robots think and solve problems."* or "*when a form of technology is able to do something without another person programming it to do that.*" Many (n = 12) gave definitions that were not technical but showed some awareness of the field such as relevance to programming, brains, or robots. Several learners indicated uncertainty in their responses (e.g., responding with a question mark). Afterward, some learners showed a more complex understanding of AI in the follow-up interviews, with 4 (of 7) learners able to give a technical definition of AI, of which two had already given working definitions initially. While the workshop may not have supported all learners in clearly defining AI, most learners in the follow-up interviews drew on new concepts and showed an increased ability to talk about AI and related topics.

We were further interested in understanding learners' mental models of artificial intelligence. For instance, some misconceptions potentially arise from believing machines have no faults, with past work finding that by age 7-10, children believe that AI is "smarter than they are" (Druga et al., 2018). Our middle school-age learners had varied perceptions to this question, e.g., in the second half of the pre-survey when learners were asked if AI was smarter than them, most (10 of 14) answered that `yes,' they thought so. However, by the time of the follow-up interviews, half (5 of 10) responded 'no' or 'neither' was smarter than the other. For those who believed AI was smarter, their reasoning related to intelligence comprising informational knowledge and facts, a finding consistent with Druga et al., 2017. On the other hand, the learners who considered themselves "smarter" than AI mentioned reasons such as the fact that humans build AI, and recognized that this creates limitations in AI capabilities, e.g., "*if the AI wasn't very trained at something, then a human would probably find a more accurate solution*". Other girls held a more expansive view of intelligence, that AI "*doesn't necessarily have emotions or think the exact way that I would think...*" Although some of their ideas about AI may not be completely unpacked, we found that all learners, even those with low prior knowledge in AI, were able to engage with and hypothesize about AI. Specifically, after the workshop, learners displayed more nuanced views of the concept of intelligence, and compared AI to human intelligence, where AI may be smarter regarding certain types of knowledge (e.g., semantic) and humans smarter in terms of other knowledge and judgments (e.g., emotional intelligence). Our brief AI and algorithmic bias content provided a foundation for them to gain some new mental models and make inferences about AI and be emboldened to share ideas.

Ethical considerations: Understanding of bias and harm

Foundational to AI and ethics is bias that arises from systemic inequity in data, as well as in the algorithms and from developers. We aimed to understand how learners understood bias. Their answers at the beginning of sessions on defining bias suggested that they generally thought that bias meant a preference for something (e.g., "*being in favor of one side or option over the other*"), which could have harmless or sometimes harmful consequences, given the context and outcome (e.g., "*it can be unfair when someone is biased without proper*

reasoning"). This is different from prior work that suggests younger children may not know what the term bias means (Druga et al., 2021). In all groups, multiple learners were able to articulate what bias means, and the instructor further solidified it before tying it into algorithmic bias later in the workshop. Learners engaged with a number of large-scale examples of algorithmic bias in the workshop content, emphasized through discussion prompts and were able to engage in critical discussion. After watching the short video further showing examples of algorithmic bias, learners voiced that racism in AI is salient and concerning. To support critical analysis, we encouraged learners to brainstorm the benefits and harms of AI technology. They quickly identified harms that might be caused by AI, though initial ideas were not always tied into data-driven algorithmic bias.

In another take on bias, and sometimes touching on algorithmic bias, learners also identified that AI could provide misinformation (whether intentionally or not), which the learners specified could cause bias in human consumers. One learner voiced that a fair AI "*gives a neutral opinion; it's not really siding with anything.*" Learners further connected that a preference in the algorithm may affect human preference, and some suggested that AI technology give users a message as a caveat that the suggestions are only just that. Data was also a topic that is intertwined heavily with AI, which we included in our curriculum and activities. Learners were eager to discuss and bring up data, especially as it related to privacy. Multiple learners were concerned about data and how it could be collected and used (similar to Skinner et al. 2020), although they did not always tie it back to AI. For instance, when discussing existing digital assistants and chatbot technology in the Digital Assistants Help and Harm activity, learners described how data could be taken without consent or people could be hacked (an activity which could be done by a human perpetrator without AI). They also noted how large companies could profit from data, although the AI implications were not specified (e.g., using data to personalize ads), and a few learners felt that it was important systems ask permission to collect data. Lastly, we saw that most learners were able to identify stakeholders and motivations (e.g., who would create, benefit, be harmed, by tech etc.) in our Jamboard and final project activities. Some learners mentioned businesses as stakeholders and harmful technology being lucrative, suggesting that they are aware of possible harmful impacts of big companies. Thus, there are multiple avenues to encourage learners to consider stakeholders and relate these ideas to how AI can both help and harm.

Attribution of harm and sources of awareness

To create learning experiences that encourage agency, it is important to understand how the girls perceive who has responsibility for harm caused by AI. Overall, learners had little focus on how human techmakers could be responsible for unfairness in AI beyond stealing data or intentionally providing misinformation, but rather, they often attributed harm and unfairness to the technology itself. This was particularly the case when learners mentioned embodied AI (robots) for intentional (e.g., a robot becomes 'evil,' a word learners used to describe unfair technology, and purposely does something bad) and unanticipated harm (e.g., a robot mistake resulting in injury to a human). We saw that harms learners brought up differed for existing technology versus their own future technology ideas—when the learners were asked to analyze existing digital assistant and chatbot technology in the Digital Assistants Help and Harm activity, the types of harms they identified were primarily intentional and characterized by purposely setting out to cause hurt (e.g., stealing data, spreading misinformation about a competitor, impersonating others, writing mean things online). While speculating about future robot AI they would like to build in their community, on the other hand, the harms identified were primarily unanticipated—specifically, a mistake or incorrect behavior from the AI (e.g., miscategorizing objects) rather than a bias.

Because learners brainstormed AI that was in the form of robots or had other ways of socially interfacing with humans, we observed learners' notions of fair interaction included kindness and kind language, in line with findings from Skinner et al., 2020. 'Kindness' associated with fairness and 'evil' associated with unfairness suggests that the middle school-aged participants in our study have a 'fairytale' mental model that equates fair with good and unfair with evil interactions, which may limit the ways in which learners engage with conceptualizing harmful AI. However, future work is needed to investigate how to best shift mental models to support learners in considering unanticipated (data-driven) ways AI could harm, as well as the prevalence of unanticipated bias in all technologies. Additionally, an indirect harm that learners often brought up was how AI could cause inequity indirectly by being too expensive and inaccessible to groups of people with lower income.

Sources of awareness from where learners get information about AI can inform how to relate learning content to their prior knowledge. We saw that learners' perceptions were in line with concerns presented in the media or by adults. Regular topics that came up across groups were concerns around data and privacy, and the rise of AI-driven automation taking away jobs from people, recent hot topics in the news and in line with parent perspectives (Chklovski et al., 2019). It often came up that learners believed AI could eventually become evil and turn against humans, a common sci-fi plot. All of these media-driven ideas are in line with findings in (Ali et al., 2019). However, in follow-up interviews when we asked about if any media sources influenced their ideas about

AI, only 2 of 9 said that media had an impact (1 interviewee was not asked due to time constraints). This suggests that perhaps learners may not be aware of the impact of media on their perceptions of AI.

Application of knowledge to ideate and evaluate AI: Unique and relevant ideas

Aiming to position learners as technosocial change agents and tech designers using futuring (Dunne & Raby, 2013), we investigated how learners thought of AI applications to come and found that they easily thought of pressing issues in their daily lives that were ripe for change and brainstormed future AI systems that could have a role in the solution. Despite concerns about AI noted above, learners were also very optimistic about how AI could be a part of the future. All learners who were present in all group and individual final project activities were able to consider how AI could help solve challenges. For example, learners saw possible benefits of AI in supporting accessibility needs (e.g., AI that could carry out tasks that may be difficult for a person who is physically disabled). Three specific common types of issues that learners felt passionate about in the group-wide Jamboard activities and final projects related to a) the environment and climate change (e.g., planting trees, reducing litter), b) animal well-being (e.g., rehoming animals in shelters), and c) challenges related to being a child in middle school (e.g., fitting in with peers). Many of the challenges they surfaced were highly specific to their lives (e.g., one learner focused on preventing human-environment conflict by deterring deer from eating plants in her backyard, and another on detecting crime in her neighborhood), suggesting that our asset-based approach successfully centered and worked to build off the life experiences of the learners. Creation of other AI literacy materials for middle school girls may also utilize these topics, since they may resonate with the learners.

Our data also showed that there were fewer mentions of discrimination, racism, and other forms of well-recognized unfairness that surface in algorithmic bias as issues that learners wanted to focus on in their future AI systems, despite the overarching computing program and AI curriculum mentioning some of these biases as examples (e.g., visual detection not working on all skin tones). There was less of a focus on people, identity, and nuanced types of bias overall, since in most projects and activity topics, learners chose to focus on topics related to nature or common concerns about being a middle schooler. Their brainstormed solutions also primarily focused on non-human solutions to the problem, such as a robot addressing environmental degradation by cleaning up local parks (as opposed to confronting or educating humans who litter in the first place). Across groups and activities, only one learner mentioned `sexism' as a broad problem that she was interested in using AI to solve, even though considering identity and power was a core focus of the all-girls program that the AI curriculum was a part of, and at least one salient example of sexism in AI was discussed by the instructors. Prior work has noted the contradiction that modern girls feel about sexism in their daily lives. With girls being more frequently told that they can be and do anything they want, Pomerantz et al. (2013) hypothesize that the current notion of gender equality in the US may cause young women to disregard or disbelieve existing gender injustice and threats to women's rights. Therefore, our learners may have chosen not to engage with these topics, as they may not have seen them as particularly pressing compared to other community problems. The salience of gender injustice may also have been lower due to the all-girls setting.

Tensions between asset-based, open-ended opportunities for applying AI knowledge

In an effort to center learners' interests, values, and prior knowledge, we also aimed to understand the benefits and challenges of how AI literacy could be supported using an open-ended and asset-based approach. After learners came up with ideas of their own for AI tech in group and individual final projects, we asked them to do the same analysis activity that they did with existing digital assistant technology. When learners considered their own ideas, they were particularly excited about the possibilities for AI to solve problems in their communities. Many AI systems learners discussed, ideated, and analyzed were embodied, including robots in the Community AI Robot activity and semi-embodied digital assistants. 9 of 16 learners chose to brainstorm AI technology in the form of a robot for their individual final project, perhaps influenced by Activity 2's focus on robots.

In contrast to recent prior work from Druga et al. (2021), which found that children 7-11 years old prioritize having fun with AI technology over ruminating on technological drawbacks, we saw that learners who participated in our workshop could easily pinpoint harms potentially arising from existing digital assistant technology. Yet, they were less likely to come up with possible harms with their own future tech ideas compared to when analyzing existing digital assistant tech. In both the Community AI Robot activity and final projects, we dedicated prompts and slides to brainstorming potential harms. In the group activities, we asked learners to identify as many benefits and harms as possible. 5 harms on average were identified for existing digital assistant technology, while only two harms on average were identified for future robot AI technology. Three explanations for this may be that it was harder to think of harms with a futuristic technology compared to one that already exists, it is difficult to consider how one's own idea may have negative impacts, or this may relate to the finding that learners were less likely to mention humans in general as the responsible for unfair interactions with AI.

However, three learners in the follow-up interviews reasoned that AI has at least the collective knowledge of its developers. We infer that learners may connect that AI may hold biases that human techmakers have.

While learners chose problems that mattered to them, we also saw that some of the AI systems may not have lent themselves to straightforward application of AI and training data knowledge to critically analyze bias, in comparison to algorithm-focused disembodied systems (e.g., recommendations algorithm). For example, our learners who chose to discuss robots mostly came up with harms that were mistakes and/or tangible (e.g., a self defense instructor robot mistakenly attacking a person). Due to the focus on physical harms and embodied AI, it was sometimes difficult to then apply training data concepts as solutions, as we describe more next.

Discussion

In this work, we approached AI education with a lightweight workshop approach including interactive group activities, in which learners analyzed existing and future AI technologies. Compared to other programs, our workshop content and activities included group discussions and ideation, with less use of interactive tools, as a means to understand opinions, perceptions, and knowledge gaps. We prioritized understanding algorithmic bias and help vs. harm of AI in our content and activities over technical aspects of machine learning and training data. We observed that while the lightweight workshop and activities did not offer an in-depth AI and ethics education, it appeared to `plant a seed,' with some learners we interviewed having walked away with a shift in their conceptions and gained more complex ideas about AI and related topics, as observed in follow-up interviews and final projects after less than 3 hours. This lightweight approach may be more accessible to learners who could otherwise not attend a longer, all-inclusive AI education program. Further, learners were able to understand important, overarching patterns and concepts related to algorithmic bias.

Limitations include the limited generalizability of our results by our small, self-selected sample. This may have had an impact on the types of challenges and solutions that learners focused on throughout the workshop sessions. Finally, as is common in design studies, we noticed that researcher examples (e.g., an example about accent recognition by digital assistants led learners to discuss language barriers) for specific prompts and the prompts themselves (e.g., 'how might this AI do harm') may have shifted learner responses.

Design Implications: Grounded in our data and findings, we recommend three overarching aspects to keep in mind when designing AI education opportunities that center historically excluded learners. First, we suggest ***emphasizing unanticipated bias as in all technologies, and specifically as it relates to data-driven ways AI could harm***. From our study, we saw that many learners paralleled fairness with kindness and unfairness with intentional evil, so learning content may need to directly address this mental model to be more flexible. Second, ***give training data more time and exploration***. If a learning goal is for participants to have a more in-depth, technical understanding of training data concepts, more opportunities to experiment and build a stronger mental model is needed, i.e., our lightweight approach is not as effective for particularly complex or technical learning goals in AI literacy. This is inline with prior work that presents the benefits of interactive tools (Hiltron et al., 2019). However, a comprehensive understanding of training data may not be needed for learners to understand high level patterns and concepts, since we found that learners demonstrated understanding and engaged in discussions in our lightweight approach. Third, ***opportunities to apply training data and AI bias in open-ended activities***. Since some of the topics that learners choose in an open-ended prompt may not lend themselves as easy AI and bias learning examples, we encourage instructional designers to create opportunities for more straightforward application. This may include a more specific, scaffolded prompt for learners to think of community challenges they would like to solve with AI, or breaking down their future AI ideas into considering different sensors as suggested by Touretzky et al. (2019) and considering bias from data for the sensors. Future work may also incorporate different types of bias in AI, e.g., from developers and algorithm design. We believe that these findings will help support the creation of inclusive, accessible, learner-centered opportunities for middle school girls to increase their AI literacy, engage in conversations around AI, and become empowered techmakers.

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Learning From and About Failure in a Hybrid Collaborative Game Environment

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Abstract: Traditional classroom culture and social norms might stigmatize failure and hurt learners' self-esteem. Consequently, learners might miss learning opportunities by avoiding failure to cope with the negativity. Scholars argue the importance of creating learning environments that allow learners to reframe failure as learning opportunities through iteration. This paper re-examines an instructional failure session in a hybrid collaborative game environment to understand how failure and learning processes emerged. We adopt a micro-ecological approach to analyze video format data collected in an afterschool design club. The analysis shows that failure and learning might begin as individual actions but can ripple across the small group and the community to create learning opportunities, especially when the environment supports playfulness and improvisation. Findings suggest that allowing the learning design and enactment to interact can support expansive learning.

Background

Failure can provide an opportunity to help learners realize that their current information, knowledge, and skill are not enough to solve the problem in the learning process (Vanlehn et al., 2003). This realization can motivate learners to deepen knowledge, understanding, and practice and benefit more from instructional explanations. Scholars in education argue that failure signals a time to provide support to approximate learning gains (Darabi et al., 2018). Though productive failure as an instructional approach was first introduced in the STEM context, scholars now argue that this approach can also support creativity and collaborative problem solving (Manalo & Kapur, 2018). This approach has been extended to art education (Sawyer, 2018) and fosters creative collaboration (Hod et al., 2018). However, failure alone does not lead to learning if learners avoid it and the learning process is not supported (Jackson et al., 2021). One of the supports identified in the literature frequently was to adopt a failure positive mindset (Canon & Edmondson, 2005; Ryoo et al., 2015).

Video game and design contexts are gaining more attention as scholars argue that both can foster learners to frame failure as a process that houses learning opportunities. Failure in gaming marks critical learning opportunities for players. While failures occur within a game, players are given more opportunities to develop a core understanding of gameplay elements. With educational games, these opportunities are greater exemplified in increased collaborative discourse moments between players that provide a deeper understanding of gameplay elements and learning goals (Anderson et al., 2018). Unlike many students' opportunities in class, video games can provide students with a playful and "optimistic motivational style" of learning (Granic et al., 2014). Games, such as Minecraft, allow students to explore creative design and choice-making with immediate visualization that promotes authentic dialogue between members (von Heland et al., 2015). Cultivating a failure positive mindset is also repeatedly discussed in the making, creating, and innovating activities (Martin, 2015). A failure positive mindset is considered a belief that designers embody through practice and is encultured in their environment and activities (Brown, 2008). In these activities, designers are allowed to learn from failure through tinkering and iteration (Ryoo et al., 2015).

Though game and design contexts can potentially support learners to frame failure with a positive attitude, the learning process to make that shift in mindset is a complex phenomenon involving interaction between participants in multiple levels, learning objects, and teachers. Persistence to overcome and learn from failure is influenced not by individual characteristics such as grit or a growth mindset (Ryoo & Kekelis, 2018) but by the sense of playfulness, collaboration, and ownership of projects (Yan & Borge, 2019; Ryoo & Kekelis, 2018). As conversing with materials and teams members are the core of the collaborative design process, learning from failure also ascribes to this socio-material nature which calls for an ecological approach to account for its complexity (Borge & Mercier, 2019; Hakkarainen et al., 2013; Mehto, 2020). This framing calls for abandoning the fixation on the arbitrary distinction to identity "success" or "failure" and focusing on understanding the conditions that construct learners' learning (Varenne & McDermott, 1998). The teacher who orchestrates the learning environment should also be able to see beyond failure as disruptive and appreciate the learning opportunities it can provide.

Theoretical Framework

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Learning from failure in a collaborative learning environment requires us to take a micro-ecological learning perspective where learning is transformational (Borge & Mercier, 2019). Students are creating novel digital objects, and the approach to that creation is constantly changing. As stated by Sannino et al. (2016, p. 600), "The collective design effort is itself the core of an expansive learning process." This is even more so in a technology-rich collaborative design environment. In this type of learning system, individuals, groups, and the whole community are interrelated where students' sense-making and meaning-making are constantly influencing each other. Looking from an expansive learning lens, we see failure events as potential learning opportunities rather than disruptive events that hinder learning.

We apply the playfulness perspective to understand the emerging learning opportunities and the interaction between video games and players. We follow the post-structuralist perspective and highlight the emerging nature of learning from failure in such an open virtual world of Minecraft as in this study. Looking through the lens of playfulness, we are in a better position to reframe learning from failure by fully conceptualizing the change in sense-making around failure events (Ryoo & Kekelis, 2018).

At the same time, as learning is unpredicted in such an environment, it gives rise to the need for both teachings and learning to be improvisational (Sawyer, 2000, 2004), where facilitators and student groups spontaneously respond to the happenings in a specific situation. Failure events could trigger negative feelings in both facilitators and students for facilitators who have designed the curriculum and instruction. These events hinder the achievement of learning objectives. For students, these events often destroy or hamper their design processes. Being improvisational in such emotionally challenging situations often requires shifts in interpreting these events from negative to providing learning opportunities such as socio-emotional regulation, problem-solving, design practices, etc. Playfulness, in turn, plays a critical role in promoting such a shift in sense-making around failure events (Mortensen & Younas, in press). With a playful mindset, facilitators and student groups could feel the lightness of those high-stakes events. They could venture more into risk-taking and take the failures as learning opportunities to problem-solve jointly (Lemke, 2013).

Synthesizing studies on game and design research around failure, we re-examine a curriculum failure event identified by the first author, who also served as the lead facilitator in the learning space. We aim to understand how failure and learning from failure emerged at the intersection of a collaborative game and design environment. Situating this work in the design context, we ask the following question to guide the study: How do failure and learning from failure events emerge in a collaborative hybrid game environment?

Research context and population

The study took place in an afterschool design club where the curriculum targeted fostering productive failure in a collaborative design context with elementary students. Design groups were asked to complete a butterfly garden challenge using different tools such as paper and pencil, LEGO Blocks, and Minecraft to iterate in the club. This study included 16 students from 4th to 6th grades, 5 female and 11 male students. Four returning students had been in the club for over two semesters. They were grouped as an expert group. We then grouped the remaining 12 students based on their ages, gender, and expertise.

The data reported in this study came from the penultimate in the club, which the first author planned as the last building session using Minecraft. The Minecraft creative game mode was chosen as a design tool. Four design teams shared the physical classroom space and the virtual space at the time of design. Since the world was shared among them virtually, each team decided to choose a faraway space from other teams to avoid trespassing. Several other features, such as teleport and build mode, were enabled to manage the server and make the building process more efficient (Table 1).

Table 1

Minecraft Features, Function, and Rationale

Minecraft Feature	Function	Rationale
Creative mode	Players have unlimited resources in creative mode compared to survival mode in which resources can only be gained through mining.	Its open world allows players to imagine and create. Also, given the limited time in the club, we use creative mode to focus on design rather than open-ended exploration.
Shared server	The whole class can join the shared server virtually to build their garden together.	To save the design and manage the Minecraft space as a whole club, we used a paid server where we gathered all designers in one virtual server.

Teleport	It is a teacher account function that brings players from one place to another.	We asked players to volunteer to use the teacher's account to give the students control. It was rotated among volunteers.
Build Mode	It is a creative mode function that allows players to create a large structure within seconds rather than a block-by-block approach.	Expert team members who used build mode in the previous semester asked the facilitator to turn it on to build more efficiently.

Data collection and analysis

Video cameras were used to capture activities in all four groups, totaling approximately 72 hours of video recordings. Guided by Interaction Analysis (Jordan & Henderson, 1995), we first created content logs for all the recordings to describe group verbal and nonverbal interactions. This step was critical to systematically selecting data from the large corpus of video data. Triangulating the content log with the first author's field notes, we selected the last Minecraft building session for in-depth analysis. We identified the episodes of failure, defined as the errors/mistakes committed by players in the Minecraft game that negatively affected design processes. We tracked the development of these events over time. The initial analysis showed that when failure events occurred in the shared virtual space, they created community-level interruptions that involved multiple students from different groups. These interruptions affected their groups' design process. As such, rather than analyzing each group as a unit, we conducted a multilevel analysis, i.e., individual, group, and community, to present the cascading effects of failure events and how, in this community, individual students shifted their perspectives on those events (Borge & Mercier, 2019). To organize the multilevel analysis, we followed Ash's (2007) three-level approach – *flow chart*, *significant events*, and *microgenetic*. Using the concept of *transecologcal event* from the micro-ecological approach (Borge & Mercier, 2019), we identified and analyzed two events where problems at one level of interaction (individual, group or community) became central across interactional levels. These two events showed how failure and learning in the collaborative game environment emerge and develop as part of an ecological system.

Findings

To understand how failure and learning emerge in a context that integrates the configuration of video games and design processes, we trace the structure of an instructional failure lesson identified by the authors using an expansive learning and playfulness perspective. This section describes the overview of both the instructional activities and the collective events that fall under it. Then we select two significant transecological events that emerged from those grand level activities to understand how they begin, end, and transit subsequently.

Event overview

After reflecting on a failure instance from team 2, each designer received a laptop and started working on their butterfly garden design project. At the same time, the lead facilitator announced that each team was expected to complete their iteration by the end of the class. Given the open space and absence of strategies to mark their build sites, almost all teams could not find the original building sites. Team 1 member Eric asked his teammate Marcos who logged in to the teacher account (Table 1) to teleport Eric to their team-building space. This instance triggered the first significant transecological event due to Marcos' mistake – other teams were teleported to team 1's site by accident. This error upset several individual students and teams, especially team 2, since they spent the next 25 minutes searching for their site after the accident. This fruitless search then led to the second significant transecological event – Ekon crashed the server by accident. Though some students' accounts were not affected by the crash, most were logged out of the system. Consequently, three members (four in total) from Team 1 spent the rest of the club time figuring out how to log back into the server. The crash also gave rise to two learning events – how to undo the last fill and break the server. Realizing that the lesson plan failed given all the technical issues, the lead facilitator reflected on the whole club's experiences in the last ten minutes before dismissal. The following section describes the two significant events' beginning, during, and ending.

Blaming and being defensive

Beginning – the good intention

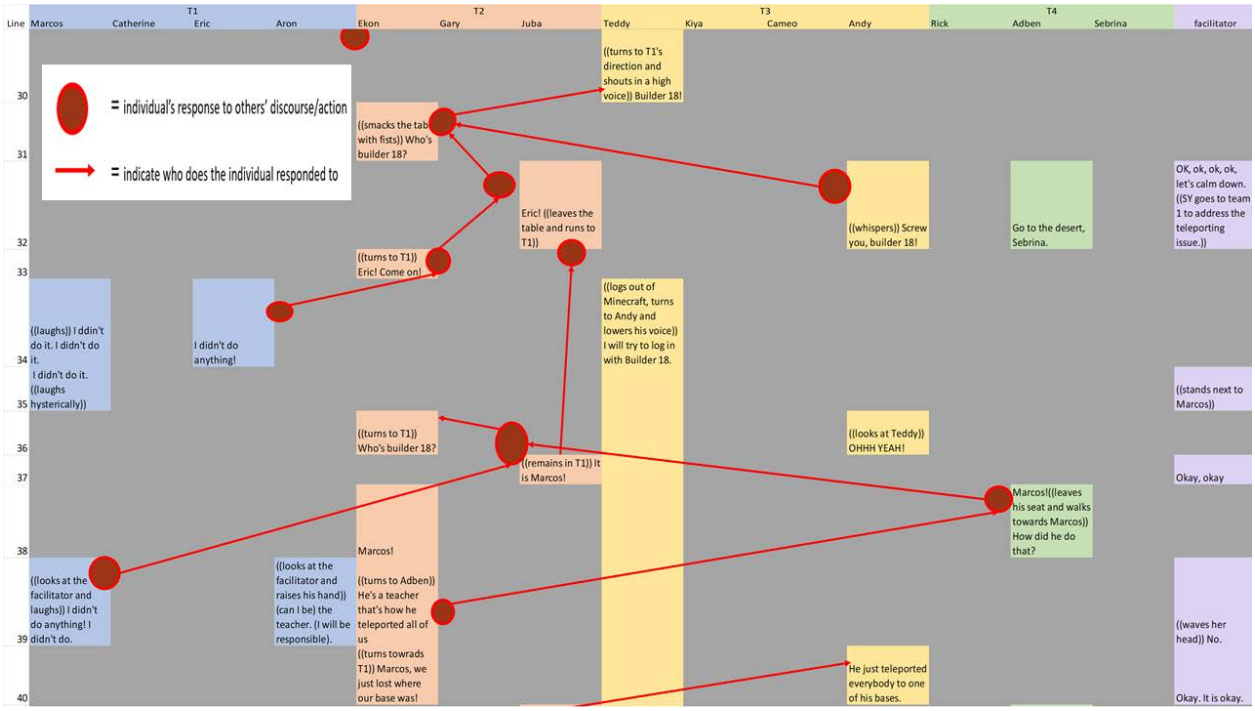
Historically, the teleport feature, unique to the teacher's account, was used to help lost players find their teammates in the vast Minecraft game space. To give the control back to the students, facilitators from the club decided to grant one student per session to use the teacher's account to manage the shared space. Marcos from team 1 volunteered to use the teacher account to help manage the Minecraft virtual space. When Eric from team 1 got lost, he asked Marcos to teleport him back to their team's building site.

Collective sense-making – who and how?

Within the body of this event, three collective sense-making dialogues occurred. The topic of the first dialogue was around figuring out who teleported the rest teams. While Eric (Team 1) and Marcos (Team 1) were figuring out the teleporting details, Juba (Team 2) shouted, "who just teleported me?" to the whole club. Marcos then realized that he and Eric might be responsible. He immediately turned to Eric, said "You! Eric!" suggesting that Eric was responsible for the teleporting. Eric laughed and said, "I didn't know" as a response. The event escalated as more students in the club shouted, "who just teleported me." Overhearing Marcos' accusation of Eric, Juba (Team 2) shouted to the whole club that Eric was responsible for the instance. Both Ekon (Team 2) and Adben (Team 4) expressed their frustration toward Eric without further investigation. Eric also became the center of blame. This triggered Eric to respond more strongly to the crowd compared to the first time. He shouted back to the crowd, "I didn't do anything."

Figure 1

A Screenshot of the Center of Blame



Just as the crowd started quieting down, Teddy (Team 3) shouted with a high-pitched voice, "Builder 18!" to show his frustration. This shout initiated the second collective sense-making dialogue. Students logged in to the server using the generic sequential naming system, from Builder 1 to Builder 18. Thus the only information about the player who teleported them was that it was "Builder 18". Ekon asked, "who's Builder 18". Juba first accused Eric (line 32) but soon discovered that Marcos was Builder 18 and announced it to the class (line 37). After this moment, the whole club shifted the center of blame from Eric to Marcos (lines 38 and 39). Marcos argued that he did not do anything. He explained that the intention was to teleport Eric to him. However, the rest of the players did not seem to accept his explanation. When the facilitator called it an accident, Andy (Team 3) stated it was a mistake. The third dialogue centered on how Marcos teleported everyone. This dialogue occurred between Adben and Ekon (line38 and line 40). Adben learned that teleport was a teacher account feature that he later used to bring his teammates back to their sites.

Ending and continuity

Gradually, the level of volume and inter-group dialogues reduced, and more intra-group dialogues occurred. This change indicated the ending of this significant transecological event. Consequently, the other three teams lost their building base. Teddy from team 3 and Adben from team 4 found their team's building sites not long after the search. Though teams were teleported to different land because of the teleport feature, both players asked the facilitator to use the teleport feature to bring their teammates to their building sites. As the whole club reflected in a later session, Teddy initiated, and Marcos maintained the argument around whether students should be allowed to use teacher accounts. Catherine from team 1 mentioned that the off-task behaviors that triggered the second significant event were a byproduct of the misuse of teleporting feature.

The ripple effect of a playful mindset and learning toward failure

Beginning – uncoordinated convergent play

Build mode in Minecraft allows players to construct a big structure, such as a wall for a house, in seconds. Historically, several club "experts", those in the club for multiple years, experienced the server breakdown at least once due to the large construction. Though, in the previous lesson, the "expert" team asked the facilitator to turn this feature on to build more efficiently. Some newcomers were still learning how to use this feature. This second significant event was triggered by a convergent action that three individuals from three teams carried out without coordination in advance.

At the beginning of the event, Team 2 members could not find their building site. Though Gary (Team 2) constantly regulated his teammate to focus on the searching task, Ekon (Team 2) decided to pause the task and play with the build mode. Later, Ekon claimed, "I'm about to break the world." While Ekon was attempting to break the world, Adben from team 4 (Ekon's older brother) also played with creating a giant pit of lava. Parallel to Ekon and Adben, Andy in team 3 announced that "Look what I did! By the way, I made a huge cavern". His self-revealing triggered a conversation between him and Teddy. Teddy encouraged him to make a bigger cavern using the build mode's filling feature. Teddy, though added, "It probably will crash the server."

Claiming responsibility after the server crashed

Aron (Team 1) was the first one affected by the uncoordinated convergent play. Eric (Team 1) asked why Aron (Team 3) left the game. Aron shared that the game crashed. As Adben (Team 4) shouted, "Oh my god! I think I almost crash the server", Aron told Adben that he had succeeded. Right after that, Ekon (Team 2) told Gary (Team 2) to "watch the sea it should fill up with gold any second now." As soon as Ekon (Team 1) finished his sentence, multiple players' screens showed they were logged out of the system. Shortly, Juba (Team 1) stood up and announced to the whole class with excitement, "Ekon! Ekon crashed the server!". Teddy (Team 3) and Adben (Team 4) all responded to Juba (Team 2) and claimed that "I crashed the game!". As server crashes became a fact, Teddy and Adben changed their narrative from "almost crashed" to "I crashed."

Ekon (Team 2), who realized that he did crash the server, started laughing (Figure 1 – blue circle). Gradually, several students from other teams rushed to Ekon's space (Figure 2). Along with Ekon, many players started laughing while looking at Ekon's screen, except Aron (Team 2). Aron (Figure 2 – red circle), instead, felt frustrated and called Ekon out, "Ekon! It is NOT FUNNY!" (line 24). Aron tried to take over Ekon's laptop (line 28) but was rejected by Ekon. They started wrestling with each other (Figure 2 – orange circle). Aron explained that he was trying to undo the last fill to solve the crashing server issue (line 28). Ekon finally let go of his laptop (line 29) and allowed Aron to operate it. Gradually, the crowds dispersed from Team 2's space.

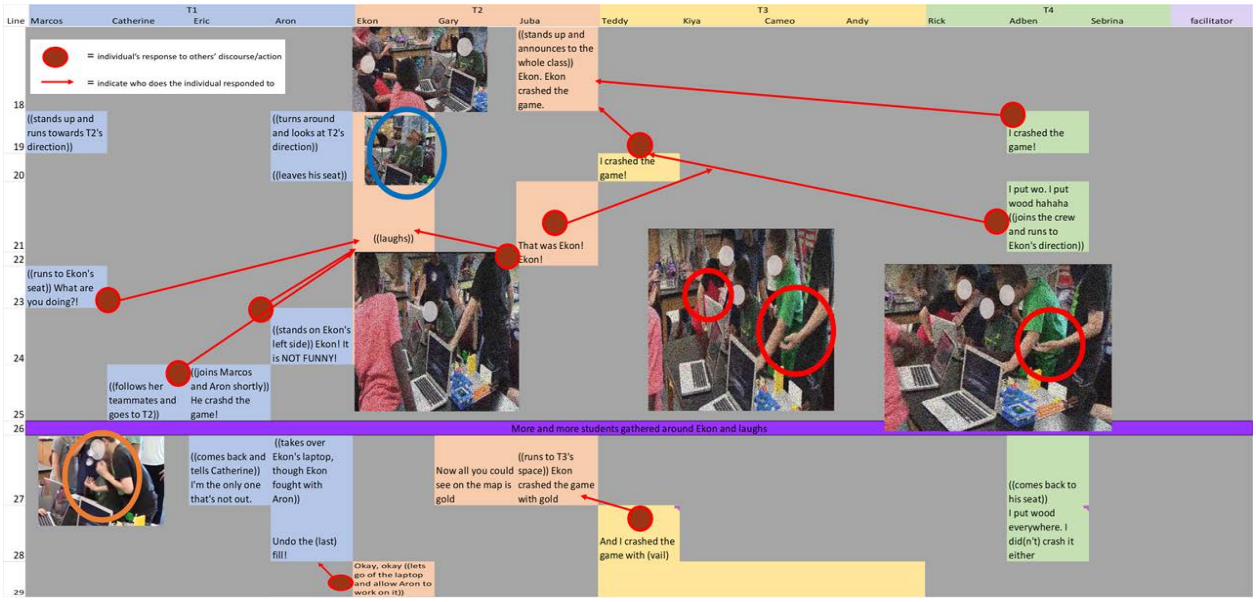
Though most players could log back to the games, team 1 members had no such luck. They were logged out of the system entirely, except for Eric. Without succeeding, Marcos (Team 1) walks to Ekon (Team 2) to ensure that Ekon did not crash the server again. Ekon defended that he did not touch anything. At the end, Ekon made a joke to the whole class, "OK, EVERYBODY I'M GONNA CRASH THE SERVER AGAIN ((laughing)) naa I am just kidding."

Playing with fire – attempt to re-crash the server

As each team resumed the building task, the inter-group interaction decreased. As team 1 tried to figure out how to log in, team 2 resumed searching their building sites. Team 3, with all members successfully logged in and no issue finding their building sites, continued working on their design. Adben (Team 4), though, started experimenting with

Figure 2

A Screenshot of Ekon (Team 2) Became the Center of Fun



the build mode to re-crash the server. He started with spamming woods in the world, which was noticed by Eric (Team 1) and Rick (Team 4) jointly. After Adben returned to his seat from Eric's (Team 1) space, he continued playing with the build mode. Suddenly, he shouted, "Yes! Build mode does help!". Rick (Team 4), who sat next to him, reminded Adben that "not if you do not use it properly." With a smirk on his face, Adben turned to Rick and whispered, "which I am about to." With Rick being the cheerleader who constantly laughed and verbally encouraged Adben, Adben enacted his plan. Once Adben finished his building, he called his brother Ekon's (Team 2). Ekon then joined team 4's space. After looking at Adben's screen, Ekon shared that Gary was the one who was responsible for the misuse of build mode, then went back to team 2. Adben and Rick both called out to Gary, which triggered Gary to join team 4's space. Feeling innocent and confused, Gary constantly claimed that "I did not do it!" and "I do not know how to do it." Adben, though, jovially called Gary out; his gaze fixated on the screen, and he stated, "really?".

The next moment, Adben repeated his play with build mode and invited Gary to witness his play. Similar reaction to Rick, Gary also cheered for Adben's testing, "Yeah, do it! Do it!". Adben's filling action was finally noticed by Juba (Team 2). He shouted, "who did this? Who spam the woods with build mode?". Adben claimed he was responsible, but he laughed, apologized, and stated, "I forgot I have build mode on." This claim attracted Ekon's (Team 2) attention. As someone responsible for the first server crashing instance, Ekon told Adben that he would consequently break the server. Juba (Team 2) echoed Adben's claim. Sebrina turned around and asked Adben to undo the last fill supported by Ekon and enacted by Adben.

Ending and continuity

The event ended when Cameo (Team 3) crashed the server again by watering the world. With the server crashing the second time, the facilitator seized the chance, ended the play, and transited to the last event – the whole class reflection. Interestingly, team 1 still suffered from the first-time server crash and could not log back for the rest of the session. However, they persisted in solving the problem jointly until they decided to create a new server for the team. Observing Adben's play with build mode, Gary learned how to fill and undo the fill. Called out by Ekon, Gary shared proudly that "I just learned how to do it, so it's fun". Then Gary used undo fill feature to erase all the gold he created.

When students reflected at the end of the session, this instance became their valuable prior experience to learn from. The whole class first debated on whether the build mode should be disabled. Students who advocated disabling it argued that the mode disturbed the design process, while those pros this feature stated that it helped speed up the building process. The class agreed that instead of disabling the feature, they should find solutions to make sure the build mode was used "correctly". Through building and negotiating on each other's ideas with the lead author's facilitation, the whole class came up with a solution that embraced the concept of learning community and mentorship, which allowed the experienced Minecraft players to teach newcomers, like Adben, to use the feature:

> "If you give the newbie some time to learn from the pros, the newbs will soon become medium newbies and then, and then they'll become pros, so then the newbies become pros and then they can

use build mode like pros instead of using it like newbs, filling the world with gold, turning the ocean into gold, filling the world with water."

Discussion

To understand how failure and learning from failure emerged in a hybrid collaborative game environment, we synthesized three analysis approaches (Ash, 2007; Author, 2019; Jordan & Henderson, 1995;) to analyze two significant transecological events. The analysis shows that the hybrid collaborative game environment supports transecological interaction, allowing players to learn game features from failure and take failure playfully. The findings also show how failure events, when supported by guided reflection, can support shared regulation processes.

The findings show a ripple effect of learning when the configuration of the learning environment allows transecological interaction. The interaction between physical club space and virtual Minecraft space allows failure to be experienced collectively, helps construct a shared understanding within the whole club and supports dialogues that aim to create collective solutions. One student or group's changed view on a failed event could ripple through other groups and change the community's perspective. In our hybrid collaborative game environment, learners expansively transformed their sense-making around failure. Students from other teams affected by the individual action learned valuable game skills in both significant events. In the teleport event, Teddy (Team 3) and Adben (Team 4) learned that they could use this feature to bring teammates back to their building sites which was the cause of the chaos in the first place. In the transition to the second event, we observed the shift from denying to claiming responsibilities and frustration to laughing. The playfulness behaviors such as laughing at breaking the server together emerged from the classroom in the second transecological event and fostered a learning and playful community. Instead of avoiding failure, players laughed and broke together to learn. The playful environment triggered the competitive sense to claim ownership of the failures. The second event started with multiple players trying to build giant structures and ended with students learning how to use build mode to create giant structures quickly and reduce the damage by using the "undo the last fill" feature. It also led to the student-led creation of shared community practices, rules, and values.

Taking a micro-ecological approach to re-examine an instructional failure, we see how the technical issues that disrupted the lesson plans could be transformed into joint learning activities for the community if the environment allowed playfulness and improvision to emerge and have the existing configuration to support learning. This finding implies the interactive relationship between design and enaction of the learning environment. The lesson plan set a structure that guided the general flow of the events. Though, its grand level structure allowed moment-by-moment improvisation and playfulness. It allowed students and the facilitator to collaborate creatively to advance a disadvantaged situation with playful attitudes (Sawyer, 2017). At the same time, the intentionally designed and cultivated guided reflection practice was there to support the whole club to learn from the failure. Failure in the Minecraft world can still be high-stakes and with real consequences, which was evident by some students' reactions toward teleporting and server crashes, but the feelings and meaning-making around those failure events promote playfulness (Juul, 2009; Lemke, 2013), and psychological safety (Edmondson & Lei, 2014), which offer opportunities for facilitators to help students learn. For facilitators in this environment, we argue that we need to incorporate a playful mindset to be more open to the emergence of problems and react accordingly. We argue that we should allow our teachers to treat every instance of failure as an opportunity to learn, let it play out, and then improvise on the emerging moment to support creative, collaborative learning (Sawyer, 2004).

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International Society of the Learning Sciences

Testing Simple Instructional Models to Promote the Spontaneous Transfer of Inquiry Strategies in New Contexts

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Abstract: Science simulations enable students to conduct rapid experimentation. Many students conduct sub-optimal experiments, even after instruction in effective inquiry. Consequently, they may not discover the underlying scientific regularities. A study with 8th-grade students compared the effectiveness of three instructional models and a control condition. Students completed a pre-test inquiry task and a transfer task using simulations, and we analyzed changes in their inquiry patterns. The results indicate that the most effective instructional model showed students an effective inquiry strategy, acknowledged the effort of using that strategy, and explained that they should resist the pull of the more common ineffective strategy. There was also a strong main effect of SES in student inquiry strategies use. Results provide initial evidence that adding a cue to resist the lure of a poor strategy improves transfer over simply explaining the right strategy.

Introduction

The COVID-19 pandemic highlighted the need to prepare children to be independent learners. Ideally, students would be equipped with the strategies to self-direct their learning given a task. While this goal is not new (Meichenbaum & Biemiller, 1998; Schunk & Zimmerman, 2007), the pandemic amplified the learning challenges for students who were otherwise accustomed to strong teacher and parental learning guidance (United Nations [UN], 2020; United Nations Educational, Scientific, and Cultural Organization [UNESCO] et al., 2020). Despite many heroic efforts, the reality is that many students needed to learn on their own. This situation created high demands on students and their families as well as learning loss for students who did not possess the strategies to self-direct their learning (Engzell et al., 2021; Patrick et al., 2020).

Inquiry is one-form of self-directed learning. Modern standards ask students to collect, analyze and interpret data, as well as form hypotheses (National Research Council [NRC], 2013). Learner success often depends on having a set of strategies to help handle the potential complexity of a system or a task (Stender et al., 2018). Of particular interest here are inquiry strategies to help gather evidence that can reveal the underlying systematicity of a scientific phenomenon exhibited in a scientific simulation. During the pandemic there was an explosion in the use science simulations as a tool to learn science in the classroom, e.g., *PhET Interactive Simulations* use has increased in some countries by 500% (Wieman et al., 2008).

One potential inquiry strategy for making headway in many physics simulations is to find a base unit that can equate different types of quantities. Figure 1 provides two simple instances, which we also used in the current investigation. In *Balancelet*, students need to find the relative weights of the colored objects. In *Tuglet*, students need to find the relative pulling-force of the players. The four examples in Figure 1 include setups used by students while exploring these simulations. The two examples in the first row display the correct use of the base-unit strategy. In both simulations, *Balancelet* (balance scale) and *Tuglet* (pulling cart), students are using one element on one side and are adding two or more of another element to find the ratio among them. The examples in the second row display a typical but ineffective strategy. In this case, students keep adding elements in an unorganized way to find the "balance" point.

If a goal is to make independent learners, then instruction should prepare them to use the strategies on their own, often in a context that differs from the original context of instruction. For instance, if students learn the base-unit strategy for *Balancelet*, they will ideally use this strategy for *Tuglet*. How can we teach inquiry strategies that equip students to transfer those strategies (Bransford & Schwartz, 1999; Day & Goldstone, 2012)? For promoting inquiry in science, one instructional approach is modeling, which we will call the *Show Right* model – *SR*). When modeling, teachers show the correct use of a strategy. For example, when running a lab experiment, a teacher can model a base-unit strategy for using the balance scale: *If I want to find the equivalence between oranges and limes, I need to keep one orange on one side and keep adding limes until the scale balances*. When teachers show students how to conduct a practice, they may later use the practice while doing the activity (Boekaerts & Corno, 2005; Chen & Klahr, 1999; Klahr & Nigam, 2004).

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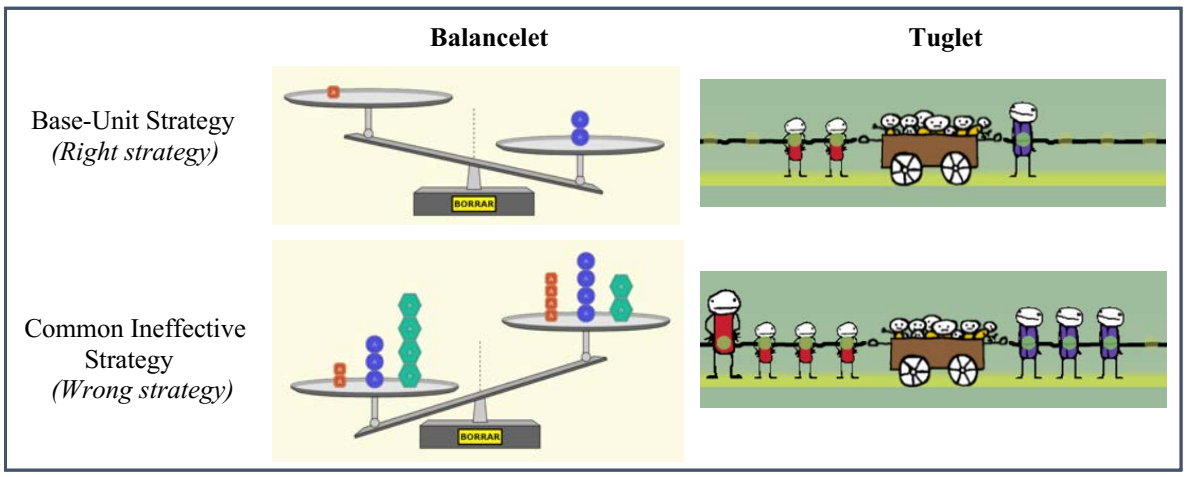
Figure 1
Instances of Two Types of Setups Use by Students in the Simulations



Another instructional approach is to combine showing the correct strategy and adding an explanation, which we will label – *SR+Exp*. For instance, an example might be: "*Keeping constant one side of the scale allows me to find the weight equivalence between fruits. Finding the ratio helps me to better predict what the scale will do when I put many lemons and oranges on it.*" Both *SR* and *SR+Exp* are good approaches. Our study examines whether we can increase spontaneous transfer by also alerting students to their natural but competing and often ineffective strategies. We hypothesize that strategy instruction can enhance transfer if it shows and explains the right strategy, and goes further to show students a common ineffective strategy and alert them to recognize when they start using the common ineffective strategy. This way, students' natural tendency to use the ineffective strategy becomes an internally generated cue to use the target strategy instead. We will call this the *Expanded* model.

The *Expanded* model approach added two elements (i) showing the ineffective (wrong) strategy and (ii) using the wrong strategy as an internal cue to overcome the demands of the cognitive effort. Students may be cued to transfer the right inquiry strategy into new environments by previously highlighting incorrect solutions (Clifford, 1984; D'Mello et al., 2014; Limón, 2001). When teachers share wrong approaches to solve an exercise, students see behaviors they want to correct and avoid (Manalo & Kapur, 2018; Vosniadou et al., 2001). Therefore, if students find themselves in a situation in which they are using a poor strategy, they may recognize it. Additionally, effective inquiry strategies may require more cognitive effort at first, at least compared to the common strategy of just changing things to see what happens. In the *Expanded* model, we also communicate to students that the common ineffective strategy may be easier at first than the target strategy, but that in the long run, the taught strategy will lead to more success in finding key patterns.

A factor that can affect students as they become independent learners is family SES (socioeconomic status). Prior research has shown that students from low-SES backgrounds have lower GPAs and standardized test scores (Reardon, 2011; Reardon & Bischoff, 2011). One contributing factor might be that schools don't focus enough in preparing independent learners. For example, in the United States, high school students from low-income backgrounds showed a learning loss of 0.4 standard deviations after 12 months of remote instruction during the pandemic (Agostinelli et al., 2022). The same pattern has also been found in other countries such as The Netherlands (Engzell et al., 2021). Therefore, we wanted to examine whether we saw less inquiry strategy patterns or different gains from instruction between students from two different SES family backgrounds.

We designed an experiment to compare treatments of no instruction (control group), *SR*, *SR+Exp*, and *Expanded*. In session one, students explore with a simulation (baseline measure), and shortly afterwards receive a brief video that uses one of the instructional models. Two weeks later, students complete a transfer task. We hypothesize that students assigned to the Expanded model will display a higher use of the taught inquiry strategy in the transfer task.

Methods

Participants

One hundred and nine students from two schools located in Bogota (Colombia) participated in the study. One institution is a public (run by a private organization) school where students (N = 59) come from a low socio-economic (SES) background. The second is a private school with students from a high-SES background (N = 50). The science teachers in both schools facilitated the activity. This study was approved by the University's Institutional Review Board. Parents provided passive consent and students provided active assent.

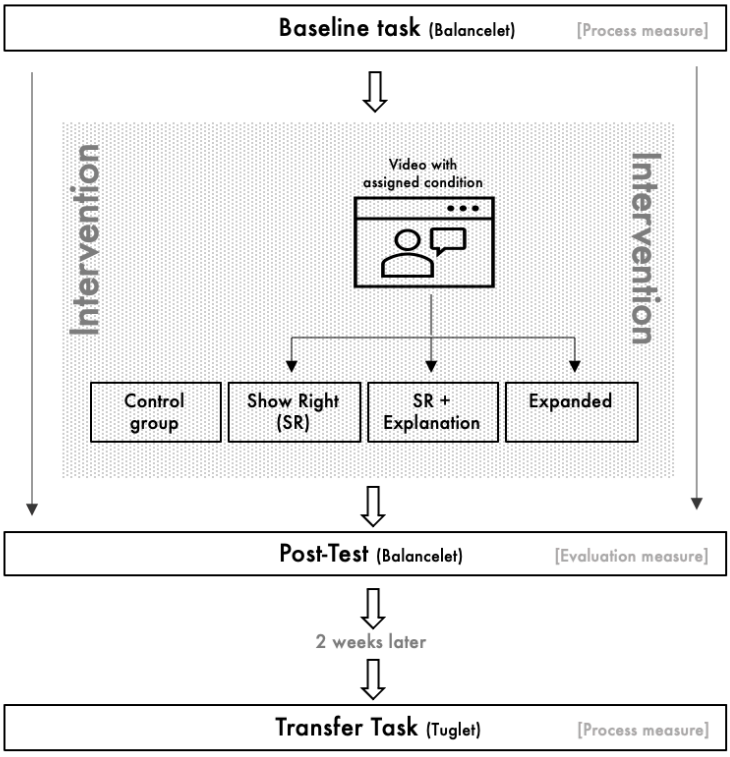
Design

The study design is composed of a control group plus three instructional models of inquiry instruction. Students assigned to the control condition do not receive the treatment video. In the first instructional model, *Show Right (SR),* a video shows students the right strategy. The second model is *SR+Exp* (Show Right + Explanation), where the video's instructor not only tells students the right strategy, but also explains the reasons why the right strategy is good. The last model is *Expanded,* which includes both components of the *SR+Exp* model and adds a brief component telling students a common wrong strategy and an explanation about why they might be inclined to use the wrong strategy even after they know that the right strategy is better. Students in both schools were randomly assigned to a condition. Randomization occurred within class.

We created one short video for each condition (<5 minutes). The videos are the key element of the intervention. All the videos feature the same teacher who follows a format used by *YouTubers*. Main messages are delivered using visual supports such as icons, images, and reinforcing text. The right strategy included in the videos is a particular strategy to learn the rules controlling a system, in this case, finding the equivalence between different types of units (e.g., how many red coins (base coin) equal a green coin?).

Procedures

Figure 2
Graphical Representation of Studies' Procedures



Studies occurred in the second half of 2021 and students in both schools were attending in-person instruction. In school A (public), students used the computer lab and in school B (private), they used laptops or tablets in the classroom. During the study, students in both schools used headphones. When needed, we provided

technical support to the teachers or the students (in school B, teachers shared the technical support session link with some students). Teachers followed a script to introduce and execute the study. Figure 2 presents a graphical representation of the procedures. On day 1, students provided assent and watched a short video with instructions on how to play *Balancelet*. Then they had five minutes to play with the simulation. We used this measure as a baseline of student inquiry. Once time elapsed, students watched the assigned condition video. They then took a post-test assessing their inquiry strategy knowledge (for space restrictions we don't include or report this evaluation measure in this paper). On day 2 (two weeks later), students played *Tuglet* for a maximum of 15 minutes. Again, they received short textual instructions about the interface. For *Tuglet*, the instructions did not state a specific task, though it becomes apparent that the inquiry goal is to predict whether any given configuration will go right, go left, or result in a tie. *Tuglet* served as the transfer task. The overall duration of the study, spread over two sessions, was approximately 60 minutes total.

Measures

We used choice-based assessments (CBAs) to measure students' inquiry processes (Schwartz & Arena, 2013). These CBAs (*Balancelet* and *Tuglet*) provided process measures about students' inquiry processes. In a CBA students are free to make choices about how to learn during the assessment, and we measure those choices directly from the logfiles of their actions. *Balancelet* provided the baseline while *Tuglet* the transfer measures.

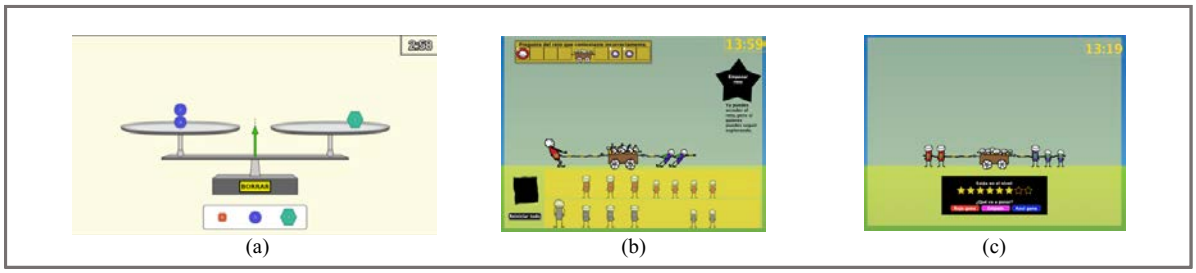
Taught (Right) Strategy Process Measures

Balancelet and *Tuglet* are CBAs about finding balance and equaling forces (see Figure 3). *Balancelet* uses weight; students need to learn to predict when a scale balances. *Tuglet* is about pulling; students need to learn to predict which team will win or tie when pulling a rope. *Balancelet* assesses students' exploration strategies to learn when a scale balances. *Balancelet* has a simple interface (Fig. 3-a): A scale, an eraser, a timer, and three types of coins. The coins have three different weights: red (*weight* = 1), blue (*weight* = 3), and green (*weight* = 6). Students stated learning task is to be able to predict what the scale will do for any combination of coins put on the scale – balance, tilt left, tilt right?

Tuglet is an analog of *Balancelet*. Students' task is to learn how to predict whether the blue or red team will win or tie in a tug-of-war. *Tuglet* characters come in three "strength" sizes: small (*pull level* = 1), medium (*pull level* = 2), and large (*pull level* = 3). In *Tuglet,* students do not receive a specific task, but they have the opportunity to run experiments every time they miss a question in the challenge room. Students can experiment in an explore room, and when they feel ready, they can move to a challenge room where they need to answer eight increasingly difficult questions in a row to win. If they make a mistake, they are sent back to the explore room where they can experiment or return to the challenge room at any time. Figures 3b and 3c show the explore and challenge rooms.

Figure 3

Interfaces Images Show a Balance Setup Using the Unit Equivalence Strategy in Balancelet (a) and in Tuglet (b). Image (c) Shows One of the Questions in the Challenge Room in Tuglet.



(a) (b) (c)

Setups run by the students in both CBAs are recorded and then extracted as logfiles. The clickstream data is later processed by classifying the setups performed by the students into meaningful categories. For the purposes of this paper, we only classified setups that displayed the taught strategy. The use of the unit equivalence (taught) strategy is calculated by counting each instance in which a student added elements when trying to isolate a specific unit (e.g., 1 red medium player on the left and 2 blue small players on the right). In essence, students got credit when they did not mix multiple sizes on either side of the scale or rope. We also count up the total number of setups run by the students in each CBA. The measure can be used as a raw frequency of strategy use, or it can be divided by the total number of actions to control for the total number of explorations. In this paper, results are reported using the latter option. Students could choose not to explore in the transfer task (*Tuglet*).

Instead of putting characters on the rope and seeing what happened, students can just go back to answer the questions. The bottom of Table 1 indicates the percentages of students who did not explore. They were treated as missing data and not included in the analyses.

Results

Table 1 shows a summary of the students' measures and interactions with *Balancelet* (pretest) and *Tuglet* (transfer test). As a reminder, numbers in Table 1 represent ratios of effective over total explores. We start by checking if there are differences between the high- and low-SES schools. Overall, high-SES students performed better than low-SES students.

Table 1

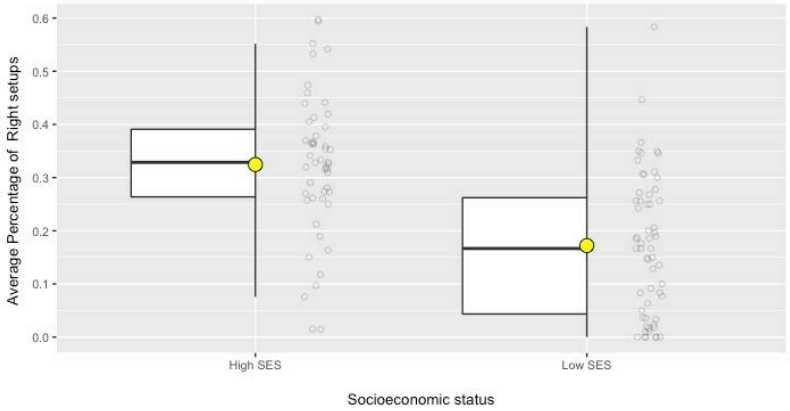
Descriptive Results and Interactions with the CBAs

	ALL				Control				Show Right (SR)				SR + Explanation (SR+Exp)				Expanded			
	Low-SES (N=59)		High-SES (N=50)		Low-SES (N=17)		High-SES (N=13)		Low-SES (N=20)		High-SES (N=11)		Low-SES (N=10)		High-SES (N = 11)		Low-SES (N=12)		High-SES (N=15)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Baseline taught strategy	0.08	(0.10)	0.18	(0.12)	0.10	(0.13)	0.21	(0.16)	0.08	(0.10)	0.20	(0.12)	0.09	(0.11)	0.15	(0.10)	0.03	(0.04)	0.17	(0.12)
Transfer task taught strategy	0.27	(0.24)	0.47	(0.22)	0.30	(0.27)	0.48	(0.21)	0.18	(0.21)	0.57	(0.18)	0.18	(0.19)	0.35	(0.26)	0.43	(0.21)	0.48	(0.20)
Tuglet specific measures																				
Tuglet duration (in minutes)	9.1	(4.40)	7.32	(4.19)	7.75	(2.96)	6.57	(4.01)	10.6	(4.96)	6.42	(3.35)	8.29	(4.24)	8.29	(4.39)	9.24	(4.96)	7.93	(4.85)
% of students who didn't explore	11%		12%		11%		13%		0%		21%		17%		15%		20%		0%	

Figure 4 shows the combined inquiry measures by SES groups. High-SES students displayed higher scores of taught strategy in pre $F(1, 107) = 21.02$, $p < .001$ and transfer $F(1, 107) = 20.93$, $p < .001$ process measures regardless of condition. Within schools, there were no differences in the taught strategy use in the *Balancelet* task (Table 1).

Figure 4

Average Percentage of Overall Process Measures by SES background



Note. Large circles are group mean. Error bars are bootstrapped 95% confidence intervals. Small circles are individual students' scores (jittered along the x-axis for visibility).

Two weeks after students received the instructional condition, low-SES students in the *Expanded* condition showed a higher percentage use of the taught strategy (in *Tuglet*). The percentage of taught strategy use in pre (*Balancelet*) and post (*Tuglet*) operated as a within-subject measure. The different instructional conditions (N=4) operated as a between-subjects factor. However, when we look at the interaction between pre-post inquiry measures x condition x SES, the interaction is marginally significant indicating that the low-SES students may have particularly benefited from the Expanded condition, $F(3, 101) = 2.545$, $p = .060$. Nevertheless, given that there are non-significant interaction effects including SES, we collapsed results across by SES to simplify the reporting of the condition effects.

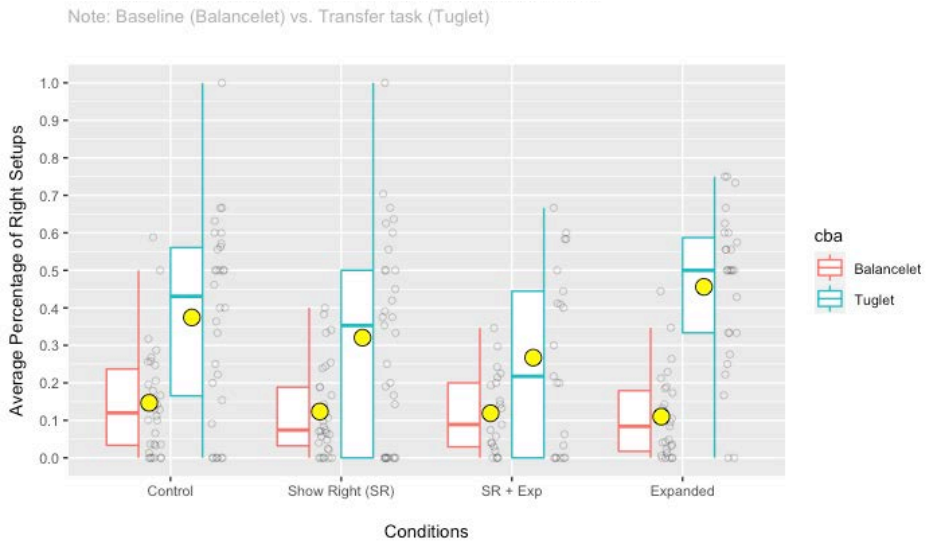
Figure 5 shows the use of inquiry strategies broken out by pre-test (*Balancelet*) and transfer test (*Tuglet*) by instructional condition (control, *SR*, *SR+Exp*, and *Expanded*). At pre-test there were no significant differences in the use of the target inquiry strategy. The two measures served as a within-subjects factor crossed by the between-subjects factor of instructional condition. Instructional condition produced a significant interaction with the difference between the pretest and transfer test measures, $F(3, 101) = 2.93$, $p = .037$. Visually inspecting Figure 5, the *Expanded* condition showed the greatest gain. One may see that the control condition also did well on the transfer test, but they were also relatively high on the pretest.

In this section we present the results of a linear regression model examining the relationship between percentage of taught strategy setups at transfer task and treatment, controlling for the percentage of right setups in *Balancelet*. Because there is a strong significant association between SES and percentage of right setups in *Balancelet* ($r = .41$, $p < .001$) this model didn't include SES to avoid collinearity. Above we show that high-SES students display higher use of the taught setup, so as expected we found that percentage of right setups in *Balancelet* predict students' right setups in the transfer task ($\beta = 0.46$, $t = 2.46$, $p = .016$).

We first compare transfer gains for each condition against the control group. None of the comparisons is significant. We found that students in the *SR* condition performed a lower percentage of taught setups than students in the control group ($\beta = -0.04$, $t = -0.70$, $p = .489$). Students in the *SR+Exp* condition on average, also performed a lower percentage of setups than students in the control group ($\beta = -0.09$, $t = -1.37$, $p = .175$). The estimate coefficient for students in the *Expanded* condition, showed that they performed a higher number of setups than students in the control group ($\beta = 0.10$, $t = 1.53$, $p = 0.129$).

Second, we ran additional parallel F tests to determine the contrasts among the other conditions. There are no significant differences in average percentage of setups between students in the *SR* and *SR + Exp* conditions ($p > .05$). The parallel F tests of *Expanded* condition with the *SR* ($p = .02$) and the *SR + Exp* ($p = .004$) conditions, showed that there are significant differences among them which confirms the patterns shown in Figure 5. While students in the control group on average made similar number of setups than students who received instruction, when we look at the different types of instruction, these results show that the expanded condition matters for transfer of the taught setups.

Figure 5
Average Percentage of Process Measures by Condition



Note. Yellow circles are group means. Error bars are bootstrapped 95% confidence intervals. Small circles are individual students' scores (jittered along the x-axis for visibility).

Discussion and Conclusion

This study directly measured whether students use a unit-equivalence strategy and whether instruction increases the transfer of this inquiry strategy. In our sample, we find that SES makes a difference in inquiry strategy process. One possible explanation for this result is that private school students engage in more inquiry. Looking at classroom size, science teachers in a private school have an average of twenty-two students, whereas those in a charter school have around forty. From an instructional perspective, given the attention inquiry instruction

demands of teachers, promoting inquiry may be easier with a smaller group of students, therefore, may happen more often for high-SES students.

We find that school type makes a difference in inquiry, but does instructional condition? The control condition students had a chance to complete *Tuglet* without receiving instructions. Yet, these students displayed a high percentage of inquiry strategy use in the transfer task in comparison to the other conditions. To offer some possible explanation it might be worth separating students by SES given the strong effect of SES on students' inquiry strategy use. For the high-SES students assigned to the control group they might not needed the instruction, and if you look at Table 1 average percentages of taught strategy use, they look similar among high-SES students. In low-SES students is possible that instruction didn't provide enough cues for spontaneous transfer and maybe instead confused them. The *Expanded* condition students had the opportunity to problem solve and then receive an instruction containing both right and wrong strategy use and explanations about why it is good to use the right strategy and cognitive effort of the right strategy to cue students to transfer into new settings. Overall, it seems that students in the *Expanded* condition do better than the students in the control condition. Instruction that cues students when learning an inquiry strategy seems to support inquiry strategy transfer to new contexts. Students in the other two conditions, *SR* and *SR + Exp*, fell in between, perhaps because individual differences are driving the effects in these latter conditions or because these instructional models are not as effective for promoting inquiry strategy transfer to new settings.

The interaction between SES and condition was marginally significant. Results show high-SES students already know a lot about inquiry and are more prepared to learn inquiry. Even the simple form of instruction (*SR*) worked for high-SES students. In the case of low-SES school, students assigned to the *Expanded* condition show the highest transfer of inquiry strategy to new contexts. It is possible that for students with low inquiry exposure, cueing them to recognize when they are using a wrong strategy and acknowledging the cognitive effort, better prepares them to use inquiry strategy in new contexts.

Finding instructional models that promote the use of inquiry strategies should be helpful to students as they move forward in their science learning. This study provides initial evidence that instruction that alerts to common ineffective strategies can promote the transfer of a taught strategy. By hypothesis, pointing out that "just adding things without a plan" is a poor strategy cues students to recognize when they are doing that behavior and reminds them to use the right strategy. Future studies will determine whether showing a wrong (ineffective) strategy vs. wrong strategy with effort cue are key to promote spontaneous transfer. Here, we examined a single strategy – find equivalence to a base unit. There are multiple inquiry strategies, such as the control-of-variables strategy (CVS). If we teach CVS to students using the expanded condition, would students spontaneously use CVS in new contexts? Subsequent studies will look at the effectiveness of the *Expanded* model for teaching other inquiry strategies.

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International Society of the Learning Sciences

Understanding Success in Library Makerspaces for Assessment Development

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Abstract: Makerspaces continue to grow in number and popularity and research on maker education has increased significantly, but most academic literature on maker education investigates the learning outcomes that are possible in these spaces (Mersand, 2021); fewer studies reflect an interest in understanding how we can recognize and assess learning outcomes for patrons (Lin et al., 2020). Current literature asserts that assessment in library makerspaces is a complex and thorny process because of the numerous learning goals and stakeholders that must be considered. This study confirms that success in these learning environments takes many forms. We introduce a Typology of Success that categorizes five types of success library staff value and want to assess. We also suggest an additional layer of complexity in assessment development may be due to the shifting nature of evidence of success that is dependent on the maker activity, the patron's goals, and the patron's disposition when it comes to facilitation.

Major issues addressed

For some, it may seem that the Maker Movement is heading toward the trough of disillusionment within its respective hype cycle (O'Leary, 2008), but educators across many countries are still committed to the promise of student-driven, hands-on learning through making (Eriksson et al., 2018; Milara et al., 2020). Makerspaces continue to grow in number and popularity, and research on maker education has increased significantly, growing from six empirical studies in 2014, to 51 in 2018 (Mersand, 2021).

Most academic literature on maker education investigates the learning outcomes that are possible in these spaces (Mersand, 2021), with particular focus on the learning afforded by makerspace environments and the relationship between learners and making (Peppler et al., 2016b, 2016a). Fewer studies reflect an interest in understanding how we can recognize and assess learning outcomes for patrons (Lin et al., 2020). This gap in literature represents an imbalanced understanding of the educative value of making. Studies that identify what is knowable in maker education only accounts for half of the learning process; we must also explicate how the knowable can be recognized, interpreted, and understood by stakeholders (e.g., educators, administrators, caregivers, learners).

Public libraries, in particular, are embracing maker education (Chang et al., 2019). The second most empirical studies on makerspaces come from the field of Library and Information Science (Mersand, 2021). This is perhaps unsurprising given that a common mission of libraries—to increase patron literacy—demands that they integrate emerging literacies (e.g., maker education, digital literacy) (Mann, 2018). However, only a small amount of the literature on assessment in maker education originates from libraries (Lin et al., 2020). This may be due to the fact that the majority of available assessments are designed for schools with relatively uniform standards and pedagogical expectations, whereas the heterogeneity of library goals, and of making processes and outcomes (Teasdale, 2020, p. 1) fundamentally differ (Rogoff et al., 2016). For instance, library staff may be less interested in assessing individual learners through making and would rather understand how their makerspace supports family learning (Roque, 2016). Endeavoring to assess family learning shifts the unit of analysis in assessment from one learner to multiple learners and would likely demand different assessment tactics. To close the gap in literature, scholars and maker educators across library settings are beginning to place equal importance on studying maker-related learning outcomes and assessment of those outcomes.

Due to unique practical and pedagogical demands, and the axiological commitments of library makerspaces, scholars intending to support assessment in these settings have taken to either developing bespoke assessments (Chang et al., 2020), or sharing assessment-building processes to help maker educators develop their own assessments (e.g., Cun et al., 2019). This study addresses the issue of limited scholarship on assessment in library makerspaces and adds to literature about processes that help facilitators create assessments for their makerspaces. We report findings from a qualitative research project in progress that investigated what library staff broadly consider evidence of success in their makerspaces and seek to assess. We introduce a Typology of Success, which encapsulates five major categories of success that emerged from analysis, and we advance the idea that

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success is, at times, a moving target in library makerspaces that requires flexible assessment tools with the capacity to capture evidence of success as it evolves.

Potential significance of the work

To support facilitators of maker education in their efforts to assess learning in their makerspaces, Cun and colleagues (2019) generated a *library makerspace assessment matrix* to identify the "assessment needs of patrons and librarians" (p. 39). The purpose of the matrix is to clarify which types of assessment tools are appropriate for any given maker activity based on when and how a patron most benefits from assessment and what a librarian wants to learn about the patron using an assessment. The matrix also provides a list of six categories of assessment "that could be implemented given typical librarians' knowledge and resources" (p. 45).

Though a promising tool that contributes to assessment of maker education both practically and conceptually, the matrix centers on a specific kind of learning. By focusing on skill development and mastery of technology, the matrix only documents learning that is "acquisitional" (Sfard, 1998). This theory of learning "implies that there is a clear end point to the process of learning" (Sfard, 1998, p. 6)." A library maker educator assessing for acquisitional learning might administer a pre- and post-survey under the assumption that they can track the knowledge or skill a patron had before and after attending a program. In contrast to learning as acquisition, learning can be participatory. Learning as participation is "a process of becoming a member of a certain community" (Sfard, 1998, p. 6), which is considered an important outcome in literature on maker education (Barajas-López & Bang, 2018; Blikstein & Worsley, 2016; Einarsson, 2021). If one is interested in assessing learning as participation, one might provide exit surveys that ask patrons to describe how welcome they feel in a makerspace or observe moments of collaboration between patrons.

Teasdale's work (2020) incorporates different stakeholder perspectives "to foster in-depth understanding of evaluative criteria for the makerspace in its real-world context, based on multiple sources of evidence drawn from multiple perspectives" (p. 4). She draws from observations of the makerspace, interviews with library staff and leaders to understand the goals of the library, and interviews with library patrons "to investigate their purposes and desired benefits related to makerspace participation" (p. 4). By triangulating these data sources, Teasdale defines outcomes and visions of success that stakeholders want from maker education experiences for the purpose of developing evaluative criteria for assessments. Teasdale presents seven evaluative criteria that reflect conceptions of success held by library staff and makers:

- Access to technology
- Learning to use technology
- Fostering entrepreneurship
- Nurturing creativity
- Strengthening communities and families
- Realizing intrinsic benefits
- Saving money

The seven criteria provide a broad picture of the kind of success that is possible and desired by library staff and makers, extending learning outcomes beyond those captured in the library makerspace assessment matrix. However, as Teasdale notes, each criterion will not be relevant to all participants; a strong assessment would "identify the criteria that were relevant to each participant and apply those specific criteria to data collected from that individual" (p. 8). Gathering data from various stakeholders and soliciting information about their desires and intentions in a makerspace appears to be a promising approach to developing relevant criteria that can be used to assess maker activities. And yet, the criteria Teasdale offers do not clarify for maker educators the types of assessments that might be useful for capturing evidence the way Cun et al. do (2019).

The findings from this study build off the contributions from Cun et al. and Teasdale by introducing a Typology of Success for maker education in libraries. The Typology identifies five categories of success that emerged from interviews with library staff at two libraries. Like Teasdale's work (2020), this study shares conceptions of success that can be used to inform which types of assessments employed or designed for a given maker activity or program. Like the work of Cun et al. (2019), the Typology is meant to direct library maker educators toward a narrowed set of assessment possibilities to aid their decision making.

While the Typology is still being refined, we introduce it as context for the broader finding we present regarding the evolving nature of success. Both the Typology and our general finding contribute to burgeoning literature on assessment in makerspaces in library settings. The main significance of this work is to advance the idea that what appears to be noise in data about assessment in library makerspaces (e.g., responses from library

staff that contradict each other, or constant appeals to "it depends" when a staff member describes how they know a program is working) is in fact a feature of making and learning in library makerspaces that must be addressed more fully to authentically assess these unique environments without losing their richness.

Theoretical and methodological approaches pursued

Theory

The study is grounded in the constructivist paradigm of epistemology, which asserts that "knowing" is a socially and culturally situated process that builds on previous meaning making and the activity of learners both individually and collectively (Efland, 2002). There is nuance and debate within constructivism that is worth exploring (Packer & Goicoechea, 2000), but it is beyond the scope of this paper. Most importantly, this work does not adhere to a positivist paradigm of epistemology, in which knowing, or truth is considered universal, complete, and discoverable. In concert with constructivism, our study was designed to understand how library staff experience assessment, how they practice it, and how they perceive both assessment and success in maker education.

More specifically, the research presented here draws on *evidence-centered assessment design (ECD)* (Mislevy & Riconscente, 2005), a method for designing assessment using data associated with authentic practices in the learning setting in which assessment will take place. ECD is multi-step process of designing assessment that first asks what "complex of knowledge, skills, or other attributes should be assessed" in a learning environment (Messick, 1994, p. 16, as cited in Mislevy & Riconscente, 2005). The five steps include: *domain analysis*, which includes substantial analysis of the content and concepts that will be assessed and identifying what evidence will indicate that the content or concept has been understood by a learner; *domain modeling*, a process of adapting the information gathered from the domain analysis phase into a narrative argument that will become the foundation of the assessment; *conceptual assessment framework,* is the process of adapting the narrative argument into a blueprint of tasks or items necessary to conduct the assessment; *assessment implementation,* which encompasses the development of assessment tools (e.g., tasks, rubrics, and samples); *assessment delivery,* the process of enacting the assessment and reporting its findings to the appropriate audience (Mislevy & Riconscente, 2005). This paper presents findings on the domain analysis portion of ECD, the only phase that has been completed thus far. Although the project was interrupted by COVID 19, we intend to follow the four subsequent steps and develop a suite of assessment tools for maker-based learning based on our domain analysis.

Methodology

This study follows the methodological framework of a basic qualitative study (Merriam & Tisdell, 2016). "A central characteristic of all qualitative research is that individuals construct reality in interaction with their social worlds," and the purpose of qualitative research is to understand "the meaning a phenomenon has for those involved...to understand how people make sense of their lives and their experiences" (Merriam & Tisdell, 2016, p. 24). Our research questions ask:

- What learning goals do library staff and maker educators have for their maker-based learning programs?
- How do they define success in those programs?
- How do they recognize and describe evidence of success and the learning goals they identified?

These research questions allowed us to make sense of what staff want to assess in their maker education programs without placing explicit emphasis on assessment. Focusing on assessment might have been more difficult for staff to articulate, especially if they did not already have robust assessment practices or assessment literacy. To elicit responses to those questions, library staff and maker educators were asked to explain how they know when their program is going well and what evidence they look for.

Study sites

Makerspaces in two libraries serving medium-sized cities in the Midwest were included in this study. Learn to Make Lab (1) serves nine library branches in a single system, though it is physically housed in the centrally located downtown branch. Learn to Make Lab hosts artists-in-residence and drop-in sessions at their physical space, and shares maker-kits which include various materials to the other branches, summer school sites, and outreach programs. Most of the materials at Learn to Make Lab are considered low-tech (e.g., craft materials, art supplies, recycled goods), but they also boast a media lab. The makerspace known as Making an Impact (1) is also located in the main, downtown branch of its library system. In contrast to Learn to Make Lab, it is one of 37 branches that

have sites throughout suburban, somewhat rural, and inner-city regions alike. Due to limited residential housing surrounding this branch, it mostly serves people who commute to the library. Making an Impact has two full studio spaces in addition to other technology common in makerspaces, like 3D printers, laser cutters, robots, and interactive technologies, as well as more analog tools like a button maker.

Sample

Interviews for the full domain analysis were conducted with library staff and maker educators, and library patrons (e.g., learners and their caregivers). In this paper, however, we present findings based on analysis of the responses from library staff and maker educators only. Rather than target a large sample size and make claims about the average response to the research questions, staff were purposely selected to amass a maximum variation sampling of responses for each library site that would illustrate variety and range (Merriam & Tisdell, 2016). Library staff were selected to participate in interviews based on how directly tied their work and responsibilities were to their respective library makerspaces. Each staff member that participated was connected in some way to the maker programs offered by their library, but the staff varied in terms of their exact roles within the library. The majority of staff who participated in the study were maker educators or librarians who also implemented maker education programs; staff supervisors and a manager of operations were also interviewed.

Data collection

Seventeen library staff were interviewed through a semi-structured interviewing process (Rubin & Rubin, 2005). Interviews ranged from 25 to 50 minutes and were conducted in person by two members of the research team (one at each library site). The research team guided the interviews so that conversation focused on learning and engagement in library maker programs, but participants were encouraged to draw from experiences with other programs as well, especially when discussing how learner engagement can look different depending on the programmatic focus. Specifically, they were asked, *what is happening when things are going really well in the Launchpad/Bubbler? How do/would you know? How could you know?* If participants needed more scaffolding to answer the questions, the research team would probe further by asking *What does it look/sound/feel/smell like when things are going well? Even if hasn't happened yet, what would it look like?* They also encouraged participants to share about a specific time or program that was really successful and to describe what happened.

Data analysis

After audio recordings of interviews were transcribed, the researcher who did not conduct the interviews underwent several cycles of inductive, emic coding analysis. Data was analyzed using (a) descriptive coding that highlights the topic of a response, (b) concept coding, which describes the content that is discussed in the response, and (c) subcoding, which assigns a secondary code to enrich the primary or parent code (Saldaña, 2016). The first iteration of coding was conducted using an analytic matrix that included verbatim quotes about success from the transcripts, analytic memos describing the topic and content of each quote from the researcher, and potential codes that encapsulated the main themes in the quote (Maxwell, 2013). The matrix was used to organize the data and trace the researcher's interpretation. The initial phase of coding produced a long list of codes, which were then transferred to a code map (Saldaña, 2016), a list of codes and subcodes organized by theme. The researcher condensed and expanded the codes in the list while reviewing the analytic matrix. Following that, the researcher created a new analytic matrix, free of any analysis or notes, and coded the verbatim quotes again using the list of codes. This process afforded her an opportunity to test whether the same themes emerged. Once the second phase of coding was completed, the researcher updated the code list and began a process of coding the list for thematic patterns and organizing (and reorganizing) them into categories. Those codes were then shared and discussed with the library partner from each site, so they could challenge or confirm their accuracy and potential utility for developing assessment moving forward, a process called member checking (Merriam & Tisdell, 2016). With their input, redundant subcodes were eliminated, and parent codes were reorganized, revised, and condensed into central concepts that related to how library staff know when a program is working. Throughout data analysis, all three research members met bi-monthly to discuss the data and engage in constant comparison of themes or "incidents" in the data as they emerged (Corbin & Strauss, 2008).

Major findings

Typology of success

Five themes emerged when library staff described how they know when a program works and what counts as success in library marker education. Success is encapsulated in the *metrics* they collect, the *lasting impact* a program has on patrons, the moments when patrons experience *learning as participation*, the opportunities to

check off *learning as acquisition*, and the proficiency with which learning is facilitated by maker educators (*facilitation of learning)*. *Metrics* refer to a concept of success as the accumulation and collection of quantitative data on magnitude of outreach and audience demographics, usually over time. When success is understood as *lasting impact*, it means a program influenced patrons in a way that was holistic (e.g., programs connected to school curriculum) or long-term (e.g., patrons are inspired to engage in similar programming outside of the library site). A program is considered successful if it demonstrates *learning as participation*, that is, learning as a "constant flux of doing" inseparable from the learning context and "a process of becoming a member of a certain community" (Sfard, 1998, p. 6). A program may also be considered successful if a maker educator observes *learning as acquisition,* in which a patron picks up a skill or learns something new (Sfard, 1998). Finally, success may be denoted by the *facilitation of learning*, including how "well" learning is facilitated during an activity or by the maker educator's experience of meeting their own teaching and learning goals. These five types illustrate the varied ways in which success in library programming manifests according to library staff.

Again, this Typology is still being refined, but we include it here to provide context for an important idea that has emerged from the data regarding the complexity of assessment in library makerspaces. As it is now, the different success types suggest assessment is meaningful at vastly different timescales, not only formatively (ongoing throughout the course of instruction) and summatively (occurring at the end of an activity, program, or series of programs) (Shute, 2009), but also in relation to whether success is assessed within the learning event (e.g., *learning as participation* or *acquisition*), or over the course of multiple distinct learning events (e.g., *metrics* or *lasting impact*). The types also indicate different units of analysis for assessment, from individual patrons to patrons as a collective or community to maker educators. Importantly, the Typology reflects learning as both participation and acquisition, a feature that is often missing from assessment tools and protocols. The inclusion of both types of learning might be considered epistemologically incompatible, but Sfard insists they are productively contradictory:

> Each has something to offer that the other cannot provide… metaphorical pluralism embraces a promise of a better research and a more satisfactory practice. The basic tension between seemingly conflicting metaphors is our protection against theoretical excesses, and is a source of power. (1998, p. 10)

Ultimately, the Typology demonstrates that the learning outcomes and success library staff value and want to assess differs greatly, by timescales, units of analysis, and even theories of learning. By categorizing types of success that staff care about, this tool may help maker educators select or design assessments for their makerspaces. For instance, when engaging in domain analysis of their own sites, they might start with the Typology to identify the outcomes and models of success they value. Library staff might also conduct their own analysis and compare their findings with the Typology as a way to articulate the timescales, units of analysis, and models of learning they want to focus on. A precise framework for the Typology and a comprehensive guide is outside the scope of the paper but is forthcoming.

Evidence of success is a moving target

In addition to the sheer variety of definitions of success in library makerspaces, our findings indicate that evidence of success, too, is difficult to identify because it can shift. For instance, one library staff asserted that the way they determine a patron's progress "depends on what activity they're doing." In fact, six of the 17 library staff interviewed, about 35%, were coded as responding with "it depends" when asked how they know when a program is working or successful. The staff member went on to say that in the case of a patron who wants to use the recording studio, they are more likely to pose questions if they do not understand what to do, because their session time is limited. In contrast, when people visit the makerspace to explore materials and activities, they may not ask for assistance right away. It is then up to the maker educator to observe their behavior and recognize when a patron is using a tool without fully understanding it. Essentially, the library staff in this example implies that maker activities do not occur in a vacuum; they are socially and culturally embedded, and inherent in each activity are cultural practices around seeking support that facilitators need to be aware of while assessing, because those practices can inform how evidence of success looks.

Another staff member noted that certain maker behavior, like "coming in and just downloading one thing offline that they didn't use or didn't make," may be evidence that the makerspace is not successfully inviting patrons to "progress deeper." However, they admit that such behavior might also communicate success if the patron's goal is to use the library for its available resources. Teasdale (2020) discusses this phenomenon of assessment as a moving target in her work as well, when she writes, "applying (assessment) criteria uniformly

could, therefore, lead to a mismatch for some participants." She calls for "individualized criteria" in assessment instead "to identify the criteria that [are] relevant to each participant" (p. 8).

Moreover, our analysis indicates that evidence of success not only varies by activity or the patron's personal goals, but it can sometimes shift depending on the patron's perceived dispositions. One library staff stated that they could tell "things are well" or that a patron is enjoying themselves or engaged "if they're asking more questions…and they're wanting to find out more about what's going on." When pressed by the interviewer what specifically about the questions or number of questions indicates success, the staff member stated,

> Well, I think it really depends on the type of question. Some people might be the type of person that might not ask any questions, and if I see that they've been sitting quiet and all of a sudden, they start asking a couple of questions about something, that indicates to me that they're interested. They're interest is more piqued. Whereas somebody else might be just asking all kinds of questions about everything, "What is this? What is that? What is that?" If they start ramping up their questions or start focusing their questions on a certain area, I can tell that they're more engaged in that area or they're getting more engaged.

The quote suggests that even when a maker educator is looking for certain behavior or criteria to assess a patron's experience or success, the meaning of that behavior shifts depending on how that person normally behaves. Certainly, whether a make educator can really know in a short period how a patron "normally" behaves is question worth exploring in its own dedicated study. The key point, however, is that evidence of success is sometimes a moving target, adding to the layer of complexity for assessment in public library makerspaces. While more research is necessary to fully investigate the notion that evidence of success can be dynamic rather than static, we share implications for assessing a moving target in the following section.

Conclusions and implications

Across the literature on assessment in library makerspaces, scholars specifically note how difficult it is to design assessments for these settings, because of the numerous learning goals worth addressing and diverse public library stakeholders. Teasdale (2020) comments on how the heterogeneity of patrons and maker educators, and their diverse goals for learning through making, make the challenge of developing or selecting assessment "particularly pronounced for public library makerspaces" (p. 1). Cun et al. (2019) recognize that assessment for library makerspaces is connected to the assessment needs of the library at large, and that part of developing authentic assessments for makerspaces requires compatibility between the two, or there is a risk of assessment being "viewed as having little or no value to a stakeholder of the library makerspace (e.g., a patron, librarian, administrator, library board member, or municipal agency)" (p. 41). Wardrip et al. (2019) note that the vast array of stakeholders associated with libraries pose a challenge when it comes to assessment; the question of "what should be assessed and for whom" is not as straightforward as it may seem (p. 34).

This study confirms that success takes many forms. The Typology of Success introduces five different types of success that emerged from interviews with library staff. Additionally, the Typology begins to address the need to understand "success that accounts for makers' and libraries' varying priorities" (Teasdale, 2020, p. 1) and aid in the design or selection of new assessment tools to support assessment of these unique learning environments. For instance, the Typology might be used with maker educators to clarify the success type they most care about, thereby helping them identify the unit of analysis that they might target. Another implication of the Typology is that maker educators and their ability to facilitate learning in makerspaces may be a useful focus for assessment. Educators must make numerous inferences about patrons, particularly when it comes to assessing a patron's progress and providing appropriate feedback to support their learning (Michalchik & Gallagher, 2010); it is worth exploring how well they make those inferences when it comes to assessment and what practices, tools, and professional development can help attune them to making stronger inferences.

In their review, Lin and colleagues (2020) refer to assessment in any makerspace as a "moving target," "with varying students, educators, activities, disciplines, arrangements, and learning outcomes" (p. 3). This study confirms that another layer of complexity in assessment of library makerspaces may be due to the shifting nature of evidence of success, which depends on the maker activity, the patron's goals, and the patron's disposition when it comes to facilitation of a program and their own participation. We imagine, too, that evidence of success may change as a maker educator continuously develops expertise for eliciting evidence from patrons, developing inferences of patrons' learning, and making interpretations of those inferences. One implication for this finding is that library staff need support in identifying success and evidence of success with more consistency, so they might improve their informal assessment techniques (Gahagan & Calvert, 2020) and systematize the claims about their programs.

Another possible implication is that staff members' penchant for saying, "it depends" when asked how they know their program is going well, may not an indication of uncertainty, but rather recognition that what counts as evidence of success can shift in a moment's notice, especially as they take in more information about the patron. This implication evokes several questions. If evidence of success shifts depending on multiple factors, what specifically are those factors? This study begins to answer that by pointing to the activity, the patron's goals, and the patron's disposition when learning, but more research is needed to address that provocation fully. Additionally, if evidence of success is not always static, are formative assessments sufficient to capture its dynamism? Or are other, more flexible assessment tools necessary to capture the evidence of success as it shifts? What do/would those tools need to look like? How would they operate differently from current available assessment tools and practices? Moreover, if evidence of success can be in flux, what does that mean for assessing learners across learning settings? In describing the learning as participation metaphor, Sfard (1998) says,

> Being "in action" means being in a constant flux. The awareness of the change that never stops means refraining from a permanent labeling. Actions can be clever or unsuccessful, but these adjectives do not apply to the actors. For the learner, all options are always open, even if he or she carries a history of failure…Today you act one way; tomorrow you may act differently. (p. 8)

Perhaps our penchant for labeling students as a reflection of their assessment results (e.g, gifted and talented, or below average) will be troubled by the finding that evidence of success is a moving target. If success evolves as the learner does, perhaps we will come to learn that current assessments cannot fully measure students' ability to learn or grow and should not be used in this capacity. Maybe there will come a time when we abandon assessment practices that seek to define students by what they can do, and instead find ways to understand how students' potential for learning expands with each new day.

Endnotes

(1) The names of these makerspaces have been changed to protect study participants' anonymity.

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Abstract: We designed a lesson about Urban Heat Islands (UHI) that features Snap*!* programming challenges. The lesson is designed to enable students to leverage their computational and scientific understanding synergistically to further their learning in each area. The lesson also features fictitious automated college student mentors to enhance students' sense of belonging as they engage in the programming challenges. We report on students' level of success with three increasingly complex programming challenges as well as their level of understanding of how UHI occur after completing the challenges. We also provide brief case studies to illustrate how students used their scientific knowledge to debug their code and solve the challenges. Despite varied success with the challenges, most students were able to demonstrate an understanding of UHI. Many reported feeling interested and nervous when starting the programming challenges and shared they did not feel alone after engaging with the college student mentors.

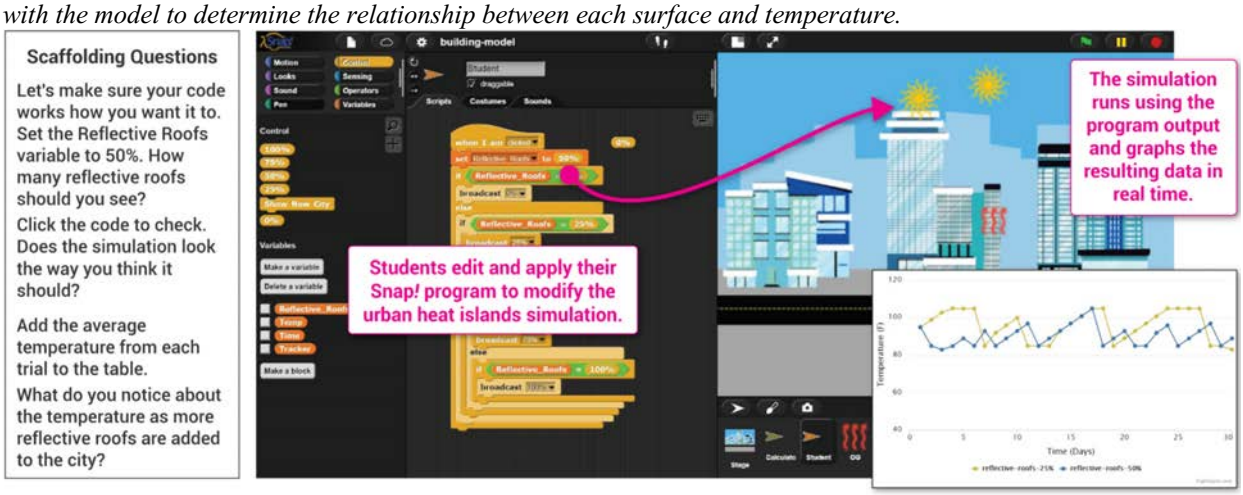
Objective

Computational thinking (CT) is vital for designing and analyzing models of environmental systems and is a skill increasingly valued by middle school teachers. Participation in the public discourse about environmental stewardship involves questioning and interpreting computational models. Enabling students in middle school science classrooms to engage with models of complex environmental dilemmas such as Urban Heat Islands prepares them to explore phenomena that impact their lives. By leveraging science knowledge, students can detect bugs in their code and make sense of model output. By developing programming knowledge to test their conjectures about remedies for urban heat islands, students can investigate questions that interest them, such as the impact of planting more trees. Further, middle school is a critical time to bolster student identity as a computational thinker and to foster a sense of belonging while engaging in computational activities.

To assess the potential of Snap*!* programming for engaging students in computational thinking in science, we designed, and pilot tested a lesson about Urban Heat Islands (UHI). The lesson features three progressively more difficult programming challenges that support students to explore the heat island phenomenon and generate a solution for a fictitious neighborhood (see Figure 1).

Figure 1

Third programming challenge in the UHI lesson. Students complete if-statements by filling out both condition and broadcast blocks. Scaffolding questions support students to debug their code and make sense of the trials they run with the model to determine the relationship between each surface and temperature.



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Using a computational model, learners can analyze the impact of multiple solutions such as adding reflective roofs or planting trees. Students can evaluate the trade-offs necessary to achieve personal goals such as "space for skating" or "hidden hangout places" by designing a Snap*!* model to reduce urban heat islands in their city. We explored students' feelings while programming using Snap*!* for the first time and investigated ways to support their sense of belonging.

We ask the following questions: How do students apply science knowledge to solve programming challenges? How do students feel when attempting computer programming and how do they feel after engaging with automated college student mentors? What is the teacher's perspective on the value of integrating CT with science?

Rationale

Integrating CT with science understanding

The UHI lesson in this study aims to support students to leverage their science understanding to support the development of their computational thinking skills, while also using computational thinking to deepen students' understanding of the scientific phenomena. This approach of viewing CT and science learning as mutually reinforcing builds on prior work showing that when students learn graphing in the context of science they gain proficiency in interpreting graphs and also increased ability to understand the related science concepts (Wiese, Rafferty, & Linn, 2017; Boda et al, 2020). This prior work suggests the potential of curricula and assessments designed using the Knowledge Integration instructional framework (KI; Linn & Eylon, 2011) to support students to integrate and mutually develop knowledge in computational and scientific domains. As such, the UHI lesson featured in this study was designed according to the KI framework. A KI approach to curriculum design recognizes that learners hold varied ideas that reflect their lived experiences. It advocates for supporting students to develop coherent understanding by *eliciting* students' prior ideas, providing opportunities to *discover* new ideas, using evidence to *distinguish* among existing ideas and new ideas, and guiding students to *make connections* among their ideas to form an explanation or argument (Linn & Eylon, 2011).

To create learning experiences that support students to deepen and integrate their CT and science understandings, we apply the KI framework and prior research in computer science and science education to design activities that: *elicit* students' relevant ideas from prior science instruction and relevant everyday experiences as starting points (Hammer & VanZee, 2006); *guide* discovery of new science concepts and programming patterns by analyzing and modifying computational models (Basu et al, 2017; Sengupta et al, 2013; Wilensky et al, 2014); promote *distinguishing* among ideas by annotating peer responses and comparing solutions (Buffum et al, 2016; Lewis et al, 2012; McElhaney et al., 2015; Vitale et al, 2019); and *facilitate links* among CT and science ideas by guiding use of CT to inform science and science to inform CT, such as for debugging (Hutchins, Biswas et al, 2020). In the UHI lesson, students first use and then create Snap*!* programs where they explore scientific models to connect their ideas about CT and climate. Students deepen their science understanding by first testing the impact of a single variable and then identifying interactions between variables. Students use their science understanding to debug their code and check if their output matches their expectations based on their knowledge of the UHI phenomena. Students distinguish ways to reduce the UHI effect by analyzing tradeoffs between alternative solutions. Ultimately they *connect* their ideas in a proposed solution.

Developing a sense of belonging

Students often report feeling unwelcome in classes involving computer programming (Garcia, 2020; Gorson & O'Rourke, 2020) and benefit most from learning environments that support them to develop a sense of belonging (Jagers et al., 2019; Trujillo & Tanner, 2014). We endeavored to build a sense of belonging where students identify as part of their classroom community and eventually, the computational community by creating automated mentors. Students often feel like imposters or think they are the only ones who are confused, when really many students feel that way. In one study, across three university introductory programming courses, students tended to negatively self-assess in programming situations, like having a syntax error or struggling to debug a program, that are common in professional programming practice. These moments of negative self-assessment were correlated with low self-efficacy and inability to imagine success as a programmer (Gorson & O'Rourke, 2020). Thus, students might not have a clear understanding of the experiences to expect while programming and might benefit from assurance that their feelings are held by others. These patterns of negative self-assessment and frustration impede student pursuit of computer science beyond middle school and can be remedied by collaborative, engaging computational experiences that are personally meaningful (Kafai & Burke, 2013). We designed the automated mentors by asking Computer Science undergraduates who serve as Teaching

Assistants in the non-majors introductory programming course at a large research university to respond to frequently expressed beliefs of middle school students. The automated mentors elicit and affirm the beliefs of the novice programmers and help them connect their experiences to the mentors' similar experiences.

Methods

Context and Participants

The UHI activities were implemented at a public K-12 school located in the United States. This study occurred in one teacher's three 7th-grade science classes (N=72). Students had two 70-minute class periods to complete the lesson. The teacher expressed a strong commitment to environmental science and engaging students in exploring local environmental issues but had no prior programming experience. Students had limited prior programming experience as well; only 11 students mentioned other prior coding experience at home or at school. During the study, students worked in groups of two or three; each group had one laptop. Placing students in pairs allowed them to ask each other questions, problem-solve, and take turns typing responses to questions. When students got stuck and raised their hands for help, the teacher encouraged them to approach their challenge like a scientist; ask good questions, be curious, and experiment. After offering this advice, the teacher walked away and observed that, in most cases, students would turn to each other to discuss ideas and methods for solving the problem.

Curriculum

The lesson is designed in two parts, informed by the KI Framework. The first focuses on developing student understanding of UHI through programming challenges. The second part tasks students with applying their learning to do a city planning activity. The first part starts by introducing students to the phenomenon of Urban Heat Islands by eliciting their prior knowledge about climate change and the effects that result from a changing climate. Students then build on their lived experiences by considering how different surfaces in a park feel and where they would sit if they were having a picnic in the park on a hot day. Next, students discover more ideas through a series of progressively more difficult block-based programming challenges that are designed to scaffold student understanding of and ability to apply programming control structures. In the first activity, students use Snap*!* blocks to set the variables in a model that tests the effect of varied amounts of grass coverage in the neighborhood and the impact on temperature over a month. Before engaging with the next, more difficult programming challenge, students annotate a sample program using pre-authored labels to identify the function of each of the different blocks in the program. Next, students are tasked with filling in a few missing blocks in the conditional if-statements that control the model and then use their code to test varied amounts of tree coverage in the neighborhood. In the third programming challenge, students fill in the gaps to create the majority of the program by writing conditional if-statements to test varied amounts of reflective roofing (See Figure 1). After using code to program the model, students observed the changes in the temperature of a city using a temperature graph, which updated in real-time as the model ran.

In the second part of the lesson, students apply the coding and modeling skills they learned to design a city that could reduce the ambient temperature. Students consider their favorite parts about their own neighborhood and how they would like to improve it. They then map out the city design, considering tradeoffs as they select surfaces that maintain functionality and prevent the city from becoming a UHI. In the final activity, students are asked about how they felt when they began writing computer programs with Snap*!* in the lesson. Students were then introduced to fictitious automated college student mentors (Figure 2) who shared how they felt when they started programming. The mentors' responses are based on ideas shared by the undergraduate teaching assistants described above.

Data sources and analysis

CT and science

Data sources to assess student CT and science learning include Snap*!* code for the three programming challenges and their written explanations of the UHI mechanism in response to the prompt: "Explain why an urban heat island is hotter than the areas around it".

We examined student approaches to solving the programming challenge and identified four progressively more sophisticated approaches: a) did not attempt moving the code blocks, b) attempted the activity and found a partial solution enabling them to test only one condition, c) hacked the code by getting the model to run using an unanticipated solution, and d) programmed the intended solution. See hacked and intended solutions in Figure 3.

Student responses to the UHI mechanism item were characterized by the degree to which they integrated ideas to explain how urban heat islands arise: a) alternative explanations such as "it gets the most sun", b) identifying surface features that contribute to UHIs, and c) connecting surface features to the proportion of solar radiation absorbed and transformed into heat. Our analyses include student groups who completed all programming challenges (N=28).

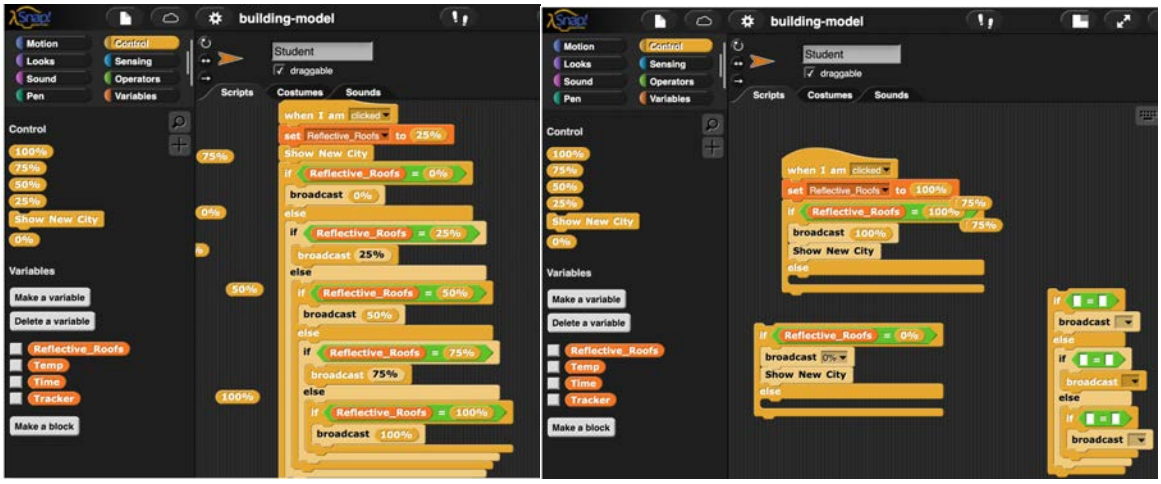
Figure 2

Automated mentors' ideas are modeled on real college students who have experience supporting other computer science students. Each mentor shares how they felt during their first experience writing a computer program.

We also draw on data from classroom observations and Zoom video recordings of three student groups, with one group in each class period. The teacher selected the observed groups from among the students who returned consent forms based on students' expressed willingness to think aloud while working. The students were generally representative of the entire class in terms of prior programming experience. Observation notes were collected in the form of a running transcript, recording dialogue and behaviors, to capture the group's thinking and interactions as they worked with Snap*!*. We reviewed the transcripts to identify moments where students used their scientific understanding to make sense of their computational activities or used their computational skills to deepen their science understanding. We present one such moment from each of the observed groups to provide narrative examples of how students engaged in the programming challenges.

Figure 3

Example of intended programming solution (a) for the third programming challenge and a "hacked" solution (b). In the hacked solution, a student group removed most of the scaffolding blocks that indicate the if-statements in the program. They instead used only one, making the code more similar to the first programming challenge, but requiring them to rewrite the program's conditional each time they ran a new trial.



Sense of belonging

Data sources to gauge student sense of belonging include one multiple choice item asking students, "How did you feel about writing a computer program in Snap*!* during this lesson?" Students could select multiple responses among excited, interested, confident, and afraid. We also analyze student responses to the open responses question, "What do you think and feel after reading these ideas from the college student mentors?" We calculate the percentage of students who chose each multiple-choice option. Inductive coding (Thomas, 2006) was used to identify themes in the student responses. We report the frequency of each theme and representative student responses reflecting the theme.

Teacher perspective

We conducted an interview to understand the teacher's perspective on the success of the lesson and the value of integrating CT into environmental science. Questions included: "How did the lesson go from your perspective; what surprised you?", "What did you notice about students' science learning in this unit? How did it compare to other curriculum they have used?", "Did you see evidence of students engaging in computational thinking or linking ideas about science with ideas about computer models?", and "If you were to teach this again, what support or resources would you want in order to prepare?". The teacher also wrote a reflective memo of her experience teaching, drawing on her field notes.

Results and discussion

Science-CT learning

During the first programming challenge, 60% of student groups were fully successful, using the Snap*!* coding blocks to test varied amounts of grass coverage versus asphalt in the model. All of these students generated the intended solution. Observations revealed how the challenge elicited students' science thinking about energy transfer and transformation. As one student remarked, "Less grass has more heat energy and when there was more grass it was just solar radiation." Students observed that when they programmed the model to have more grass than asphalt, more of the solar radiation was absorbed and transformed into heat energy.

In the second, more difficult programming challenge, 21% of students were able to program the intended solution and another 11% were able to manipulate or hack the code in ways that allowed them to run the model and test the appropriate conditions. The flexibility of Snap*!* enabled the students to experience programming success even when they had not fully developed an understanding of how to write if-statements or how to efficiently combine a series of if-else-statements. A partial solution was achieved by 18% who experimented with moving the Snap*!* blocks and tested one condition. The remaining 50% of students did not manipulate the blocks.

By the third activity, 39% of the students designed the conditional and output statements to test reflective roofing, with 21% completing the activity as intended and 18% successfully hacking the code to create an unanticipated solution. Several student groups who had a partial coding solution during the second activity were able to hack the code and run trials with the model during the third activity. Their experience experimenting with the blocks in the second activity supported them to keep experimenting until they found a solution in the third activity.

Following their programming investigations of the model, 71% of students were able to accurately describe the types of surfaces that contribute to an area becoming a UHI. Of those students, 40% were able to connect their ideas about the surfaces to the energy transformation mechanism. Thus, despite struggling to complete the programming challenges, students gained understanding of the science concepts underlying UHIs.

Case studies

Drawing on observation notes, video data, and student written work of the three observed pairs, we describe instances that illustrate how these students leveraged their science understanding to support their computational practices or used their CT understanding to support their sense-making around science concepts.

Using observations of the model to troubleshoot programming challenges

When starting the first programming challenge, one pair of students we observed worked together to figure out how to move Snap*!* blocks into their program to control the model. They noticed that even when they dragged over the 25% block to set the "grass coverage" variable, they still couldn't see any grass on the model. They were able to use their program to run the model, but their observations indicated that the model did not behave as they expected. With some prompting from the researcher-observer, they noticed they needed to click on the code to broadcast the value they had set for the variable to the model. With a little bit of prompting, they looked more

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closely at the Snap*!* blocks and realized the block where they set the variable was connected to another block (line of code) that said "When I am clicked." Students then clicked the block and saw that the amount of grass visible in the model changed. Once the appearance of the model reflected their expectations, they continued to use their science understanding to make sense of the graphical output from running the code: "When I set it at 25%, I saw more heat. When there was more grass there was less heat energy". The students recognized that as they increased the amount of grass, less solar radiation was converted to heat energy. This helped them to interpret the graph generated by the model and make sense of why the temperature on the graph was lower when they set the amount of grass higher than 25%.

Connecting coding and science by making predictions

After writing the code for the third programming challenge, one group of students closely examined the graph to determine whether their model output matched their predictions. After setting the variable to a high percentage of "reflective roofs", they ran their model. One student in the group remarked, "Oh wait it [the temperature] just went down a bunch!" The other student commented back, "Yeah I was thinking it'd be 105 or something" as the first student observed "It's staying below 100 and above 80." Students were able to use their observations of the connections between the model and the graph to deepen their understanding of the impact that more reflective roofs would have on a city's temperature. Students did not initially predict that reflective roofs would lower a city's temperature and were surprised by what they observed. They were confident in their interpretation of the graphical output from the model controlled by their code. This supported them to revise their initial prediction and deepen their understanding of the role that reflective roofs could play in a solution for UHI.

Applying science understanding and annotated code for debugging

After successfully completing the second programming challenge, one group of students quickly got to work on the third challenge where they were to test the impact of reflective roofs. They began dragging blocks into the missing components of the if-statements without attending closely to what was missing in the statements. They followed their approach from the previous challenge, making sure that everything in each if-statement matched. For example, they wrote lines of code that read, "If 0%=0%, broadcast 0%, else if 25%=25%, broadcast 25%". They began running trials at various amounts of reflective roofs. However, they noticed the graphical output for each trial looked the same and the amount of reflective roofs depicted wasn't changing. Because of their science understanding, the students believed that varying the amount of reflective roofs should result in different temperature graphs. This led them to revisit their code and look for issues. After some time grappling with the code, the researcher asked them whether they had any resources they could go back to help them think about what each part of the code does. The students clicked back to the part of the lesson where they had annotated sample code. Almost immediately one of the students exclaimed, "Aha! I found out!" and clicked back to the coding challenge. They replaced blocks in their if-statements so that it read, "If reflective_roofs=0%, broadcast 0%, else if reflective_roofs=25%, broadcast 25%". They realized the if-statements were the part of the code that changed what was broadcast, depending on what value they set for the variable "reflective_roofs". They tried running the model again and while looking at the model output exclaimed: "There we go!" and "Yay! It works!" Students' science knowledge cued them that something was not working correctly in their code and the annotated code helped them to fix their code and figure out the purpose of the if-statements they were writing.

Looking across all three cases, we see that students drew on both their science and computational understanding to work through the programming challenges. When they struggled with programming tasks or interpreting their computational artifacts (i.e., graphs) students could draw on their developing knowledge of UHI. Similarly, as students succeeded with programming challenges and graph interpretation, they were able to advance their understanding of how different surfaces contribute to UHI. Working together with a peer and having the occasional prompt from a researcher supported students to think through their resources and leverage their understandings in helpful ways.

Promoting belonging

All of the students were using Snap*!* for the first time. They reported feeling interested (64%), confident (40%), excited (16%), nervous (12%), and afraid (24%) when they began the first programming challenge. While two-thirds of the students expressed interest in writing code, many were also experiencing complicating emotions, like feeling nervous or afraid. After engaging with the role models, several themes emerged in student responses. 44% of participants expressed that they felt like they were not alone in their experience or that they identified with the college student mentors. For example, one student shared, "I felt that I wasn't alone and there are people who are thinking just like me." Another participant wrote that the mentors are "like us who were interested but also get confused on how". Several students expressed which of the mentors they most felt alike to: "I think I'm kinda

like Amina." Students also reiterated how they were feeling about their own programming (32%). Some students wrote statements like I feel "interested", "I think the program was pretty fun" or that they felt "good and inspired to help people." 20% shared that it was helpful to learn what older computer science students think. For example, one student wrote: "I feel way more informed and now I know that everyone has a different perspective about there first day on computer science" and another wrote, "I think that it is interesting because I learn what older students are taught and I think I will have fun learning this." The automated mentors helped students to continue to articulate their own feelings and to envision what it might look like to continue learning to program. Importantly, the mentors also provided reassurance to the students that their feelings were valid and not unusual when learning programing.

Teacher Perspectives

Overall, the teacher valued the activity as an opportunity for her students to develop new programming skills while leveraging their science knowledge. The teacher observed, "At least for my students, I think they understood how these different variables [in the Snap*!* model] can have an impact on the city because we've talked about [climate change]." She believed that their science understanding helped them to overcome frustration or discouragement when coding challenges proved to be difficult. The teacher also reported high student engagement in persisting through the challenges. She remarked, "It was neat to see them being challenged in that way. Some of them found it really cool and interesting and spent a lot of time playing with the different tools." She also identified strategies she would use to support students through those difficulties the next time she taught the lesson. She noticed common student questions that indicated the instruction supported students to seek connections between the activities in the lesson and their own lived experiences. She reported students asked questions such as: What could we do to improve our neighborhood?; How fast is the world's climate changing?; How is this information useful for [our state]?; How can we implement green solutions as a community?; What would happen if the world did not have trees or grass? Thus, the lesson prompted students to consider how they could use their science and CT skills to make changes in their own communities. The teacher built on these questions by asking students to consider where there might be UHIs within their own community. Because their school is in an area with high vegetation, the teacher helped students to distinguish between their school setting and other parts of their community. She shared that students really deepened their connections when she got them thinking about the area surrounding their local airport. When reflecting on what was most challenging for her students, the teacher reported that, in general, students struggled the most with the initial programming challenges. However, she also noted that when asked at the end of instruction about what aspect of the lesson they enjoyed the most, an overwhelming majority of students selected the coding and modeling section. Although challenging, once they understood how to properly use the model, it became their favorite part of the lesson. They liked the idea of designing a city that is, "literally cooler", as one student stated.

Conclusion and Significance

Overall, we found preliminary evidence that the design of the UHI lesson activities prompted students to use science and CT ideas synergistically to integrate environmental science and computer programming. Taking a Knowledge Integration approach to the lesson design supported students to connect their science and CT ideas in ways that strengthened their understanding of both. We observed that students' science knowledge and practices supported them to stay engaged and to sustain their efforts while trying to solve the programming challenges. Even when struggling to find full solutions to the programming challenges, students were able to deepen their understanding of UHI phenomenon.

Our findings also suggest the promise of using Snap*!* as a programming language to introduce CT into middle school science. With some guidance from their teacher, many students were able to engage in Snap*!* programming with only two days of classroom instruction. Further, the flexibility of the Snap*!* programming language and interface enabled multiple operational solutions to the programming challenges. This supported students' creativity and allowed students to experience success even if they did not come up with the intended code solution. This experience communicates to students that they have valuable computational ideas and reveals to students the creative nature of computer programming that is not always visible during early programming experiences.

Two thirds of students expressed interest in programming when they began the coding challenges, although many also held complex feelings like nervousness or fear. After engaging with the automated college student mentors, students felt validated in holding multiple, sometimes conflicting feelings. The mentors helped them feel as though they were not alone in their experience by offering reassurance about their feelings. This mentoring practice could be valuable for more complex modeling as well. Taken together, our findings suggest

the value of using the KI-design approach to introduce students to CT through relevant middle school science topics and using mentoring modeled on undergraduate teaching assistants to support a sense of belonging and community.

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Challenges and Design Opportunities in Data Analysis for ML-Empowered Scientific Inquiry - Insights from a Teacher Professional Development Study

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Abstract: The increasing impact of machine learning (ML) on real-world scientific investigations demands a shift to teaching ML-empowered scientific inquiry to familiarize younger students with authentic science practices. Evidence from previous studies has suggested that glyph-based data visualization is promising for making multidimensional data analysis accessible for novice learners. Little research, however, has examined the contextualized challenges of applying glyphs in K-12 ML-empowered scientific inquiry. Since teachers play a critical role at the frontier of technology integration for learning, as an initial attempt to address this research gap, we investigated the pattern recognition and interpretation behaviors of 18 K-12 STEM teachers when engaged in ML-empowered scientific inquiry during a professional development workshop. Findings confirm that teachers identified and interpreted ML-revealed patterns for scientific hypothesis formulation while it is challenging for novices to analyze and synthesize different patterns conceptually and extensively for more sophisticated inference. Underlying design opportunities and implications are discussed.

Introduction

In real-world science, an increasing number of scientists are applying machine learning (ML) to discover patterns from multidimensional data (Kitano, 2016). The majority of the current K-12 STEM teaching practices, however, focus on bivariable experiments and data analysis, which may limit students' learning opportunities of data analysis to investigate complex scientific phenomena (Kuhn, 2016). Recognizing and interpreting relevant patterns such as category, relationship, trend, and anomaly discovered by ML methods on multidimensional datasets may offer unique learning opportunities for evidence-based science practices aligned with the NGSS science and engineering practices (States, 2013). It is challenging, however, for K-12 students and teachers to recognize and interpret ML discovered patterns in science contexts due to their lack of ML and data literacy. Glyph-based data visualization (Ward et al., 2015), which maps multidimensional attributes of an individual data point to vivid visual features of everyday objects such as faces, stars, and trees, offers promising opportunities to make ML-discovered patterns accessible to novice learners. Glyph-based visualization supports visual reasoning (e.g., search, pattern recognition) over multidimensional datasets with high accuracy (Chung et al., 2015; Keck et al., 2017). There is a neglect of existing studies of glyph-based data visualization on supporting K-12 students and teachers for efficient data interpretation, an important skill for gaining insights into what the visuals show (Rau, 2017).

Teachers play a critical role in integrating technology for learning (Koehler & Mishra, 2009), which is especially important for integrating ML in STEM education. Therefore, as a first attempt to tackle the above research gaps, we (1) propose cluster analysis as an accessible ML technique for K-12 scientific inquiry and (2) examine how K-12 STEM teachers identify and interpret patterns from datasets using a glyph-based visualization tool named SmileyDiscovery (Zhou et al., 2021) in a professional development workshop. SmileyDiscovery utilizes face-based glyphs for data analysis with *k*-means clustering while requiring few efforts in learning ML. We collected log data of what patterns of scientific phenomenon (e.g., ecosystem, heart disease) are identified by 18 in-service K-12 STEM teachers using SmileyDiscovery, and analyzed how teachers interpreted these patterns to form scientific hypotheses. Teachers also provided feedback on potential learning experiences from the student perspective. Our research questions include **RQ1**: To what extent can teachers identify and interpret patterns during cluster analysis for scientific inquiry with face-based glyphs? **RQ2**: What challenges prevent teachers from effective scientific inquiry? The main contributions are:

- A framework on how cluster analysis can be an accessible discovery tool for K-12 teachers and students to conduct exploratory analysis on multidimensional data for scientific inquiry.
- Challenges in ML-empowered scientific inquiry by using face-based glyph visualization.
- Design implications to empower novice learners to analyze ML-generated multidimensional results.

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Background

Multidimensional data analysis and visual representation in K-12 Education

Researchers have discovered positive results in developing middle school students' multivariable reasoning skills (Kuhn et al., 2015), training primary and high school students to make informal statistical inferences by modeling with multidimensional datasets (Braham & Ben-Zvi, 2017; Kazak et al., 2021), and facilitating high school students to identify multidimensional patterns from ML-generated results (Wan et al., 2020). These works show young learners' potential to apply ML as an advanced multidimensional data analysis tool for scientific inquiry and highlight the need to enrich more authentic scientific inquiry skills for K-12 STEM learning (Nayak et al., 2016) .

Visual representation facilitates multidimensional data analysis but can confuse students if they do not fully understand the visualized mechanisms and concepts (Rau, 2017). Previous studies have shown that full competence in visual representation comprehension is not achieved even by college and university graduates (Nayak et al., 2016; Roth et al., 1999). To develop students' representational competencies, Rau (2017) argued that two types of knowledge and skills were necessary for students to acquire: (a) visual understanding and fluency, referring to knowledge of general principles about how the visual representation depicts concepts and abilities to efficiently identify the corresponding conceptual meanings reflected by visual features; (b) connectional understanding and fluency, indicating an understanding of conventions for using multiple visual representations together and abilities to communicate conceptual implications of connections (i.e., similarities and differences) between different visual features.

Glyph-based visualization

Glyphs are well-suited for depicting high-dimensional data due to their capabilities of simultaneously displaying information through multiple visual channels, including shape, size, and color (Chung et al., 2015). Several studies have created and shown the effectiveness of glyph-based visualization in promoting multidimensional data analysis. Cao et al. (2011) presented an interactive system, DICON, which combined treemap-liked icons with Voronoi icons to illustrate multivariate data clusters. A case study demonstrated it supported cluster exploration and interpretation of a large dataset in the healthcare domain. Chung et al. (2015) designed a novel glyph and validated it with the analysis of Rugby matches. Findings confirmed its effectiveness in supporting multidimensional visual search and comparative analyses of multiple attributes between different matches. Keck et al. (2017) developed a flower glyph to facilitate big data analyses via clustering algorithms. An experimental study showed that it was more efficient than the traditional tabular displays for task completion and the accuracy for both conditions was almost the same. However, these positive effects are all about pattern recognition through data visualization, while little research has investigated whether or not the glyph approach enhances data analysis in relation to the mapped concepts. Therefore, this study attempts to gain a comprehensive understanding of how glyph design facilitates multidimensional pattern recognition and interpretation. It analyzed data from a study engaging k-12 teachers in pattern exploration enhanced by Chernoff faces (Chernoff, 1973) via *k*-means clustering. Chernoff faces aim to make multidimensional data accessible for human beings since people can easily recognize faces and notice changes in facial features (e.g., nose length, eye radius, and eyebrow slant, *etc*). Previous studies examined the visual effectiveness of Chernoff faces on displaying patterns (e.g., Lee et al., 2003; Morris et al., 2000), but did not address its interpretability in the K-12 STEM contexts.

A theoretical framework of applying cluster analysis for scientific inquiry in K-12 STEM education

Cognitive benefits of applying ML for scientific inquiry

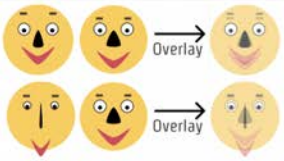
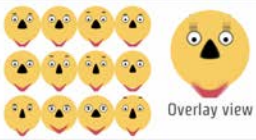
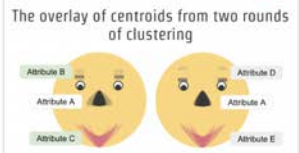
Pattern recognition could support inductive reasoning for scientific inquiry, which is a bottom-up probabilistic reasoning process that derives general principles of target phenomena from a large amount of observation (Rodrigues, 2011). Traditionally, induction plays a key role in hypothesis testing through accumulating evidence (Folger & Stein, 2017) for scientific inquiry. With ML revealing patterns from big data, learners' capability of inductive reasoning can be significantly enhanced not only during the investigation but also at the early stage of generating inquiry or formulating scientific hypotheses (Muller et al., 2016). In addition, ML analysis is usually accompanied by reasoning with contrastive explanation (Folger & Stein, 2017; Miller, 2019), which refers to the generation of explanation when encountering contrastive cases sharing similarities as well as differences in properties (Chin-Parker & Bradner, 2017). Contrastive explanation generates key insights from the puzzling event that occurred during the scientific inquiry (Folger & Stein, 2017; Miller, 2019).

Cluster analysis for inquiry-based learning in K-12 STEM education

As one of the most common ML techniques for data mining, cluster analysis has broad affordances to serve as an initial investigation for diverse directions to further analyze multidimensional data. By grouping similar data objects, it presents big data in a more accessible way, reveals inter-/intra-cluster patterns for further investigation, and discovers early insights for characterization, classification, outlier analysis, *etc* (Han et al., 2011). Thus, cluster analysis has been widely applied by researchers to explore datasets, bringing unique benefits in creating a scientific question, and/or formulating a scientific hypothesis (Romesburg, 2004), which connects with the conceptualization phase in inquiry-based learning for STEM education (Pedaste et al., 2015). For example, after thousands of multidimensional data points about ecological factors collected from field sites are grouped into different clusters, researchers can form hypotheses by contrasting the most dissimilar centroids or make inferences inductively on data clusters, and then investigate with another dataset. Besides the cognitive benefits of inductive reasoning and contrastive explanation, the main mathematical concepts behind clustering (i.e., centroid and distance-based clustering) are relatively intuitive for young learners to readily grasp (Greenwald et al., 2021). Furthermore, the skill to interpret trends and patterns from data could be aligned with NGSS (Next Generation Science Standards). Therefore, we attempted to propose clustering as an accessible and versatile inquiry-based learning tool for K-12 STEM education.

Figure 1

Cluster analysis for conceptualization in inquiry-based learning (Anderberg, 2014; Romesburg, 2004)

1. Pattern revealed by clustering	2. Glyph representation of the pattern in SmileyDiscovery	3. How does the pattern can support conceptualization in inquiry-based learning? Creating a scientific question	Formulating a scientific hypothesis
Similarities and dissimilarities between two data objects		E.g., cluster multivariate dental formulas of different animals. The result shows that the mole and the pig have identical formulas. What research hypothesis could explain this?	E.g., cluster multivariate dental formulas of different animals. The result shows that the walrus' formula is very different from the other carnivores. Does Walruses feeding habit accordingly modified their dental structure?
Intra-cluster pattern: Similarities and variations		E.g., cluster different species of primates based on 34 skin attributes. Intra-cluster pattern shows that the grouping is related to the features of the dermis, epidermis, and sweat glands, which is intriguing for further study.	E.g., within a relatively homogeneous group of ecological field sites created by clustering, sites with lower temperature have fewer small mammals. For this type of ecosystems, is higher temperature less livable for small mammals?
Inter-cluster pattern		E.g., cluster multivariate dental formulas and the sizes of different animals. The inter-cluster differentiating features show no apparent relation between an animal's dental formula and its size. Why?	E.g., cluster different wines based on their chemical factors and quality scores. The inter-cluster patterns show that wines with better quality have lower volatile acidity and more alcohol, which could be a hypothesis for further testing.
Clustering results with different sets of features		E.g., cluster different animals based on (1) the diets of animals, (2) shapes of the teeth, (3) dental formulas. The clusters from the first clustering are more similar to the clusters from the second round than the clusters from the third. Why?	E.g., cluster different people by their income levels with two sets of other factors separately. The first round of clustering generates a better inter-cluster seperation in income levels. Does this set of factors (education, working hours) have a stronger influence on income?

Inspired by previous studies on cluster analysis (Anderberg, 2014; Han et al., 2011; Romesburg, 2004), we summarized a list of main patterns revealed by clustering which can be utilized for conceptualization in inquiry-based learning (see Fig. 1 column 1 & 3). Cluster analysis can help to formulate hypotheses for questions whose truth entails (dis)similarities among data objects. For example, cluster labels assigned to data objects could support the hypothesis of what data attributes lead to such grouping. Intra- and inter-cluster patterns could generate insights to hypothesize on correlations among data attributes for factor analysis or analysis of variance. Clustering with different sets of data attributes can suggest a set of data attributes distinguishing across the groups to a sufficient degree to aid discriminant analysis and classification. Besides assisting to form hypotheses, these patterns revealed by clustering could trigger further scientific questions. Considering the pedagogical and cognitive benefit of cluster analysis in inquiry-based learning, we utilized face-based glyphs to make cluster analysis an engaging and accessible tool for K-12 STEM teachers and students (Fig. 1 column 2). And this work is a preliminary evaluation of the initial design.

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Methods and analysis

Research participants and procedure

We recruited 18 in-service K-12 STEM teachers who were taking a course named Integrating Technology with STEM Teaching, at a research-based university. They have very limited CS/ML backgrounds, different subjects, and various teaching grades (Table 1). The study session was conducted via an online meeting platform Zoom.

Table 1
Subjects and grade levels teachers teach

	Elementary school	Middle school	High school
Science	N = 2	N = 3	N = 6
Math	N = 2	N = 2	N = 3

In this study session, teachers participated in one cycle of scientific inquiry through cluster analysis on a dataset of field sites described by a set of ecological factors (Zhou et al., 2021), involving five steps: (1) generate the concept mapping for the face-based glyph (i.e., mapping each ecological factor to a facial feature) and get familiar with the value mapping (i.e., how the value of an ecological factor changes the corresponding facial feature); (2) compute the similarities between two representative ecological field sites; (3) explore the dataset by manually clustering a few data points around two representatives and interpret intra- and inter-cluster patterns; (4) apply the well-studied *k*-means clustering and interpret intra- and inter-cluster patterns; (5) formulate a hypothesis on how ecological factors dynamically influence each other based on the cluster analysis results. More detailed demonstration of this ML-empowered scientific discovery learning activity can be found in our previous work introducing the SmileyDiscovery system (Zhou et al., 2021).

During the study session, each teacher worked individually on their own device by following the instructional text in SmileyDiscovery, without any external guidance from researchers. Four teachers didn't complete the activity due to technical issues and their data were excluded. In the end, we collected teachers' feedback on potential learning experiences from students' perspectives.

Data analysis

RQ1*: To what extent can teachers conduct cluster analysis for scientific inquiry with face-based glyphs?* We employed system log data (i.e., clicking behavior and text input) and teachers' feedback to answer this question. First, we replicated teachers' clicking behaviors to revivify the concept mapping (i.e., how data attributes are mapped with facial features) and their learning experience. Second, we open coded (Strauss & Corbin, 1990) the text input and feedback on pattern recognition to measure *patterns recognized or neglected by teachers.* Third, we coded teachers' text inputs of scientific hypotheses drawn from clustering-revealed patterns to measure the *quality (i.e., accuracy and sufficiency) of interpretations of these patterns for forming scientific hypotheses.*

RQ2*: What challenges prevent teachers from conducting effective scientific inquiry?* Teachers described difficulties that they encountered when engaging scientific inquiry with face-based glyphs in both text inputs and feedback. We conducted a thematic analysis of the data and generated challenges that prevent effective pattern recognition and interpretation, respectively.

Three researchers coded data independently, met regularly to address disagreements, and refined codes.

Results

RQ1: To what extent can teachers conduct cluster analysis for scientific inquiry with face-based glyphs?

Novice learners' pattern recognition via face-based glyphs

By looking into the system log data recording teachers' clicking behaviors and text input of the patterns they identified for each step in the learning activity, we analyzed how novice learners identified patterns from face-based glyph visualization. During the step where teachers explored the dataset by manually clustering a few data points based on two representatives, some teachers engaged with more fail-and-trial experience by exploring the dataset, selecting more data points to test out the similarities, and removing the dissimilar ones. Other teachers carefully scanned through the dataset and only selected a few faces that were highly similar to the target face. While analyzing the patterns identified and reported by different teachers, we noticed inconsistent tolerance for variations, both across teachers and across facial features. For example, some teachers have a relatively high

tolerance for variations and thus report more data attributes as shared patterns within clusters; teachers with a low tolerance for variations tended to identify most attributes as differentiating features. In addition, we found wrong/missing translations from facial features to data attributes, indicating the high cost of code-switching between science context and glyph visualization.

Five advantages of applying face-based glyphs to identify ML-revealed patterns are mentioned by teachers. First, teachers pointed out the pedagogical benefit of using emojis to visualize multidimensional data, which can be both familiar and playful for young learners: "This could be a fun way to allow students to explore data sets and draw connections in a way that allows for visualization". Second, teachers found that being able to customize the data visualization helps them to have a deeper understanding of different data attributes and how they form a glyph: "I tried to mentally pick ones that matched, like when I see a beetle my eyes get big like I don't want to see one, so to me was eye radius. Or latitude, I used the eyebrow height." Third, teachers appreciated the computation efficiency of using one piece of the glyph to represent a multidimensional data point and overlaying two pieces to compute the (dis)similarities between them. Fourth, teachers found center emojis (i.e., centroids) helpful to represent information in a concise way for more effective pattern recognition. Last, teachers confirmed the potential of applying cluster analysis as a discovery tool as it supports students to identify different types of patterns (e.g., intra & inter-cluster pattern, centroid) for further interpretation.

Patterns interpreted for scientific hypothesis formulation

While formulating a scientific hypothesis in the end, we found that teachers interpreted different patterns recognized from cluster analysis in different ways. First, teachers utilized patterns of inter-cluster differentiating features in three different approaches: (1) two teachers' attention was caught by the cluster with the minimum or maximum value of some data attribute; for example, P1 identified the cluster of field sites that has the highest precipitation, the highest temperature, and the highest beetle richness as evidence for their hypothesis; (2) nine teachers interpreted differentiating features between different pairs of clusters; for example, P12 recognized that, compared to the first field site cluster, the second cluster of field sites are drier, have more beetles and higher canopy, and the third cluster has more beetles, and the fourth has lower latitude, more beetles, higher temperature and higher precipitation; (3) five out of these nine teachers successfully formed hypotheses on relationships among ecological factors by further interpreting the identified inter-cluster differentiating features; for example, P9 hypothesized that "latitude and temperature have a large impact on the beetle richness and canopy height", while P12 was not able to produce a more meaningful hypothesis with eight pairs of inter-cluster differentiating features identified.

Second, three teachers paid attention to inter-cluster shared features. P11 identified canopy height, precipitation, and latitude as the similarities shared among the field sites of interest. Third, while 11 teachers considered intra-cluster similarities, only P2 paid attention to intra-cluster variations: "small mammal richness varies widely even in a cluster". In addition, another very unique pattern utilized is that P13 compared the similarities between each pair of clusters and identified the cluster that is the most dissimilar to the rest clusters, as the most distinct cluster and identified the cluster it is most distinct from.

RQ2: What challenges prevent teachers from conducting effective scientific inquiry?

Cognitive challenges for novice learners to identify multidimensional patterns from face-based glyphs

By analyzing feedback and log data around pattern recognition with face-based glyphs, we identified cognitive challenges related to (1) concept mapping and (2) value mapping in face-based glyph visualization.

Related to the concept mapping where data attributes are mapped to facial features, we identified different causes introducing extra cognitive load into pattern recognition. First, the legend showing corresponding data attributes when the cursor is hovering over a certain area is still temporarily visible, which leads to the lack of connection to scientific context. Second, teachers had attention bias that they perceived certain facial features as more conspicuous than others. Third, from the patterns teachers identified from glyphs, we recognized inaccurate pattern recognition caused by ambiguous or less accurate verbalization of certain visual features due to people's habits in language using while describing faces. For example, six teachers described mouth features with inaccurate language, such as using mouth shape to refer to mouth curvature which caused confusion in the interpretation of mouth size and mouth curvature as both affect mouth shape.

With the value mapping of face-based glyphs where different data attributes' values are translated into different visual channels, we recognized the difficulty in deciding if certain values are (dis)similar enough because of the low separability of the multiple values mapped to one face part (e.g., brow length, brow vertical location, brow slant are all mapped to eyebrows). Teachers also commented that it's hard for them to decide if a certain pattern should be identified as a large/medium/small value or if certain degrees of variations should be tolerant

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because there is no visual indicator for the dispersion of each facial feature. Furthermore, by analyzing the patterns identified during cluster analysis, we identified that teachers have different tolerance for variations in different facial features. On the one hand, teachers discerned deviations in mouth vertical, mouth curve, and eye radius, with 17.5%, 15.63%, and 13.89% instances of high tolerance for variations in hypothesis development, respectively. On the other hand, teachers tended to be more sensitive to changes in eyebrow length (16.67%), eyebrow slant (11.36%), and nose length (11.11%).

Challenges in more sufficient pattern interpretation during hypothesis generation

By measuring the quality of teachers' pattern interpretation for evidence-based hypothesis generation in the end, we identified teachers who (1) failed to illustrate the patterns, (2) needed further inference, (3) needed to analyze the direction of the correlation, (4) needed to have a contrast group to make the inference. We found two main causes of deficient hypothesis generation:(1) the insufficient interpretation and synthesis of different patterns, (2) lacking in-depth analysis for more sophisticated multidimensional data inference.

First, five out of six teachers who hypothesized relationships among ecological factors didn't further elaborate on whether the relationships are positive or negative by interpreting the value mappings in the patterns identified. For example, P14 interpreted that clusters with different latitudes have different amounts of precipitation, instead of elaborating that the field sites with higher latitudes share lower amounts of precipitation than the cluster with lower latitudes. Besides such insufficient interpretation of data attributes' values, we observed that five teachers lacked synthesizing multiple pattern interpretations to formulate a more meaningful scientific hypothesis. Such insufficient synthesis could indicate the need for some basic domain knowledge about ecosystems to guide learners' attention to what patterns could be more interesting to focus on or how the information behind different patterns can be effectively synthesized and form a scientific hypothesis leading to a more in-depth understanding of the domain. By looking into the interaction data of two teachers who failed to illustrate the patterns from cluster analysis, we found that one of them only compared two centroids, and the other only examined one cluster centroid. Both of them didn't explicitly identify the value mapping during pattern recognition. This further indicates that the insufficient interpretation and synthesis of different patterns may lead to unsuccessful evidence-based hypothesis generation and corresponding scaffoldings are needed.

Second, some teachers lacked more careful analysis of different patterns and missed more sophisticated inferences on different ecological attributes. For example, P4 hypothesized that canopy height influences beetle richness. Without digging into the other shared or differentiating features among clusters, P4 didn't interpret that only for field sites with medium amounts of precipitation, canopy height and beetle richness are positively related. Therefore, P4 missed introducing precipitation as a moderator to form a more elaborated data-driven scientific hypothesis. We also observed the case where teachers didn't include multiple contributing features as independent variables for the dependent variables in their hypotheses, and the case where a teacher didn't more carefully support their hypothesis with comparison from patterns identified.

Discussion

For each challenge identified from novice learners' data recognition and interpretation in clustering-supported scientific hypothesis generation, we summarized a set of fundamental learner needs underneath all the challenges we identified from novice learners' pattern recognition and interpretation for generating clustering-supported hypotheses with face-based glyphs (Table 2). **First**, learners need more in-time access to the scientific context and more effective scientific communication with smoother code-switching between glyph visual features and data attributes (N1.1, N1.2). Therefore, more design opportunities lie in the embedded legend design for glyph visualization with continuous visibility or an intelligent mapping mechanism creating concept mapping with better learnability (Chung et al., 2015). **Second**, during identifying multidimensional patterns from glyphs, learners are viewing all data attributes at once and thus need scientifically guided attention to select features of interest and interpret the visual channel in a more informed and accurate way (N1.3, N2.1). This suggests a potential design of an intelligent value mapping mechanism utilizing people's varying attention across facial features and visually related glyph features (Chung et al., 2015). **Third**, when digging into the interpretation of a specific data attribute, learners need more measurable displays of that attribute's spread and deviation (N2.2, N2.3). Thus, more in-time indicators of a comprehensive list of parameters describing the distribution of each data attribute (e.g., center, spread, shape) are needed for glyph visualization. **Fourth**, various multidimensional patterns can be identified and interpreted for cluster analysis, which is challenging for novices to analyze, interpret and evaluate as different forms of evidence in relation to potential scientific hypotheses (Kuhn & Lerman, 2021) (N3.1, N3.2). This could be scaffolded via probabilistic reasoning and contrastive explanation in the context of ML-enhanced scientific inquiry (Miller, 2019). For example, when commonalities between two clusters are observed, then learners can be reminded of what patterns are missing as comparisons in order to indicate correlations between data attributes.

Table 2
Design opportunities of face-based glyph visualization for multidimensional data interpretation

Challenges	Underlying fundamental needs as design opportunities
C1.1 Extra cognitive load from the temporarily visible concept mapping	***N1.1*** Easy access to the scientific context behind the data
C1.2 Less precise verbalization	***N1.2*** Effective scientific communication of multivariate data and patterns
C1.3 Attention bias across facial features	***N1.3*** Guided attention for more informed and effective selection of features of interest
C2.1. Low separability of some visual features ***C2.2*** Absence of the scale	***N2.1*** Independent interpretation of each visual channel ***N2.2*** Spread of each data attribute
C2.3 Uncertainty in variation interpretation	***N2.3*** Deviation of each data attribute
C3.1 Insufficient interpretation and synthesis of different patterns	***N3.1*** Guided analysis and synthesis of all the potential patterns and their relations
C3.2 Lacking in-depth analysis for sophisticated multivariate inference	***N3.2*** Evaluation of different patterns in relation to intended inferences

As the initial stage in an iterative design of data visualization and interaction for ML-enhanced K-12 STEM learning, we only set up a preliminary framework connecting cluster analysis with the conceptualization in inquiry-based learning and haven't fully implemented and evaluated it with both K-12 teachers and students. Additionally, we noticed that the step-by-step scaffolding for cluster analysis in the current learning activity design could guide more learner attention to intra-cluster shared features and inter-cluster differentiating features. Therefore, as a next step, we are planning to create new scaffoldings for a more open-ended learning environment to empower students to explore the data and create scientific questions or hypotheses. Besides collecting feedback from teachers with student perspectives, we will evaluate new designs with young students.

Conclusion

This work proposes a framework showing the pedagogical and cognitive potential of using face-based glyphs to introduce cluster analysis as an accessible and versatile tool for K-12 inquiry-based learning. Eighteen K-12 STEM teachers conducted scientific inquiry through cluster analysis. We evaluate their performance under pattern recognition and interpretation for hypothesis generation. Challenges are identified in recognizing patterns with face-based glyphs, conceptually and extensively synthesizing different types of patterns, and scrutinizing for more sophisticated multidimensional relationships. We reflect on the fundamental learner needs behind these challenges and discuss corresponding design opportunities and implications.

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Embodied responsive teaching for supporting computational thinking in early childhood

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Abstract: Tangible programming toys support body syntonicity, where children use knowledge of their own bodies to solve problems computationally. However, we currently know little about how teachers can support these embodied computational learning processes. In this study, we examine how teachers are *responsive to* and *support* preschoolers' embodied engagement in three computational thinking practices: problem decomposition, debugging, and abstraction. Through interaction analysis, we show how teachers re-"voice" embodied proposals by purposefully taking up and transforming preschoolers' body syntonic problem solving efforts to focus, recontextualize, and decontextualize them. Implications for the embodied teaching and learning of computational thinking with tangible programming toys are discussed.

Introduction

There is broad consensus that tangible programming toys are powerful tools for young children learning to program, problem solve, and engage in a range of *computational thinking practices* (Bers, 2008; Hamilton et al., 2020; Wang et al., 2021a). One promising mechanism through which tangible programming toys support computational thinking is through what Seymour Papert called *body syntonicity*: Children are able to leverage knowledge of how their own bodies move and react, and use this embodied knowledge to engage in a wide variety of computational practices (Papert, 1980). Although there is increasing attention to the role of body syntonicity in learning to program and think computationally (e.g., Berland et al., 2011, Cho et al., 2017, Farris, 2021; Sung et al., 2017), little is known about the role teachers and other adults can play in supporting children's embodied forms of computational thinking with tangible programming toys.

In this paper, we demonstrate how teachers attend and respond to the seeds of computational thinking (K–12 Computer Science Framework, 2016) in preschoolers' (ages 3-4) embodied activity as children work with a tangible programming toy. To reveal the fine details of these instructional processes, we adopt an approach to interactional analysis inspired by ethnomethodology, conversation analysis, and Goodwin's co-operative action framework (2018). In particular, we illustrate how teachers purposefully take up, re-use, and transform learners' embodied ideas to focus, recontextualize, and decontextualize body syntonic knowledge to support students' engagement in the computational practices of problem decomposition, debugging, and abstraction. Overall, our investigation contributes to a better understanding of interactional mechanisms that support computational thinking in early childhood and the nuanced ways in which responsive teaching (Pierson, 2008; Robertson et al., 2016) is a multimodal, embodied phenomenon (Flood et al., 2020).

Background & Theoretical Framework

When children of all ages make sense of STEM ideas, they often use their bodies as meaning making resources to physically adopt the point of view of the phenomena under consideration and draw parallels through body syntonicity (e.g., Crowder, 1996; Keifert, 2019). Through this process, children act out and work through possibilities as if they were the phenomena, leading to important insights into how and why things behave the way they do. Notably, practicing scientists and mathematicians at the frontiers of discovery also use body syntonicity for thought experiments, taking on the viewpoint of and physically embodying abstract theoretical entities and phenomena (e.g., a super-heated crystalline lattice) they are trying to imagine (e.g., Ochs, 1996). Since Papert's seminal research, a number of studies have examined how students use body syntonicity to successfully program, problem solve, and develop computational thinking skills (e.g., Berland et al., 2011; Farris, 2021; Kopcha, 2021; Sung et al., 2017). Children engage in computational thinking practices with their bodies to break down complex problems into manageable parts (decomposition), identify common features to create generalizations (developing and using abstractions), and to recognize, find, and fix errors (debugging), among other practices (Papert, 1980; Berland et al., 2011; Fadjo et al., 2009; Kopcha et al., 2021; Wang et al., 2021b).

In the last decade, there has been an influx of tangible programming learning environments and tools specifically designed to capitalize on and support children's embodied engagement with computational problems (Yu & Roque, 2019). One increasingly popular type of tangible programming learning design includes toy animals and robots that can be programmed to navigate through and interact with the world. Examples include: BeeBot (a

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bee), Cubetto (a cube-shaped robot with a smiley face), Topobo (a dragon), and Code-a-pillar (a caterpillar), among others. These engaging toys have imaginary needs and desires, bodies, facial features, and ways of moving that children can physically relate to, and offer rich opportunities for computational thinking through body syntonicity. In addition to providing powerful playgrounds for computational thinking, tangible programming toys also foster mathematical thinking and learning, art and design skills, storytelling, and the development of fine motor skills (Bers, 2008; Bers et al., 2014).

However, despite the generally well-accepted role the body plays in sense-making while learning to program, there is still much unknown about how teachers can support children's use of body syntonicity to foster computational thinking. Our study joins recent investigations of how educators support students' embodied learning in STEM contexts such as makerspaces (e.g., Vossoughi et al., 2020; Vossoughi et al., 2021) and mathematics (e.g., Flood, 2018; Flood et al., 2020). In particular, we know little about how teachers are responsive to children's use of *body syntonicity* and how they take up and work with embodied knowledge in the classroom. In STEM education, *responsive teaching* involves eliciting, recognizing, and responding to children's ideas with potential disciplinary value or substance, and adapting instructional guidance to make use of these student contributions (Pierson, 2008; Robertson et al., 2016). When teachers take up and are responsive to the "seeds" of disciplinary STEM ideas and practices, it increases students' participation and promotes learning (e.g., Pierson, 2008). In this paper, we investigate what *embodied* responsive teaching (Flood et al., 2020) looks like in the case of preschoolers learning to program a tangible programming toy.

One powerful form of responsiveness is the use of *revoicing* where teachers take up, repeat, and reformulate the ideas children express (O'Connor & Michaels, 1993). Adults' revoicing (also known as recasting) plays important roles in how young children develop language and abstract concepts (Baker & Nelson, 1984; O'Connor & Michaels, 1993). In preschool classrooms specifically, revoicing is ubiquitous and accomplishes a number of functions including building linguistic skills, positively evaluating students' ideas, seeking clarification, and comparing and contrasting different ideas (Yifat et al., 2008). In particular, one of the most important functions of revoicing for all ages is the *reformulation* of learners' ideas, and the reflection of these reformulations back to students (Cazden, 2001; O'Connor & Michaels, 1993). Studies of classroom discourse have identified a number of ways that teachers reformulate the information students contribute. These include: (1*) focusing* students' contributions, where teachers will selectively revoice only parts of what students said, and omit parts that are incorrect or superfluous from a disciplinary perspective; (2) *recontextualizing* students' contributions, where the reformulation shifts or extends the scope of the original contribution, often making new connections with additional information or details that may have been omitted by the student and are relevant to the topic at hand; and (3) *decontextualization* where students' contributions are reformulated to be more general, all-encompassing, or less situated in the immediate, specific details of the situation or context compared to the original contribution (Cazden, 2001; O'Connor & Michaels, 1993).

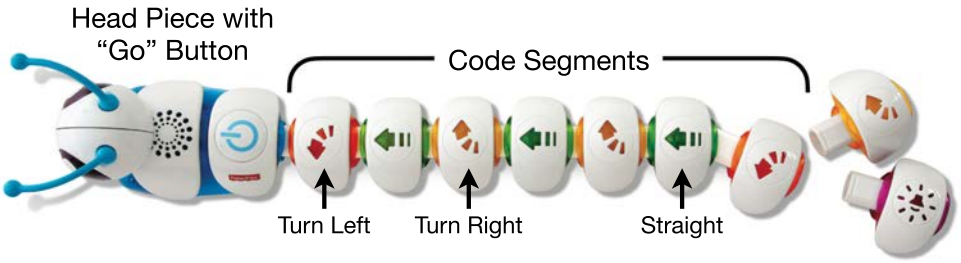
To date, however, studies of revoicing and recasting have tended to investigate revoicing in speech and have paid less attention to how teachers attend and respond to children's embodied ideas. Drawing on Vygotsky, Goodwin (2018) argues that a fundamental feature of how people learn is through dialogic interactions where more capable others (parents, teachers, mentors, etc.) carefully attune to the bodily experiences of newcomers and are responsive to, take up, and reformulate *all* of the multimodal, embodied communicative resources (e.g., gesture, gaze, bodily demonstration) that newcomers make available when they share ideas or make proposals. Consistent with this perspective, recent work in STEM at the secondary level has demonstrated that teachers are responsive to how learners use their bodies to express and work through ideas multimodally; and they often selectively repeat, reformulate nonverbal resources like gesture or full-body demonstrations, in addition to what learners say (Alibali et al., 2019; Flood, 2018; Flood et al., 2020; Shein, 2012). Inspired by this recent work in secondary STEM education, our present study seeks to better identify and characterize how preschool teachers use embodied responsive teaching, and specifically, how they re-"voice" and reformulate learners' body syntonic engagement with computational problem solving as they work with a tangible programming toy.

Study Context & Methods

This study emerged from a broader investigation of how to support young children's computational thinking with a commercially available tangible programming toy: Fisher-Price's Think and Learn Code-a-pillar (https://www.youtube.com/watch?v=3d4zXauy6EM). As part of this study, a series of programming sessions with the Code-a-pillar were video recorded over 12 weeks at a university-affiliated preschool. Children worked in small groups to complete 15-minute programming challenges with the toy once or twice a week, guided by experienced classroom teachers. Twenty-two children and two teachers participated. The programming challenges involved "helping" the Code-a-pillar navigate to desired locations. The Code-a-pillar (named "Rapunzel" by the children) has color-coded interchangeable body segments that each provide a command: turn right, turn left, go straight,

and play music (Figure 1). As part of each challenge, children engage in a range of computational thinking practices including defining computational problems (e.g., decomposing), developing abstractions (e.g., identifying patterns), and testing and refining programs (e.g., debugging). In each challenge, children spontaneously used their bodies to problem solve with the teachers' guidance.

Figure 1. *Code-a-pillar, a tangible programming toy with body segments that provide commands*



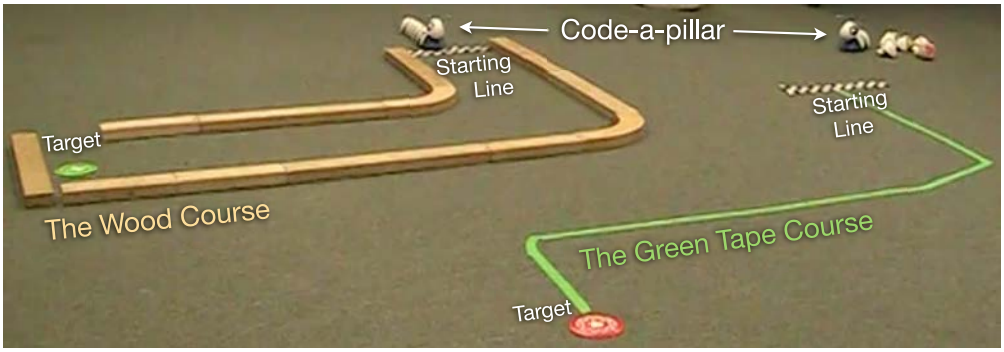
We reviewed the 12-week corpus in its entirety and located each instance where the teacher repeated or reformulated students' ideas that were expressed through gesture, demonstrative action with the Code-a-pillar, and/or full bodily activity (e.g., crawling through an obstacle course). Drawing on ethnomethodology, conversation analysis (EMCA, Mondada, 2012), and Goodwin's co-operative action framework (2018), we microanalyzed these interactional sequences to understand what multimodal, embodied resources students used to make proposals, and what aspects of these multimodal and embodied resources were repeated, omitted, or modified in teacher's subsequent revoicing turns. The goal of EMCA is to uncover and document the precise methods and resources participants use to negotiate and make meaning together (Mondada, 2012). Goodwin's co-operative action framework (2018) enriches EMCA by focusing on the embodied ways in which participants take up and transform each other's embodied, multimodal contributions (e.g., gesture, facial expression, prosody, talk, and so on). Each multimodal utterance a participant contributes is considered to be a substrate that can be broken down, reused, and reshaped in the process of co-constructing emergent new ideas and meanings together. Our findings emerged from the careful comparison of student and teacher turns.

For this paper, we selected one focal lesson involving three different groups of children to illustrate three representative cases of how teachers can be responsive to children's body syntonicity through (1) focusing, (2) recontextualizing, and (3) decontextualizing embodied proposals to support the computational thinking practices of (1) problem decomposition, (2) debugging, and (3) abstraction, respectively. We created detailed transcriptions of participants' body movements, gesture, speech, gaze, facial expressions, and vocalizations using conventions adapted from conversation analysis and Goodwin (2018): degree signs for quiet speech (°°); capitals for louder speech; question marks for rising intonation (?); periods (.) for falling intonation; timed pauses appear in parentheses (2.5); colons denote elongated syllables (::); and square brackets show overlapping actions ([ ). Embodied actions are illustrated and co-timed speech is outlined with boxes.

Findings

Throughout the 12 weeks, children spontaneously used their bodies to take the perspective of the Code-a-pillar to complete each programming challenge. The teacher was responsive to students' use of body syntonicity and in almost every case, re-"voiced" students' contributions. Our analysis breaks down students' embodied contributions and the teachers' multimodal revoicing turns to demonstrate how the teacher engages in (1) focusing, (2) recontextualizing, and (3) decontextualizing their embodied proposals. We present a representative example below for each of these forms of embodied responsive teaching. In the focal lesson, children have been tasked with a programming challenge to "help" the Code-a-pillar navigate a path surrounded by wood blocks (The Wood Course) and a path made of green tape (The Green Tape Course) to reach targets at the end of each path (Figure 2). During this challenge, a number of opportunities for computational thinking arise. As children work together to complete the task, they must break down the complex spatial trajectory of The Wood Course and The Green Tape course into a series of discrete steps (decomposition) and select appropriate segments for Code-a-pillar. If Code-a-pillar deviates from the course, they must recognize there is a problem, locate the segments that are responsible, and develop an alternative solution (debug). Finally, students are also asked to notice and investigate patterns that arise for their potential to simplify or aid with the planning process (abstraction).

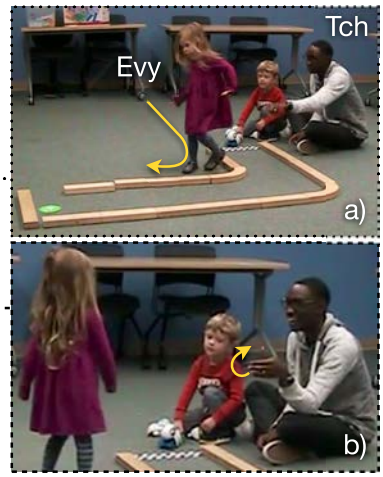
Figure 2. *The challenge: program Code-a-pillar to reach the targets at the end of each course*



Focusing embodied proposals to support body syntonic decomposition

In Excerpt 1, Evy, Cal, and the teacher are working on helping Rapunzel the Code-a-pillar navigate The Wood Course to reach the green target at the end. To "help" Code-a-pillar navigate the curved path to her target, children must decompose a continuous spatial route into discrete programmable steps. Then, they must attach body segments with commands such as go straight, turn left, and turn right in the appropriate sequence. Decomposition involves breaking down complex problems into smaller or more manageable parts (Shute et al., 2017). In this case, Evy, Cal, and the teacher have already attached a straight segment to Rapunzel and are now examining the course and deciding what to do next. Evy uses her whole body to make a proposal by walking the path: Taking the Code-a-pillar's perspective, she begins from the starting line, strides forward, and then rotates her whole body to the right where the track curves, as if she is Rapunzel the Code-a-pillar (E1.a). As she turns, she raises her arms up and points her hands forward. During the full-body turn, she shouts "left" (E1.05). Her suggestion, from start to finish, is performed in one continuous, fluid motion.

Excerpt 1. *Which Way?*




```
01 Tch: And then which way does Rapunzel need to turn,
02      [after she goes straight.
03 Evy: [((walks straight))
04      ((turns right))
05      LEFT!
06      (0.9)
07 Tch: Or [right
08         [((curves and waves hand to the right))
09      [(0.3)
10 Evy: [°Ri::ght°
11 Tch: Right. But you got the right idea,
12      yeah right, so put on the next piece.
```

Evy's suggestion uses body syntonicity to make a proposal for how to navigate the beginning of The Wood Course and thus contains productive beginnings of decomposition. However, although Evy enacts a right turn, her proposal for what to do next is ambiguous because her bodily activity does not clearly separate the first step (a straight) from the second step (a right turn). When working with Code-a-pillar, children sometimes don't recognize that certain distances will likely correspond with more than one command. Although unclear from her actions, it is possible Evy believes a single turn segment would be sufficient to navigate Code-a-pillar to where she walked to. In addition, Evy's suggestion contains a mismatch in speech and bodily activity (Alibali et al., 1993), since she describes the right turn she enacts as a "left" (E1.05).

The teacher is responsive to Evy's body syntonic proposal for the Code-a-pillar: He takes up and reformulates the proposal to highlight the aspects of decomposition that it embodies. By carefully attending to her embodied proposal, the teacher is able to see that Evy has productive embodied knowledge about the situation, despite the mismatch between her speech and bodily activity, and the potential inclusion of an extra step (the straight). He selectively repeats just one part of Evy's embodied proposal by curving and waving his hand to the

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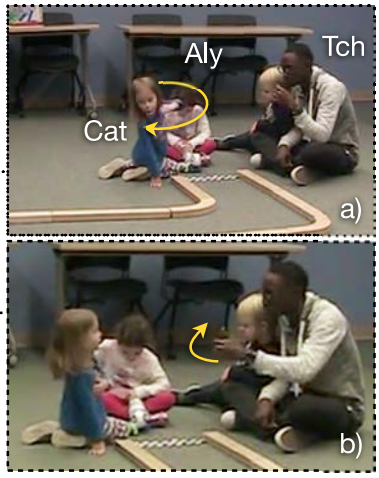
right. This simplification focuses attention on the right turn and not the straight motion. As he re-creates the right-turn motion, he also describes it as a "right" turn (E1.07). Omitting superfluous and ambiguous aspects of the multimodal contribution reinforces a productive direction for the decomposition of the problem: The next step after the straight already added is a right turn. Thus, although Evy's original embodied proposal visually contained two steps (straight and right), the teacher provides a narrower focus to help the children decide on the next step. Evy takes up the teachers' reformulation and repeats "right" (E1.10), and working with Cal, they attach a right turn segment.

Recontextualizing embodied proposals to support body syntonic debugging

In Excerpt 2, Cat, Aly, Ted and the teacher are working to help the Code-a-pillar reach the target in The Wood Course. Currently, the Code-a-pillar has a straight segment, two right turn segments, and another straight segment attached. The group has sent Code-a-pillar for a test run, and during the run, the Code-a-pillar runs into the wooden boundary. As the children simultaneously grab the Code-a-pillar to start pulling off body segments, the teacher asks them to consider what the second-to-last segment (referred to as "it" in E2.01) made the Code-a-pillar do to help them debug their current set of commands. Debugging describes the processes of recognizing, finding, and fixing errors in computer programs. In order to detect, locate, and resolve the bugs that arise with Code-a-pillar's programmed routes, preschoolers must first recognize discrepancies between the program's behavior and the desired outcome (e.g., Code-a-pillar deviates from the desired path), then isolate the problematic command segment(s), and successfully replace them with segments that will cause the desired result.

Excerpt 2. *The Crash*

01 **Tch:** What did it make her do?
02 **Aly:** Str[ai::ght?
03 **Cat:** [Cwra:::sh.
04 [*((twists torso clockwise,*
05 *reaches left hand around right shoulder))*
06 **Tch:** It makes her [crash
07 [*((thrusts hand quickly to the right))*
08 into that block. Yeah. Okay.
09 **Aly:** *((removes second segment))*



To answer, Aly says "straight" (E2.02), and Cat makes a different embodied proposal (E2.a). Her upper body moves as if she is the Code-a-pillar, in the same direction that Code-a-pillar makes the problematic turn into the barrier. She twists her whole torso towards the location where the Code-a-pillar struck the wooden track, and she also stretches her right arm across her body, twisting her right hand past her left shoulder to point at the crash site. As she turns, she gazes towards the exact location where the collision occurred. To make this turning motion and twist her arm around, she contorts her body in a way that appears uncomfortable, which may be an attempt to illustrate the discomfort, awkwardness, or the undesirability of the situation. As she moves, she says "cwrash" (E2.03). Cat's bodily activity provides important information that is not captured in her speech about the location of the crash and the undesirable nature of the situation. In particular, exactly where along the track the collision occurred is valuable information that has the potential to help them locate and confirm the source of the bug, and decide which of the segments (the end piece or an earlier piece) was responsible for the undesirable outcome.

The teacher takes up Cat's embodied proposal and is responsive to the productive beginnings of debugging that it contains. He *recontextualizes* this proposal by extending and reconnecting the undesirable outcome Cat embodies with its *cause.* With his hand, he transforms Cat's embodied twist into a quick jerking motion to the right, depicting the direction of the crash. The quick speed of his hand motion preserves Cat's depiction of its undesirable nature (E2.b). While his gesture depicts the right turn that results in the crash, the teacher's speech *extends the context* of Cat's contribution and links the undesirable outcome (the crash into a particular part of the wooden track) back to the specific code segment they are discussing. He performs this extension by adding "it" (which *ties* the idea back to the second segment; Goodwin, 2018) "makes her" (which adds the *causal link*) (E2.06). This addition also clarifies the agency involved in the crash: It is the programmer's choice of commands that is responsible for the error, not the Code-a-pillar herself, and the faulty command can

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be isolated and changed by the children. Overall, this additional information recontextualizes Cat's proposal in the specific details of the situation – the reason for the crash – and implies a potential fix, which are all important aspects of the debugging processes. Although Cat does not immediately respond, Aly, who is holding the Code-a-pillar, demonstrates her understanding of the recontextualized proposal and removes the problematic segment.

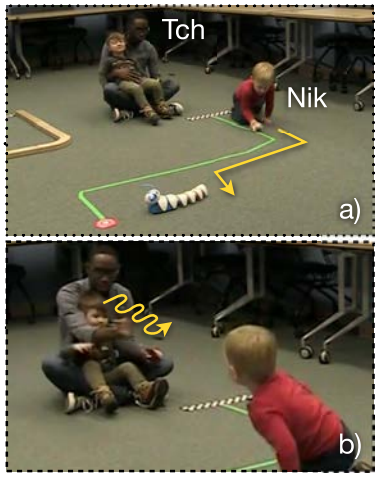
Decontextualizing embodied proposals to support body syntonic abstraction

In Excerpt 3, Nik, Pat, and the teacher are working to help the Code-a-pillar navigate to the target at the end of The Green Tape Course. After some trial and error, they eventually program a route where the Code-a-pillar mostly stays on the green tape and ends up very close to the target. The teacher asks the children to reflect on this route, and asks what they have done to get Code-a-pillar near the target. Nik answers, grabbing a spare Code-a-pillar segment and tracing it along the Green Tape Course where the Code-a-pillar traveled (E3.a). As he traces, he also crawls the path and narrates the processes, starting with "She went this way" (E3.01). As he makes each turn, he narrates with the same sound effect "zoom" (E3.02, E3.04). When he gets to the end of the route, he changes the sound effect to "vroom," (E3.06) pretending to connect the segment he is holding to the Code-a-pillar.

Nik's embodied proposal is body syntonic and adopts the point of view of the Code-a-pillar as he crawls through the course, demonstrating the specific ways the Code-a-pillar moved to get to where she is. His embodied idea contains productive beginnings of *abstraction*: He uses the word "zoom" to punctuate *both* the left turn and the right turn, marking them as similar, and potentially, as members of the same category (or type of thing).

Excerpt 3. *Keep Turning!*

```
01 Nik: She went this way
02      [°zoom°
03      [((turns segment and crawls right))
04        [°zoom°
05        [((turns segment and crawls left))
06      [and vroom.
07      [((pretends to add segment to caterpillar))
08 Tch: So you added on
09      [different pieces that helped her keep turning
10      [((turns hand back and forth))
11      to the food.
12      ((turns hand back and forth again))
13 Nik: Yeah.
14 Tch: Yeah.
```



The teacher is responsive to Nik's embodied proposal and the potential elements of abstraction it presents. He takes up and re-"voices" the proposal, but modifies it in a way that *decontextualizes* it and increases the level of abstraction: While Nik's full-body enactment through the course is environmentally-coupled (Goodwin, 2018) and preserves the precise *location* and *direction* of the left and right turns, the teacher uses a more general gesture, turning his hand back and forth left and right, to represent the *general* case of turns (which can be in either direction). In speech, he provides a more generalized description of what helped the Code-a-pillar get to the target: "keep turning" (E3.09). He also re-emphasizes the causal connection (i.e., adding the code segments) and the children's agency in the process.

Computational problem-solving processes can be simplified by recognizing patterns and similarities within and across situations. Nik's original proposal is situated in the specific context and details of their last run of the Code-a-pillar on The Green Tape Course. Identifying common features in complex scenarios (e.g., the *turns* in a winding course with several left and right turns) is an important aspect of pattern finding and abstraction. To support the children's abstraction and pattern finding, the teacher's reformulation extracts relevant, common information from Nik's proposal and recasts it with less detail. After the reformulation, Nik agrees with the teacher's generalized version of his proposal (E3.13).

Concluding remarks, significance, and implications

By closely examining the ways in which teachers take up and respond to preschoolers' *body syntonic* problem solving with the Fischer Price Code-a-pillar, this study helps to expand our understanding of embodied responsive teaching practices and strategies teachers can use to support children's engagement in computational thinking. In particular, we showed how a teacher attended and responded to the productive beginnings of problem

decomposition, debugging, and abstraction present in children's embodied problem solving. To be responsive, teachers can reformulate children's embodied proposals by (1) focusing them, (2) recontextualizing them, and (3) decontextualizing them, which each can respectively support different computational thinking practices.

In each case, elements of the spatio-dynamic and kinesthetic information children shared with their bodies were preserved by the teacher's use of gesture. This provided a visual, embodied bridge for the children to see connections between their original idea and the teacher's reformulation. This process is congruent with the mechanism Vygotsky (1986) proposed for how interactions between adults and children drive learning and development: It provides an arena for spontaneous, intuitive interpretations of the world (e.g., those that arise from body syntonic experiences) to grow together with cultural and academic concepts. By reformulating children's embodied proposals, teachers may help children reconcile body syntonic intuitions and interpretations with specific cultural and disciplinary ways of organizing the world and approaching problems (e.g., in computer science, processes of decomposition or abstraction). In addition, reflecting these embodied ideas back to children may provide them with important opportunities for increased examination of their own ideas (Flood et al., 2020).

In particular, we argue that understanding how teachers support young children's learning with tangible programming toys requires careful attention to bodily activity and multimodal resources. By attending and responding to body syntonicity, teachers are able to shape the computational thinking that emerges through this physical activity. Our study demonstrates how a focus on speech alone would provide an incomplete picture of the nature of the instructional support in these settings. In addition, understanding children's embodied learning in this setting is irreducible to each child's isolated, individual ideas. Instead, it is necessary to expand the unit of analysis for learning with tangible programming toys to the broader interactional context. Our investigation joins other recent approaches in the learning sciences (e.g., Farris, 2021; Vossoughi et al., 2020; Vossoughi et al., 2021; Wang et al., 2021b) to show how the intricacies of computational thinking practices can be distributed across participants' bodies and co-constructed between preschoolers and teachers. We demonstrated how Goodwin's co-operative action framework (2018) provides a powerful analytic approach for illuminating the embodied nature of responsive teaching that may otherwise go overlooked: The multimodal microanalysis of interaction provides a powerful tool to understand the nuanced ways in which teachers take up, re-use, and transform students' embodied utterances during programming sessions.

Notably, teachers' abilities to be responsive to young children's embodied computational thinking also suggests that children need not have sophisticated vocabulary and language skills as a prerequisite for meaningful engagement in practices like abstraction, decomposition, and debugging. As computer science, programming, and computational thinking are increasingly being introduced in early childhood, teachers sometimes feel unprepared to teach these areas to young children. Our study illustrates how teachers can adapt techniques from their existing repertoire of teaching practices (e.g., revoicing) in embodied ways to support children's computational thinking. In addition, creating professional development to support teachers to recognize and embrace early learners' embodied forms of computational thinking may be especially important since, historically, embodied competencies and ways of knowing have been delegitimized in STEM spaces (Takeuchi et al., 2019).

One limitation of our study is that we cannot know from our current investigation how these embodied responsive teaching practices impact longitudinal learning outcomes surrounding computational thinking. As Cazden (2001) notes, any one instance of revoicing where focusing, recontextualization, or decontextualization occurs is not likely to result in mastery of academic topics or practices. However, Cazden argues that continuous engagement with adults, in which children's ideas are frequently taken up, reformulated, and reflected back to them, provides a powerful sociocultural mechanism for learning through socialization. Given the well-established importance of body syntonicity in children's development of computational thinking, more research is needed to understand how embodied responsive teaching supports children's computational thinking and what impact this has over time.

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Developing Productive Classroom Dialogue Using Analytics-Supported Video-Based Approach for Teacher Learning

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Abstract: This study investigates the role of a video-based teacher professional development approach supported by a visual learning analytics tool, Classroom Discourse Analyzer (CDA), for helping teachers to understand and to enrich their classroom dialogue in the teacher education context. Data were drawn from three teacher educators and their pre-service student teachers (n = 52) spanning over six months on enriching classroom dialogue. Teacher educators met regularly in six teacher meetings to discuss and reflect on classroom dialogue using video clips enriched by CDA visualizations. Coding of classroom talk using accountable productive talk moves indicates changes in teachers' increased use of productive classroom dialogue moves. Qualitative analysis of teacher reflection and discussion illustrated how CDA supported teachers in noticing their own and student discourse, using dialogue moves as the framework for reflection, and developing deeper meanings of dialogue using CDA as objects of inquiry. Implications of the designed analytics-supported video-based teacher professional development approach are discussed.

Introduction

Developing productive classroom dialogue is a major research theme and gaining significance in light of changing global and educational contexts for dialogical education (Mercer et al., 2019). While research on classroom dialogue is well established (Howe & Abedin, 2013), teachers often meet challenges in orchestrating productive classroom discourse in teaching and learning (Chen et al., 2020). Compared with the traditional initiation-response-follow-up (IRF) pattern (Sinclair & Coulthard, 1975), productive classroom dialogue requires teachers to encourage students to engage in dialogic interaction-practice by sharing, build-on, arguing, elaborating and reflecting in the classroom discussions. To help teachers conduct productive classroom dialogue, research into teacher professional development (TPD) has given substantial attention to using classroom videos to support teacher learning and teacher collaboration has played a vital role in these video-based TPD programmes (Beisiegel et al, 2018; Shrien & van Es, 2009). With the advances in technology, the use of video-based TPD supported by teacher collaboration has been recognized as a major approach for teacher learning in the learning sciences. This paper presents an analytics-supported video-based approach that aims to help teachers and students foster productive classroom dialogue.

The social-cultural theory emphasizes social interaction as a key mediator to support learning (Pifarré & Staarman, 2011). Increased attention has been paid in recent years to the notion of productive classroom dialogue for mediating joint understanding. For example, Mercer (2008) identified exploratory talk as productive dialogue through which students engage in collective knowledge construction in the form of critical and constructive building on each other's ideas. Michaels et al. (2008) discussed accountable talk, which is a productive form of discourse emphasizing accountability to the learning community, accurate knowledge, and rigorous thinking. Productive classroom dialogue, as a form of talk, is well examined to be effective for students' learning (Howe et al., 2019; Murphy et al., 2009). Given the important role of productive classroom dialogue, an overarching question is proposed for educators that how to help teachers learn and foster productive dialogue in classrooms. There has been considerable research interest in strategies training for teachers in the TPD programs, in turn, to orchestrate productive dialogue with students in the classrooms (e.g., Chen & Chan, 2022; Chen et al. 2020; Pehmer et al., 2015).

Although video-recording of classroom dialogue is a central tool in TPD to help teachers to reflect on classroom teaching, challenges still exist due to the large amounts of classroom dialogue data that teachers must process, especially to identify useful video clips and episodes. Different approaches have been taken to address the problem such as teachers selecting their video clips and collaborative discussion among teachers (Sherin & van Es, 2009). In recent years, researchers have developed visualization and analytics tools to help teachers notice and identify salient classroom events. Specifically, the Classroom Discourse Analyzer (CDA), a visual learning analytics tool (Chen, 2020), was developed to visualize classroom dialogue using analytics data. Using CDA, teachers can navigate and synchronize selected classroom events (video clips) with classroom talk (transcripts) and productive dialogic moves (dashboard analytics) (Figure 1). CDA has different affordances, including

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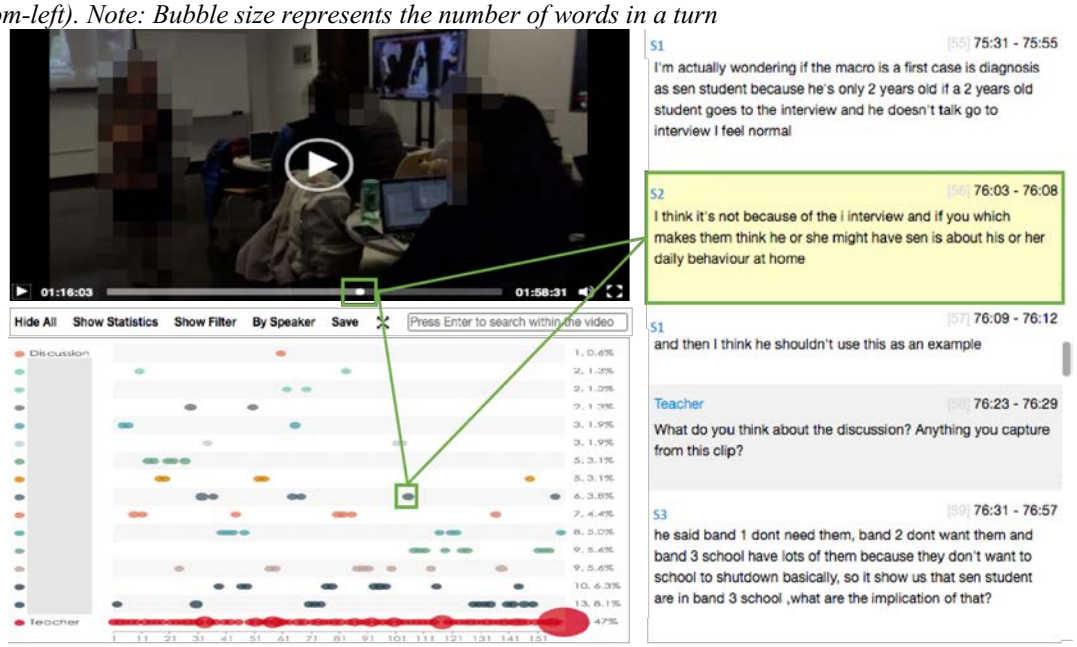
multiple representations, interactive visualization, and contextualized evidence. The CDA platform provides strategies for solving the difficulties teachers meet in reflecting on and analyzing classroom dialogue, including those related to large datasets, coding, visualization, and tracking and comparison (Chen, 2020).

Figure 1

Classroom Discourse Analyzer interface, with classroom video events (top-left), classroom discourse utterances/transcripts (right), dashboard-analytics information on teacher dialogic moves and student talk turns (bottom-left). Note: Bubble size represents the number of words in a turn



Current research on classroom dialogue spans different educational levels and subjects and has mostly examined in-service teacher learning from K-12 levels. It is also important to examine the development of a dialogical approach among teacher educators, as they are modeled for pre-service teachers whose experience would aid future school transformation. In particular, the focus in teacher education is often placed on subject matter knowledge and pedagogical and teaching skills, rather than collaborative and dialogical learning. Jurow et al. (2012) discussed the need for incorporating a learning sciences lens in teacher education, noting that a dialogical approach would be fruitful. This study was conducted in a teacher education setting to examine teacher change towards developing productive classroom dialogue. Specifically, its goal was to integrate the development of a visual learning analytic tool to help teachers orchestrate academically productive talk moves in classroom teaching. Specifically, two research questions were addressed: (1) Did the teacher educators increase their use of academically productive talk moves, and what characterized these productive dialogic moves? And (2) How did teacher educators employ visualization and analytics information from CDA to promote their understanding of academically productive talk in the classroom?

Methods

Research context and participants

Data were drawn from three teacher educators and their preservice student teachers (n = 52) who participated in a six-month programme for developing productive classroom dialogue for teacher development. The group consisted of eight university teachers who met once a month to share their practices in teaching a pre-service teacher education course on Educational Inquiry. Other teachers also joined the discussion at different times, but these three teachers opted to make a more focused inquiry into their own practice, including video analysis supported by CDA. Altogether, six teacher meetings were held, including discussing the classroom dialogue scheme adapted from the accountable talk (Table 1) (Michaels et al., 2008), teachers sharing video clips of their classroom teaching, and using CDA to examine and interpret classroom dialogue.

Data sources and analysis

Teacher educators' classroom dialogue moves were examined using two classroom videos obtained from each of the three teachers during the early and late phases of intervention (TPD discussion on classroom dialogue). There were six classroom videos, with each class lasting 120 minutes. The classroom transcripts were analyzed and coded using the adapted "academically productive talk" (APT) scheme (Chen et al., 2020; Michaels et al., 2008; Resnick et al., 2010). Table 1 shows the five main talk types: sharing their own ideas (elaborating), deepening their reasoning (reasoning), listening carefully to one another (listening), and engaging with others' ideas (thinking with others). In addition, based on a theory- and data-driven approach, we added a new type – reflecting with others (reflecting). A second rater coded 20% of the data and the inter-rater reliability was .87 (Cohen's kappa; Cohen, 1968). Teacher discussions in TPD meetings were transcribed and qualitative analyses were conducted to examine salient events and themes on how CDA supported teacher learning.

Table 1
The framework of teachers' academically productive talk moves – adapted from Chen et al. (2020), Michaels et al. (2008) and Resnick et al. (2010)

APT Strategy	APT Moves	Description and Examples
Type 1: Elaborating	Say more	Ask students to expand on their ideas by saying more ("Can you give an example?")
	Revoice	Revoice students' reasoning and provide opportunities for them to verify it ("Are you saying…?")
Type 2: Reasoning	Press for reasoning	Ask students to explain their reasoning ("Why do you think that?")
	Challenge	Challenge students or give a counter-example ("Does it always work that way?")
Type 3: Listening	Restate	Ask students to repeat or rephrase the idea of others ("Can you rephrase or repeat what (s)he just said?")
Type 4: Thinking with others	Agree/disagree	Ask students to apply their reasoning to another's reasoning ("Do you agree/disagree?")
	Add on	Prompt students to extend the idea of others ("Who can add to that idea?")
	Explain other	Ask students to explain what someone else means ("Why do you think he said that?")
Type 5: Reflecting	Refer back	Prompt students to summarize or link previous ideas ("Can you summarize/compare what they said?")

Results

RQ1. Did the teacher educators increase the use of academically productive talk and what characterized these productive dialogic moves?

We first provided basic quantitative data on the amount of teacher and student talk in the three classrooms. Using the CDA, we assessed the mean of the "percentage of words" used by teacher educators and student teachers. Table 2 shows that for all teachers, there is a decrease in the amount of talk whereas their students increased the amount of talk from early to late phases (pre-post intervention).

Table 2
Percentage of teacher and student talk words at pre- and post intervention of program

	Teacher Talk		Student Talk	
	Pre	Post	Pre	Post
Teacher A	88%	79%	12%	21%
Teacher B	79%	66%	21%	34%
Teacher C	69%	66%	31%	34%

We then examined the teacher educators' use of productive dialogic moves in two lessons at the early and late phases of the intervention program. Table 3 shows the frequency of use of the five types of productive classroom talk moves for the three teacher educators.

Table 3
Frequency of the five productive classroom talk moves at pre- and post-intervention of program

	Elaborating		Reasoning		Listening		Thinking with others		Reflecting	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Teacher A	14	19	5	3	0	2	2	17	0	2
Teacher B	5	13	1	2	0	3	4	13	0	2
Teacher C	7	18	5	12	0	0	2	10	4	2

A paired sample t-test was conducted to examine whether teacher educators increased their use of academically productive talk moves. Analysis showed that teacher educators significantly improved their overall use of the five types of academically productive talk strategies between early phase (M = 16.33; SD = 5.69) and late phase (M = 40.00; SD = 4.36), $t(2) = 26.835$, $p < .01$. Specifically, there were significant changes in the use of *Elaborating*, $t(2) = 4.619$, $p < .05$ (Pre: 8.67(4.73); Post: 16.67(3.21)), and *Thinking with others*, $t(2) = 4.880$, $p < .05$ (Pre: 2.67(1.15); Post: 13.33(3.51)). Generally, these results suggest that the teacher educators increased the orchestration of productive classroom discourse after the TPD intervention.

We also included classroom dialogic examples to show how these productive dialogic moves were employed.

> 1. Teacher (T): Take a look at this cartoon shown on screen (topic: Catering for individual difference), what do you think when you see this cartoon?
> 2. Mary: One size fits all. [term used in lesson PowerPoint]
> 3. T: One size fits all? Can you tell us more? [Teacher invites a student to *elaborate*]
> 4. Mary: Um... Cartoon shows teaching fitting stuff into the box. It seems here that the teacher thinks one set of materials is good. And if students do not perform well, then it is their problem... Just fitting students to the box.
> 5. T: What do others think about what Mary said? (Some silence, wait time) [Teacher invites students to *add on*]
> 6. T: Anything you want to add? You can agree or disagree with Mary? [Teacher invites *thinking with others*]
> 7. Tom: Um I do not like the image shown in the cartoon.
> 8. T: Tell us more. What do you not like? [Teacher invites *elaboration*]
> 9. Tom: It is like what Mary said.
> 10. T: What did she say earlier? Can someone rephrase that? [Teacher *listening*]
> 11. David: She (Mary) said one size fits all may not work well. As in this picture, the teacher just tried to shape or modify the student to fit into the box. It may be like one size fit all strategy the teacher used.
> 12. Dennis: Yes, because not all teaching strategies fit the students. But often students just try to pretend they understand.
> 13. T: That is interesting... pretending to understand? [Teacher follows up on Dennis' ideas. *Listening*]
> 14. Dennis: I mean with this one size fit approach. I may feel confused about what the teacher taught. But I see other students seem to understand, so I am afraid to ask more questions. [Student elaborating his ideas]

In this example taken from Teacher B from the lesson taken later in the program, the teacher was working at incorporating the different productive dialogue moves in her classroom teaching. She started by showing a cartoon to the student teachers to generate open responses and have the students set the direction of classroom talk. Rather than just asking closed-end content-related questions, she employed different moves including inviting the students to elaborate [Lines 3 and 8, *Can you tell us more*?], to add on and think with others (Line 6, *you can agree or disagree with Mary?*), to listen to others and to paraphrase what is said earlier (Line 10, *what did she say earlier? Can someone rephrase that?*). And following up on what the student teachers had suggested (Line 13, *that is interesting…pretend to understand?*). Teacher B has been using the student-centered approach in her university teaching, and this dialogic framework presented in the TPD project helps her to use a set of productive talk moves more systematically. These productive talk moves also help encourage student teachers to express more (longer speaking turns) and to build on peers' different ideas moving towards enriching classroom dialogue.

RQ2. How did teacher educators employ CDA visualization and analytics in supporting their understanding and enactment of productive classroom dialogue?

We included examples and analyses of how CDA supported the teacher educators' reflection and discussion to develop their understanding of productive classroom dialogue. In one teacher meeting, CDA visualizations of Teacher A's classroom teaching in two lessons (early and late phases) were shared and discussed. Both the CDA lessons and the visualizations were selected and prepared by the research team. Figures 2a and 2b focus on the

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amount of talk and speaker turns – the vertical axis includes teacher and student names and their contribution, and the horizontal axis shows all turns over time The size of each bubble indicates the length of the talk, with teacher talk at the bottom of the graph. Figures 3a and 3d focus on Teacher A's use of dialogic talk moves in the two lessons, based on the adapted Accountable Talk scheme (nine types). Teachers also referred to video events and excerpts in relation to the CDA analytics information (Figure 1) in their discussion.

Figure 2

Visualization of teacher educators and student teachers' frequency of talk and speaking turns in two lessons

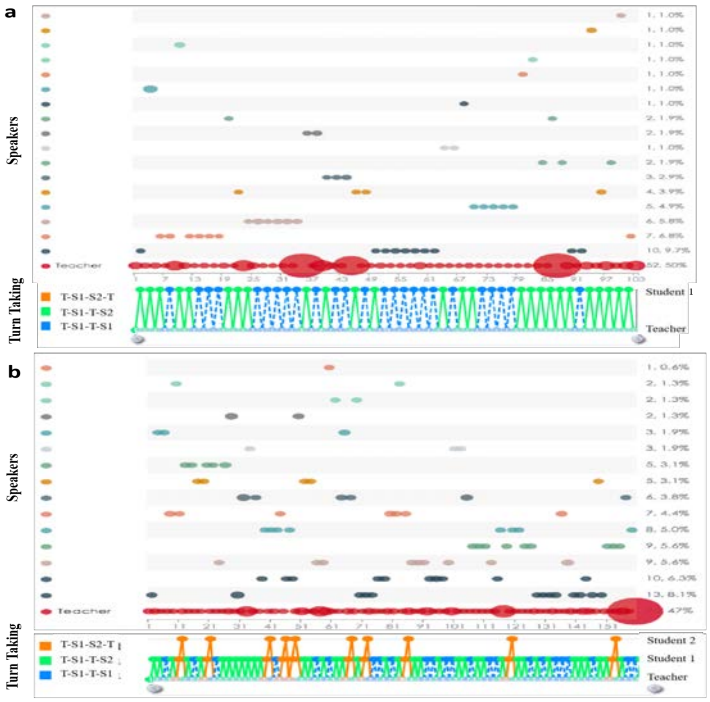

Figure 3

Visualization of Teacher A's frequency of use of different dialogic talk moves in two lessons

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The teacher educators discussed how CDA visualization supported their understanding and enactment of classroom dialogue. Several themes emerged:

Facilitating the noticing of teacher and student engagement in discourse

Teacher educators used the CDA visualization to help them notice their own and students' dialogue patterns that would form a basis for change. For example, Teacher A commented,

> "When I looked at my CDA graph (pointing to the bubble of talk, Figure 2a), I was surprised at the length of my talk...I didn't know I was talking so much…Possibly, the common pattern in our university teaching is long teacher talk and relatively short student responses."

Using the CDA visualization, Teacher A was aided to notice the length and amount of his classroom talk. This revelation may have come as a small surprise to the teachers who had joined the project, as they tended to see themselves as relatively good teacher educators. The realization may have helped Teacher A reflect on his practice for possible change. Teacher B used a different lens when looking at the CDA graphs and visualization, emphasizing student engagement and dialogue,

> "I can see how much more or less different students are participating in classroom talk quite quickly now. Also, there is an ongoing temporal dimension… I can also see the sequence of student talk… So, AG is starting and then I see what TM is talking about, and then WK also says something though it is shorter. We can move around video parts/excerpts quickly. So, we can find out more about what student teachers are saying and thinking… Nice to know which different aspects of the topics they found interesting."

Supported by CDA, teachers broadened their views from noticing their own classroom talk engagement to noticing student participation and talk patterns. Noticing student engagement is important for advancing dialogic interactions for productive classroom talk. The CDA-analytics-enriched discussion of students' dialogue patterns enriched teachers' noticing. As Teacher A remarked,

> "I am looking at my other lesson now and it is good to look at both my own and students' talks. It is nice to see I am speaking relatively less... I still have a big bubble and possibly was making a long conclusion. I am also looking at what the student teachers were doing…It is good to see from the graph that a few more were participating (Figure 2b) and speaking more and they also talking longer than before. A little different from my other classes, with shorter student responses."

Increasing teacher awareness and supporting reflection using the dialogic move framework

CDA visualization supports teacher educators to understand more about the use of dialogic classroom moves to enhance their awareness of dialogue. As Teacher B noted,

> "These classroom dialogic moves are quite complicated and may mean different things to teachers, but we can now see what they may look like using these video clips and visualizations. We can also see the utility of different dialogical moves...In this case (referring to Figure 3), the talk move please 'say more' was more commonly used; it may be an easier dialogic move to use and good to try."

Teacher A also expanded on his understanding of these dialogic moves:

> "I think the talk moves shown on the CDA graph can be used to assess our teaching but can also be used to help us do something different. The dialogic moves may be some kinds of external support…providing a certain kind of framework. We may have our way of doing our questions and dialogue all the time, but here they help to enhance our awareness of what is really happening in our classroom dialogue."

Primarily, using dialogic moves is challenging for teachers and the CDA visualizations, examples, and codes could help teacher educators develop more understanding and consider using different moves.

Providing diverse representations of teacher talk as objects for shared inquiry into the deeper meaning of dialogue

CDA representation of teacher-student talk patterns also inspired the teacher educators to ponder the meaning of dialogue for further inquiry and design. CDA differentiated teacher-student turns into 1) T-S1-T-S1, 2) T-S1-T-S2, and 3) T-S1-S2-T (blue, green, and yellow) (referring to Figure 2) depicting centralized versus distributed classroom dialogue. The discussion of these patterns brought new questions from the teacher educators. For example, Teacher C said,

> "CDA provides us with the number and patterns...I am also interested in the changes in these turns, not just the number but also the contents and teacher intentions…From there, I hope to know more about the intentions of the teachers and students... what lies behind these different speaker turns."

Teacher C's question points to an important issue – how teachers understand classroom dialogue involving teachers' meaning-making. The combination of video clips to illuminate different speaker turns and dialogue moves may provide more opportunities for teachers to understand the content and intentions of talk moves. Teacher C continued,

> "I also want to build onto the earlier point of Teacher B about the time sequence of student dialogue moves and turns. I hope we can have more analyses of the time sequence based on these different turns. It would be good if CDA in the future could include some kinds of network representation, say, how the talk moved from S1 to S2 to S3. It is almost like social networking for understanding the dialogue among student teachers better."

These CDA objects also function as boundary objects, mediating the discussion and opening new areas of inquiry among teacher educators and, possibly, deepening their understanding and enactment of productive use of classroom dialogue.

Conclusion and implications

The study has examined how a group of teacher educators improved their use of academically productive talk moves after participating in an analytics-supported, video-based, teacher professional development project. Video-based teacher professional development is now a major approach to teacher learning in the learning sciences (Chen et al., 2020; Sherin & van Es, 2009). Concurrently there is also considerable research development in using analytics information to support teaching and learning in classrooms (Wise et al., 2021; Wise & Schwartz, 2017). This study integrated the use of video-supported TPD with visualization and analytics information to address the issue of overwhelming data and selection problems in using classroom videos. Specifically, the use of video-based analytics approach is developed in the area of helping teachers employ productive classroom dialogue and the use of visualization and analytics would be particularly helpful. Results of the study using coding of classroom dialogue indicate that teachers increased their use of academically productive talk moves after the intervention, especially for *elaborating* and *thinking with others* talk types. At a more general level, teacher educators and student teachers changed the amount of total talk in the classroom with student teachers increasing their engagement in classroom talk. Analysis of teacher reflections and discussions at teacher meetings identified several key themes, including how CDA can support the noticing of current and changing teacher and student practices, facilitate their understanding and enactment of dialogical moves via providing a systematic framework, and identify how different CDA representations provide shared objects of inquiry for developing deeper collective inquiry into the nature and meaning of productive dialogue.

This study contributes to the literature on video-based supported teacher learning highlighting the role of visualization and analytics-supported reflection, with learner-generated information (classroom talk) provided to participants for them to reflect on their ongoing inquiry for making changes to their current practice. The integration of technology and pedagogy and analytics in CDA helps provide different possibilities. Many studies show the important role of classroom dialogue and this study also shows how the approach may support the development of dialogic practice. This study is of particular significance, in investigating how teachers could be helped to overcome video data selection problems by harnessing analytics information on their classroom dialogue and providing objects of shared inquiry for understanding and enacting dialogic practice.

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Harmonized Mutual Development through Exploring and Creating Sound

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Abstract: The science of sound presents a holistic learning opportunity to engage embodied intelligence and lived experience in mutually shared soundscapes where material objects become sites for the pursuit of curiosity and aesthetic beauty. When young people are presented with this view of the realm of science learning and practice, the possibility for alignment and harmony between personal knowing, social relations, and a living environment can emerge. And even more compelling, the possibility for what we describe as harmonized mutual development in a community of learners moves within reach. This paper explores the potential of a curricular and pedagogical design to produce a kind of collective ethic in learning that is often elusive in formal learning environments.

Introduction

The pervasiveness of sound, its ease of measurement, and its cultural relevance reveal the sonic world as a "natural laboratory" through which young people may become intuitively familiar with waves and their properties. From speech, to music, to street noise, sound is an integral part of our everyday lives. People are intuitively familiar with many aspects of sound waves and their perceptual signatures such as pitch, timbre, loudness, direction, and echo. People are also familiar with many objects that generate sound (vocal cords, flutes, drums, strings). Listening to Waves (LTW) is an educational program that guides students to learn the hidden and ubiquitous world of waves through the exploration of sound and vibrations. In LTW, students make and analyze sound, create waves and vibrations in physical objects, build musical instruments, use digital technology to analyze waveforms and acoustic properties and to create sound and music, and explore how sound is propagated through the environment and represented in the brain. The program was designed by Dr. Minces, a neuroscientist specializing in the science of music, and Dr. Alexander Khalil, an ethnomusicologist. The design draws from their experiences as scientists and their experimentation with sound.

Being together in a soundscape provides the basis for the design of a set of science workshops. We make a series of moves to grow roots in a disposition toward scientific thinking and practice that prioritizes everyday access to beauty and wonder. First, the design aims to re-prioritize the soundscape as an active context for learning. Second, the design honors social environments that cohere learning environments as fundamental to what makes science practice meaningful. Third, the design re-privileges embodied ways of knowing, situating learning trajectories within young people's sensed and shared experiences (Marin, 2020). Fourth, the design aims to forge a meaningful connection between personal learning and collective, mutual learning that animates shared life. This includes aesthetic, material, contextual, and social relations.

Our program design is informed by a theoretical understanding of learning and development as situated. Young people who participate arrive with their own ideas and experiences with sound and science. This program supports them to expand and integrate those experiences with new ways of exploring, representing, and understanding sound. We consider students' socio-historical sense of both sound and science, their processes of identity development, and their practices for taking on new roles (Bell et al., 2012). LTW uses a project-based design that supports students to connect their everyday knowledge and practices with disciplinary science practices (Barron & Bell, 2016) while inviting them to become increasingly full participants in a community of scientific practice (Lave & Wenger, 1991). The program design integrates middle school students, their teachers, and scientists into joint activity to support development and sustained participation. In this way, the design establishes conditions for making visible and analyzing when and how these project-based activities can support the development of particular identities and sustained engagement (Vygotsky, 1978; Chaiklin, 2003). The designers' relational challenge is of particular importance here.

Becoming and development: A relational design tension

How do designers navigate existing classroom practices that constrain learning environments toward performances of individual intellectual competence and classroom behavioral management while working to establish parallel—and at times, disruptive—forms of meaningful collective learning? Designs for collective learning in classrooms as formal learning environments encounter some practical impediments born of a set of

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developmentally-framed obligations: (a) for students to demonstrate competence independently, (b) to maintain dominant patterns of knowledge production, (c) to accept separation as necessary—as a severing of the social conditions of human learning, and (d) for educators to effectively assess individuals, allowing for students' independent and hierarchically organized advancement or delay. Even the most collectively designed academic task must eventually be filtered into individual grades, advancement, and future placements. When and how can designers effectively honor the social, cultural, historical, political, and ethical conditions of learning?

Our research design endeavored to work in concert with these challenges. We asked, what does a collective learning design allow for in terms of relationality and future practice? In what ways can individual sensory awareness yield mutual and shared learning conditions, and in turn, a learning environment where social engagements directly yield creative inquiry that makes scientific practice and science identities accessible to and sustainable for the full collective of participants? When can individual styles, approaches, interests, and knowledge be activated in service of mutual advancement in practice that moves the whole beyond what could be accomplished individually? In essence, we wondered, what would be the symphonic version of this design, and in turn, the learning opportunities that move beyond the efficiency of collective delivery (and yield more than a system aiming to avoid holding back the individual)? For learning designers, we see this as a threefold challenge intertwined with frames of development, assessment, and organizational differentiation that sort students into groups of more and less capable. Assessment practices and organizational differentiation are pre-existing conditions of classrooms and schools. Developmental frameworks may be the most pliable of the three, and therefore, the most accessible to different approaches in design.

Given our interest in identity, practice, and transformed participation, we have increasingly focused on questions in the realm of human development and processes of becoming. In our observations and in survey results reported elsewhere (Minces et al., 2021), we recognized processes of becoming in young people's engagement with the program. Likewise, we noticed our tendency to look for signals of development-in-progress in our qualitative data, yet were drawn up short by the ways in which developmental frames are frequently used to render students—like those who participated in our study—as behind a developmental norm due to contending with under-resourced circumstances and underrepresentation in science-based fields more broadly. Increasingly, the developmental frame seemed to be in tension with aspects of our situated approach to design and the processes of becoming that most intrigued us during field observation and analysis. Our design emphasized processes for engaging as a learning community in a learning environment that prioritized relationships with self, social environment, and soundscape that could reposition young people's relationship with science and prioritize equity (DiGiacomo & Gutiérrez, 2014).

Matusov's studies of democratized learning environments align with the ethos of the learning environment designed through LTW: "The participation inquiry involves issues of what facilitates and hinders such transformations, what are their directions (and how they are desired by community members), what are means for the transformations …" (Matusov, 1997, p. 340). By designing the learning environment first as a space of relation, we aimed to theorize means by which design can contribute to a prioritized collective ethic in learning while contending with the persistent perceived conflict between individual assessment and practice as communal.

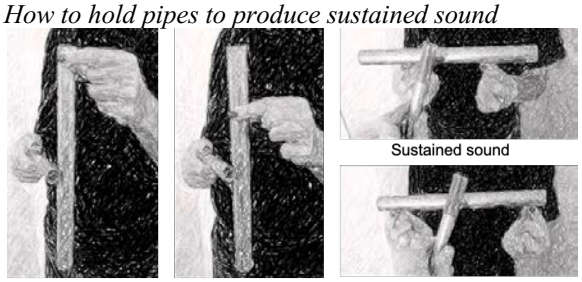
As learning scientists have continued to advance theoretical approaches to understanding development in relation with learning, the notion of becoming has been conceptualized to address equity and ethical relations in learning environments. This approach to relational aspects of becoming gives us analytical purchase on the processes of transformed relationship with science that are at the heart of the pedagogical design: "Pedagogies aimed at social transformation therefore involve examining and rearticulating the meanings that degrade our perceptions of, and relationships with, others as well as ourselves (Philip, 2011). Political-ethical becoming, as we theorize it, is thus not simply reorganizing our thoughts, but reshaping our relations" (Vossoughi et al., 2021, p. 204). Students participating in LTW workshops arrive having already been "embedded in relational ecologies" (Vossoughi et al., 2021 p. 217) that have organized their existing relationships with science at school, soundscapes, sound and music-producing materials, and formal learning environments. The design seeks to ally with students in reconfiguring relationships with the environment that emerge from re-prioritized social and peer relations of the classroom cohort. Prioritizing shared moments of surprise and access to beauty through sound and waves traveling through material requires shifting power relations in learning in that personal and peer sensory experiences are privileged in processes of producing knowledge. Given the theoretical problems we have described, the following questions arise: What mediates engagement in an environment that can be repurposed as a means for young people to forge their own pathways toward science and its potential and presence in their lives? And in what conditions can the design of the learning environment support transformed relationships between the intellectual progression of individual students and a collective intellectual practice where students contribute to the community of practice in ways that matter to the collective, in turn, expanding social practices in the classroom beyond behavioral means and toward political-ethical becoming?

Program Design

LTW program contains several modules that are integrated into eighth-grade science classes, and have been implemented primarily with underrepresented and low-income students. Participating in the program has been shown to improve the students' attitudes towards science, including the perception of themselves as capable of doing science and their intention to pursue a science career (Minces et al., 2021). This paper focuses on one of LTW's modules, the *sound vibrations lab*. A fuller description of the program can be seen in (Minces et al., 2021). The *sound vibrations lab* was facilitated by Dr. Minces. In it, students explore how pipes vibrate, which allows them to understand how musical instruments are built. For the reader to understand this module, they need to know that, for an object to vibrate freely, it needs to be held at points called vibrational nodes, referenced colloquially as sweet spots. When a pipe is held at a sweet spot, it produces a long musical tone; when it is held at other points, it produces a short "thunk!" sound (see Figure 1). A video of the pipes making these different sounds can be seen at www.listeningtowaves.com/ISLS. Building on this surprising phenomenon, this module alternates between children exploring how pipes vibrate and discussing their observations collectively.

Figure 1

How to hold pipes to produce sustained sound



Methods

We paid close attention to students' self-conception as science learners and doers as well as their sense of their potential to become members of (or their existing sense of membership in) a scientific community. The results of survey data addressing this question are outside the scope of this analysis (see Minces et al., 2021). Here we focus on students' thinking practices during project-based work (e.g., how students notice, investigate, and describe sound) and students' recognition of and/or attention to connections across school and daily life contexts. We gathered artifacts of student work, field notes from observations, and multi-camera video recordings of workshops. Our video analysis attended to student strategies, question types, negotiations among group members, responses to challenges, use of tools, proposed solutions, and descriptive practices. Our unit of analysis was the learning environment established through the project-based learning design. Our analytical goal was to understand whether and how the environment supported individual and ensemble engagements with science practice and identities and the degree to which personal interest in sound could become a bridge to personal interest in science.

LTW was implemented at a large urban middle school near the United States-Mexico border (87% Latinx, 8% African American, 47.5% English Learners, 91.5% low SES), involving 350 8th grade students. The program's duration was one month and was incorporated into the 8th-grade science curriculum, in which students learn about waves. We worked with each cohort of students for three two-hour sessions. We used grounded theory to categorize and code qualitative data (Glaser & Strauss, 1967; Charmaz, 1983). Our analysis identified four contexts across which embodied collective inquiry emerged: shared sensory environments, repurposed everyday materials, personal curiosity and awareness, and distributed social relations for learning. We then categorized three types of practices where students generated and sustained these relational contexts: a) manipulating the soundscape to notice new conceptual opportunities, b) expressing interest in sound, everyday objects, and peers' strategies, and c) embodied expressions of knowing to guide interpretation and meaning. Data revealed a distributed interest in contributing to one another's learning and accomplishing together.

Analysis

Data for this analysis comes from a series of Object Vibration Lab workshops given with six middle school science classes taught by three teachers. Each session was held in the school's library where the students were spatially positioned around six long tables arranged in a u-shape configuration, in such a way that they could easily alternate between attending to the facilitator and working together in small groups. In the vignettes described here, 26 students were seated as follows: 10 on the left, 10 on the right, and 6 at the base of the u-shaped configuration.

Video data highlighted two girls at the bottom of the frame in Camera 1 and four boys at the top of the same frame as well as four boys at the top of the frame in Camera 3, which was across the room from Camera 1 at a diagonal. All students in between were engaged in various similar modes of social engagement, making each other laugh, exploring, and listening. In the vignettes that follow, the activities described are exemplars of participants' observed experiences during the Object Vibrations Lab. These vignettes occurred roughly fifteen minutes into the workshop and were simultaneous, as is represented in Table 1. In general, the Object Vibrations Lab alternated between small group and personal exploration punctuated by moments of facilitated demonstration and brief instruction (e.g., defining terms, explaining observed phenomena, and guiding practice).

Public demonstrations: Exploring the movement of vibrations through objects

The opening experience of this workshop led students in this class to pause in surprise and good humor. The facilitator quietly picked up a pipe and a mallet (another pipe with duct tape wrapped around the end), and he began playing it. The tone rang out a few times and all of the students quickly turned their attention toward him, beginning to listen. A few students shushed each other. After playing a few times, he walked over to a group of boys visible in Camera 1 and handed the pair of pipes to Hugo (1), one of the boys who shushed his friends. Hugo tried and produced the unexpected "thunk" to quiet smiles (see Figure 1). He tried again and got a small ring out of the pipe, not quite as resonant as the facilitator's turn. The facilitator said, "pretty good," as he took the pipes and turned to offer them to another student, which led to the following exchange about five minutes into the session:

Student 1:	Me, me! [waving hands as facilitator silently held up a pair of pipes, offering another turn. Then, upon receiving them, he produced several muted "thunk" sounds causing giggles and looks of surprise around the room.]
Facilitator:	[He handed the pipes to a second student. Again, this student's effort resulted in several "thunks." A third student repeated this process to murmurs of, "Ooohhh."]
Student 4:	My turn, my turn, my turn…[reaching out for the pipes]
Facilitator:	Let me show you again. [He played the pipe several times with a wringing tone.]
Multiple:	Oh, Oh, Oh, Oh! [as if something just became clear to him]; You gotta…(inaudible); I got you. I got you! Four students then stretched out their arms, waving for the pipes; the facilitator gave them to Bianca, also visible in Camera 1.]
Bianca:	[She grasped the pipe lightly between her thumb and pinky a quarter of the way down, struck it lightly with the mallet a few times, and produced a sustained ring.]
Facilitator:	Oh, nice! [smiling and nodding]

Students around the u-shaped table were then watching intently as she made the resonant sound. The facilitator then continued to offer turns as students waved for a turn. More "thunks" were produced as surrounding students then began to offer them suggestions, as they sensed they had discovered the secret. It is important to note that the production of the soundscape as a learning environment emerged through a series of unmet expectations. Initially, the facilitator's first ringing tones garnered attention as if someone had rung a bell. However, when he handed the pipes to Students 1 and 2, and the tones were thunks, the successive inability to produce the same tone drew everyone's attention to a place of shared wonder. When the facilitator provided a second demonstration, the students began attending to three aspects at once: his body position as some noticed how he held the pipe this time (embodied practice), the quality of the tone that confirmed a sustained tone could be produced at will (the soundscape), and the pipes themselves as reliably resonant objects (repurposed material). A distributed desire to test their new ideas ran through the room, evident in the change in how they offered suggestions to peers.

Negotiating the soundscape as a learning environment

The next step in the workshop was to give every student a pair of pipes, with one fashioned as a mallet with duct tape wrapped around one end. Having experienced a collective mystery, the facilitator explained to the group that they would be exploring how things vibrate in advance of a future workshop where they would begin making musical instruments. He let them know he would eventually explain how to get the pipes vibrating in the most effective way, but first, students were encouraged to explore and discover different sounds they could make.

Students spent the next several minutes trying different ways to make sound with the pipes. Their attention was sustained, and they had to be interrupted for the next period of instruction. The sound in the room was a blend of the tinkling of metal, a series of thunks, and some sustained sounds. In many ways, it was like the sounds of windchimes on a windy day. The students worked together in small groups and independently when

taken with an idea. They effectively turned their shared environment, through the soundscape, into a space of relationship which came with mystery, aesthetic value, and the opportunity to test ideas and to theorize about the materials and how vibration moved through them. In so doing, the subtle possibility of becoming began to emerge. In Table 1, below, roughly one minute of simultaneous activity is presented in the table. The first row presents the facilitator's discussion. The second row highlights Diego, who was sitting to Hugo's left, was visible in Camera 1, and was called up to the front of the room to volunteer to demonstrate how to find the "sweet spots" that would allow sustained vibration. The third row represents Bianca, who played the first successfully sustained tone in the early demonstration, and her classmate, Maya. Simultaneously, students were engaged in personal exploration while negotiating their activity with peers as the facilitator offered instruction.

First, we note the negotiation that took place between Bianca and Maya. As the facilitator brought attention back to the front of the room to reveal the "nodes" that allow the most vibration to pass, also called sweet spots, Bianca continued to quietly play her pipes. While it was nearly inaudible on the recording, Maya clearly sought quiet to listen. To be clear, Bianca also signaled her interest in listening, keeping her eyes on the facilitator and trying out things the facilitator suggested. Likewise, the room was far from quiet during this bit of instruction. Sounds of quieted attempts to play the pipes continued. Maya, quietly and repeatedly muted Bianca's pipe with her hands. Eventually, as Bianca ignored Maya's efforts, Maya took all four pipes, and they laughed before returning attention to the front of the room.

Meanwhile, Diego and Hugo were engaged in a similar negotiation. They settled it by sharing the pipes and playing on each other's before turning their attention back to the facilitator. In each case, personal exploration was negotiated in tandem with peers, all the while, making sure not to miss the instruction about how to find the "sweet spots". As the facilitator sought a volunteer (Diego) to come demonstrate at the front of the room, negotiations were winding down. At the same time, the facilitator began comparing their pipes with instruments like the marimba and the xylophone, noting that the *keys* on those instruments are held at the nodes. The students signaled their readiness for more, quieting as a whole and observing the demonstration.

During the Object Vibration Lab, the learning environment, which can be influenced and changed, is the soundscape. It acts as a pull on students' practice and attention. The *shared* experience of delight or discovery worked to amplify the effects of experience. As the soundscape and the material (pipes) were reprioritized for more than pattern maintenance or extracting information, sound became available as a shared context for the pursuit of understanding, and in turn, began to extend meaning to acts of exploration that were distributed through the collective rather than grasped by individuals alone. In asynchronous or independent circumstances, persevering in the exploration of vibration through material and sound would take more effort to sustain. In socially supported circumstances, negotiating practices and processes of exploration granted momentum to the group. In other words, as practices emerged to respond to the change in the role of the soundscape, so, too, did the possibility of becoming part of a new way of knowing through practice. Their practices mattered personally and also socially. They were acting as curious explorers in search of patterns, surprises, and beauty, in addition to agreed-upon understanding. In that sense, the possibility of being part of science practice opened the subtle possibility of becoming a member of a science-oriented community, in an embodied and sensory-based way.

Table 1

Finding "Sweet Spots" together – material + soundscape

Time →	*15:07*	*15:13*	*15:17*	*15:23*
Facilitator	"So, the pipes have two sweet spots. Now, when you see a marimba or a xylophone, you'll see that the keys are held at these two specific sweet spots."		Facilitator looked to Diego, gesturing toward him and asked, "What's your name?" He responded, "Me?" "Yeah." "Diego."	"So…so…[pause to await Diego's arrival at the front and give the group time to quiet down]…So, Diego will be holding the keys at the sweet spots. Okay?" Facilitator gestured with both hands as if a pipe was resting on the thumb and index fingers of each hand.
Cam 1 Boys including Hugo &	Diego played two pipes, holding one upright in left hand a little above the "sweet spot" while tapping	As Hugo quietly tapped his other pipe, holding it near the node and smiling, Diego	"Can you come help me out, Diego?" Facilitator invited Diego to the front of the room.	Diego stood by, facing his classmates from the front of the room and smiling.

Diego (volunteer)	with the other. Hugo, who only held one pipe, also upright in the left hand, reached for one of Diego's. At first, Diego pulled it back and laughed, then gave it over.	reached over with his own pipe and tapped Hugo's once. He then turned to the front of the room. A moment later, the facilitator looked over.	Diego rose from his chair saying, "Yes, en inglés."	
Cam 1 Girls including Bianca & Maya	Bianca held one pipe vertically near the node with her left hand while tapping it lightly with the mallet, keeping her eyes on the facilitator.	Maya watched the facilitator. Without looking at Bianca, she took hold of Bianca's pipe and laid it on the table.	Bianca immediately picked it up again. Maya repeated the action, taking the pipe and setting on the table, this time sparing a brief glance directly toward her friend.	Bianca picked up the pipe again, and, again, Maya took the pipe saying, "stop." She then took all four pipes, and they chuckled. Both then turned their attention to the front of the room.

Aligning "felt" aesthetic experience with emergent science-rooted & personal identities

At this point, the facilitator began explaining what nodes are and how they function in a vibrating material, such as the pipes in students' hands. The explanation was both modeled and embodied. Having received the first signals of possibility when students struggled to produce sustained tones, and having explored on their own and in small groups, the students could hear and experience for themselves that finding the "sweet spots" signaled a subtle relationship between vibration and material. With Diego volunteering, the students were about to learn that each pipe had two nodes. They explored this idea, mimicking holding their own pipes at the nodes while watching Diego and the facilitator model the practice at the front of the room. At the same time, they began to negotiate the aesthetic value of the various sounds they produced. They began a pursuit of beauty, first encouraged by the facilitator in describing the workshop and attempting to make connections with their own aesthetic judgements.

Facilitator: First, um, can you put your fingers like this? [holding palms upright 6 inches apart, pinching thumb and forefinger together.] [Diego's hands were in his pockets and eyes were on his feet. Then he matched the facilitator's gesture while his friends smiled and chuckled.]

Facilitator: Perfect. Okay. Hold steady, okay? [He then placed the pipe on Diego's fingers as Diego laughed and glanced toward this friends.] First I will put the pipe on [pause]…Diego is holding it at points that are not sweet spots. [Diego slightly bent his knees and then stood upright in acknowledgment of not being on the nodes.]

Facilitator Now check this out. [He repeatedly tapped the center of the pipe causing "thunks."]

Diego: Muy feo. [Diego stated this playfully as he shook his head. The facilitator nodded in appreciation.]

Facilitator: Yeah, you couldn't really hear it, right?

Student 5: "I like that!" [stated definitively in swift counter-response to Diego's assessment.]

Facilitator: So now, I'll move you to the sweet spots. [As he repositioning Diego's hands until he held the pipe at the nodes, another student leaned forward for a better view.]

Student 6: Oh, yeah!

Facilitator: "Let's see what happens." [The room quieted briefly. The facilitator struck the pipe one time, and it rang in a sustained way.]

Diego: Hermoso. [He nodded and smiled at the facilitator with a knowing look who thanked Diego and let him return to his seat.]

Then everyone began, again, to explore in earnest. It is notable that their connection with the learning environment and available materials continued with gathering momentum. Rather than experiencing a loss of interest once the initial mystery was explained, the students continued to study patterns of sound and vibration personally, among peers, and through observations of other's approaches. When Diego returned to his seat, the boys in his group smiled at him in acknowledgement. Having explained that the nodes, or sweet spots, could be found one quarter length from either end of the pipe—which they had begun referring to as *keys*—the facilitator

encouraged everyone to play for a few minutes and suggested playing in pairs using both nodes. Hugo held his pipe at the node, and began to play rhythmically as a kind of performance for himself and the room. He danced along as he played, and the boys nearby began to pretend to play along (acting as if they were drumming their pipes together but not quite striking them…like playing air guitar). While others had been striking their pipes in the cacophony, this stood out as intentionally musical. This sound carried, and others across the room joined in, un-choreographed and seemingly unintentionally. For instance, a group of boys on the other side of the room, visible on Camera 3, were finding the nodes when one of them suddenly pretended to play the pipe in rhythm like a drum. This occurred as rhythmic sounds echoed from Hugo's pipes across the room.

These subtle processes of generating alignments between embodied sensory experiences, personal aesthetic preferences, and the discovery of new conceptions of relationships between sound, material, and environment positioned students in an emergent relationship with their own ways of knowing and validation of their practices in ways that related to the ways professional scientists experience, discover and explore the world. The satisfaction of new discoveries for the students was evident in their consistent drive to share findings, and their continued openness to receiving instruction that enhanced what they were already inclined to do in their explorations of material. For many of the students who participated in LTW workshops, recognized science identities seemed inaccessible, as described in pre- survey data. LTW opened student-driven opportunities for just-in-time feedback from their own practice, peers, and a pedagogical design that aligned their practices, strategies, and interests with what scientists do and what science aims to achieve. It was subtle yet meaningful.

Discussion

The design of Listening to Waves consistently brought students to awareness of a shared soundscape that was part of each of their daily lives, and therefore accessible and familiar. As with the start of typical classes, students quieted and oriented toward the facilitator, an act of respect that grants a limited use of the soundscape for the collective. The designed practice—to model the use of two small metal pipes to produce a sustained resonant tone and then to invite student after student to do the same—produced a shared response of wonder and curiosity. When everyone witnesses the same action and result and then, each in turn, fails to produce the same effect, the everyday nature of sound and material produces access to a new conceptual context, and in turn, a site of inquiry (see Table 2). In Table 2, we note the ways that observed practices began to overlap across four relational contexts students generated over time. It was collective experience that amplified curiosity that could power active engagement.

Table 2

Becoming an embodied collective in inquiry

Shared sensory environment	*Everyday materials repurposed*	*Personal curiosity validated*	*Social relations validated for learning*
Noticing a new conceptual opportunity			
	Everyday objects organize & coordinate attention		
		"Felt" ways of knowing guide interpretation & meaning	

As a connection was established between familiar experience and conceptual opportunity, students were subtly made aware that everyday objects presented renewed sites for learning about interactions between sound and materials as vibrations and then as waves. The subsequent modeled repurposing of everyday objects both as unexpected conduits for novel sounds and as an introduction to the world of waves that had previously been invisible, organized students' attention in two ways. First, it returned attention to their embodied experience of learning. They were free to touch, tap, blow, roll, slide, pluck, and generally manipulate everyday materials for aesthetic interest, guided by their own curiosity. Second, it validated their social engagements as part of their inquiry practices. They readily observed and adopted each other's strategies in their inquiry process. They invited both peers and teachers to join in their discoveries. They sought mutual recognition of the beauty and wonder they were discovering as well as validation of their practices for investigating the possibility and producing sound. As they shifted their conceptual awareness of the shared soundscape, and in turn, experienced repurposing everyday materials to explore vibrations and waves through varied materials, their personal curiosity, or lack thereof, and their social worlds became increasingly valid resources for pursuing their learning. Exploring together in person, in shared space, with this pedagogical design strategy functioned like an accelerant to making science-related experiences of the shared environment and, in turn, science-related identities accessible. We, in turn, conceptualized the notion of *harmonized mutual development* defined as a process in which individual explorations of a shared environment yield an increasingly integrated intellectual practice allowing individuals to

develop and mutually align their inquiries toward a collective practice of becoming, much like what is experienced by individual musicians who form musical ensembles.

Harmonized mutual development was a possibility we sensed as we observed during LTW. As we analyzed the data with a developmental frame, important aspects of students' participation were obscured. Rather than individual processes of internalization, we recognized mutual instances of becoming. When we can understand and clearly signal what harmonized becoming can look like, the competitiveness and stage-based performance demands can be lessened, and the whole group can move at an accelerated pace toward both content knowledge and access to alignment as a full participant in science worlds—not only to pursue careers, though that path is more available through removal of self or system imposed exclusion. Students can begin to move beyond identities like, "I'm just not a science person." Instead, young people can move into mutual engagements that amplify and accelerate sites of becoming. Here, we are concerned with the ways young people come into contact with science learning as a process of engaging their experiences in the world with sustained wonder, curiosity and an awareness of the presence of potential beauty. We argue that embodied collective inquiry generates conditions for harmonized mutual development.

Endnotes

(1) All names are pseudonyms.

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Disciplinary Design and Design Thinking in Scientific Inquiry

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Abstract: Design thinking (DT), strategies from engineering and business for designing, is gaining traction in education. However, little attention has been paid to how design heuristics and techniques may be domain dependent, particularly in cases where the designed artifacts address epistemic goals in disciplinary communities. In addition, authentically engaging in DT strategies may be challenging in classrooms where outcomes are focused not on students' novel solutions but acquisition of canonical content. This paper describes why we might anticipate DT to be generative outside of engineering and business contexts, and why we might anticipate that disciplines will have unique strategies for design as well. We present one case of a design generated by undergraduate students in scientific inquiry, with a focus on how design problems emerge and challenges and successes students meet in designing solutions.

Overview

Design thinking (DT) (Brown, 2008) is receiving increased attention in education in general (Razzouk & Shute, 2012), and in STEM education in particular (e.g., Li, et al, 2019; Goldman & Kabayadondo, 2016; Chin, et al, 2019). While models of design thinking exhibit heterogeneity, they all share an emphasis on methods for creating solutions to complex, real-world design problems for which there is no one "right" answer. The approach is promising for a range of reasons: the strategies of design thinking, as Chin, et al., (2019) point out, may help novice designers avoid "tendencies that can inadvertently interfere with effective design." In addition, design thinking in education positions students not as reproducing known solutions to acontextual problems, but as active participants in the construction of novel solutions to genuine problems sensitive to context. And while design thinking is an approach developed in engineering and then business (Razzouk & Shute, 2012) with the goal of improving designs of products for consumers, all disciplines engage in some form of design (e.g., Li, et al, 2019). Scientists, for example, could be considered uniquely adept designers of scientific models, experiments, and representations, to name but a few artifacts produced in the process of scientific inquiry.

At the same time, it's reasonable to expect that design thinking may require adaptations, as strategies for generating and evaluating designs may look quite different in different disciplines. For example, the emphasis placed on a "user-centered, empathy-driven approach" (Goldman & Kabayondo, 2019) is not as relevant to the experimental designs a scientist creates in a lab where the user is the scientist. Prototyping may look quite different for experimental designs where a rough design is often good enough. And constraints, often construed as material, financial or temporal, may instead be driven by disciplinary aesthetics, conventions and conservation laws. So while DT points out the importance of explicit attention to how disciplinary artifacts are designed, it is also the case that disciplines have unique techniques and attending to those is critical for developing design thinking in settings outside of engineering and business. The broad research agenda behind this paper is articulation of what disciplinary design thinking in science (particularly physics) looks like.

In science education research, a range of constructs make contact with DT. "Developing models," "constructing explanations," and "obtaining and communicating information," from NGSS represent designed artifacts. And these practices position students as designers: developing, constructing and obtaining. And so the strategies for meeting those standards may point towards design thinking processes that are productive in science.

But in most instantiations, these artifacts are not students' designed solutions to complex problems of science (e.g., Stroupe, 2014). Instead, curricula often expect that the students will recapitulate the "disciplinary core ideas" of NGSS. This seems almost inescapable. As Li, et al (2019), note, "design activity … can be easily perceived as creating new terms and procedures, activities often viewed as belonging to professional mathematicians and scientists, not students." This stands in contrast to an engineering course, in which it is not just *anticipated* but *expected* that design thinking will generate truly novel designed artifacts; science courses expect students to converge upon sanctioned solutions, as highlighted by Miller, et al (2018).

Novel design in scientific inquiry: Background and methods

The study takes place in a semester-long junior/senior undergraduate course on science research for future secondary STEM teachers (Atkins & Salter, 2015, Atkins Elliott, Jaxon & Salter, 2016). The broad goal of the course is engagement in scientific inquiry, which we define as the pursuit of coherent, mechanistic models of

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natural phenomena (Hammer & van Zee, 2004). We generally start with a puzzling phenomenon (e.g., a spring-driven clock) or question (e.g., is every color in the rainbow?), and, through mediated class conversations, small group work and individual work, make progress towards modeling the phenomena.

Over several iterations of the course, materials and designs made with those materials emerged as a critical, and undertheorized, aspect of students' activity. For the purposes of this research, we consider **design in science** as designed solutions to open-ended problems that arise in the pursuit of mechanistic models of natural phenomena. And we define **design thinking for science** as novel practices and strategies that support powerful and epistemically appropriate designs in response to those problems. Finally, the types of design challenges we are interested in are those that are **emergent from and in service of students' epistemic goals**. While designs need not be physical artifacts, for this paper we will limit our discussion to those.

We ask the following questions of these artifacts: **(1) When do opportunities for design in science emerge in students' scientific inquiry? (2) What challenges do students face in developing solutions to those problems?** and **(3) What "design thinking" strategies lead to productive design solutions in light of those problems?** In this paper we focus on the first two questions, and make conjectures for the third.

Research methods & definitions

Data: All class sessions are taped, artifacts and student work and lab notebooks are photographed, and field notes collected. To characterize extended periods of design thinking, we begin by identifying novel and complex designed artifacts, as described below, and then constructing design narratives around those objects.

Identifying designed artifacts: identifying a novel designed artifact is a gray area; even copied designs often contain some differences. For this study, we were interested in characterizing **designs that are prolonged, intentional, novel designs by students in pursuit of scientific problems.** We began by purposeful sampling, based on field notes and images, ultimately identifying 14 designed artifacts for closer analysis.

Design narratives: For these artifacts, the researchers developed, through field notes, images, and video, narratives of the designs. The narratives considered: initial design problems students sought to solve or goals for the artifact, its relationship to our ongoing modeling of phenomena, designed solutions, iterations and outcomes.

Designs in Scientific Inquiry

Below we highlight one example of design from the course: a design that is a novel, student-developed solution to an open-ended, emergent problem that also highlights tensions and challenges for productive design. Due to space limitations, we do not offer detailed moment-by-moment interactions that produced the designs, instead offering an overview of the driving questions, challenges and revisions that took place.

Corrugated surfaces: a series of designs to select between models

Context: This semester, the course focused on energy, beginning with the observation of a Gauss Gun: a simple arrangement of metal ball bearings and strong disk magnets. When an incoming ball is released, it accelerates towards the magnet, strikes it, and an outgoing ball is ejected at great speed. The sudden appearance of kinetic energy is surprising and begs explanation, and offers a rich context for modeling energy for a range of disciplines (Atkins Elliott, Sippola, & Watkins, 2018; Atkins Elliott, et al., 2019).

One student group argued that the magnet itself must supply the energy to the outgoing ball, and thus predicted that the ejected ball would leave at a higher speed than the incoming ball. Other groups disagreed. With a skeptical audience for their claim, the first group sought to determine the two speeds. Here, the design question of how to measure the speed of an object that gains and loses speed very rapidly became the core activity of their group over multiple weeks.

Designs: This group began by using a slow motion setting on their phone camera. However, the data was too blurry to make any claims; better cameras did not solve the problem. They then decided to slow down the "reaction" in a viscous fluid (syrup) and record this. While the reaction was slower, it was qualitatively quite different. They attempted to have the incoming ball fall just before striking the magnet and determine the speed from its trajectory, but the attraction was too great and the ball would not fall, but stick to the magnet. Motion detectors brought in from the undergraduate physics lab were not sensitive enough. The group then thought to roll the balls over a ridged surface and listen for a sound - anticipating that the audible "prtrtrtrtrtrt" sound would indicate speed and answer the question. After trying to use readily-available evenly-ridged surfaces (computer cds), which were not loud enough to analyze, they strung fishing line across a track at regular intervals, but the ridges were too far apart to capture changes in speed. This inspired them to 3-d print ridged surfaces.

The sound was not audibly different, and so the students went to a recording lab on campus. One student processed the waveform of the audio file, expecting that the peaks of the waveform would represent the

ball striking a ridge, allowing the group to calculate the time between strikes and therefore the speed of the ball. The waveform, however, was more complicated than expected, and peaks did not always represent the striking of a ridge. By this point, the other two groups in the course had convincing arguments against this group's model (relying on an argument from conservation of energy), and the group abandoned their efforts.

Findings & future directions

Opportunities for design in scientific inquiry

In the brief case presented above, and in most of the cases selected for our study, we notice the following relationships between scientific inquiry and design opportunities that address the above, *When do opportunities for design in science emerge in students' scientific inquiry?*

1. **Dissent can present a rich opportunity to engage in design**. When students developed different models of phenomena, they readily recognized that empirical evidence could serve as an arbiter, and turned conceptual problems ("which model best describes this phenomenon?") into design problems ("how do those models differ in observable ways, and how do I create that observation?"). We expect that it is not only the curiosity and/or confusion generated by competing models that drives students' engagement and persistence in the design (e.g., Watkins, et al, 2018), but social interactions as well: there is a genuine and skeptical audience for the claims they develop. In this way, the grasp of practice that Ford (2008) identifies, wherein scientists are constructors and *critiquers* of claims, is not imposed but emergent from the activity. Students are genuinely skeptical, even critical, of their peers' ideas and experimental designs -- driven by, and speaking to, that skepticism and critique -- offer a relatively objective arbiter.

2. **Designs themselves can generate novel design "sub"problems**. Nascent designs often contain components, some of which require their own (relatively self-contained) designs. In the example above, we see students who have the design goal of measuring speed with a slow-motion camera, engaged in creating a version of the experiment submerged in syrup. Later, the design problem was how to print a ridged surface.

3. **"Failed" designs generate novel design challenges.** Designs, of course, frequently do not fully work as anticipated. As Pickering (2010), notes, the world can offer "resistance," refusing to participate in anticipated ways, and requiring accommodations by the scientists in what he describes as the "mangle of practice." In this "mangle," we see students needing to change course, with novel designs or problems. The need to arbitrate between models became a need to measure speed, which was revised to be a way to measure sound. And designs frequently do not fully work as anticipated, with components requiring re-design.

Challenges encountered in addressing design problems

When we consider the second question, *What challenges do students face in developing solutions to those problems?* we note the following:

1. **Invisible content knowledge demands:** In the case presented here, students' designs would be strengthened or facilitated (or even obviated) by additional content knowledge. And while we value developing content knowledge in authentic contexts, where students' goals require developing the ideas, we note that students themselves did recognize their lack of knowledge (e.g., that white paper does not function as "nothing" but is reflecting the light back through the filter).

2. **Lack of familiarity with common tools or designs**: Seeing students struggle with long-solved problems (e.g., a ballistic pendulum for speed measurements), and contrasting this with their use of familiar tools (e.g., a 3-d printer), highlights the value of introducing tools, particularly ones that can be flexibly used in a range of scenarios.

3. **Lack of necessity for experimental designs:** Again, in the case presented here (and in several others) we note that there are strong scientific arguments to be made that would obviate the need for an experimental design. Frequently we see students readily turning what could be basic conceptual problems into complex empirical ones.

Disciplinary design thinking in science

We now offer some brief speculation on design thinking for science-- particularly in experimental design. First, we anticipate a tension, as noted above, between supporting students' own designs and building familiarity with standard practices that facilitate more complex designs. We also anticipate that attending to the role experimental design plays in selecting between models will require attention to statistical reasoning from data, which has not been a part of our course. Finally, we note that students often quickly engaged in constructing designed solutions when theoretical solutions (e.g., conservation of energy), which do not require additional empirical data, may be more efficient. Having more extended experience in design throughout their science

education may have prevented some of the theoretically and experimentally "clumsy" mistakes that students made in these and other design scenarios. It also positions students as designers of scientific ideas, who create authentic and unique solutions to scientific problems.

At the same time, we note that "failed," unnecessary, or inefficient designs are not synonymous with unproductive activity or a lack of progress; they can point students toward important theoretical ideas, reify those ideas in important ways, or strengthen connections between theory and evidence. Moreover, as noted in Pickering (2010), failed designs are common in science and part of the rich mangle of practice. Constructs in the math and science education literature, such as productive struggle (Warshauer, 2015), productive failure (Kapur, 2010), and invented science (Russ & Berland, 2019) highlight this distinction, and suggest further research to better articulate the value of engaging in design in scientific inquiry and identifying potential benefits and drawbacks of students' failed designs.

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Epistemic Commitments: A Lens for Heterogeneity in Science

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Abstract: Research about modeling emphasizes the importance of heterogeneity in science, yet also seeks curricular convergence. In response, we propose two constructs. *Heterogeneity-seeking curricula* emphasize multiple representations of phenomena, offering an image of science as messy and nonlinear. *Commitments* parallel epistemic cognition by focusing on values that shape students' modeling; however, rather than looking for disciplinary practices in students' modeling, we take students' values as a starting point to articulate commitments. Using commitments, we analyze six implementations of a heterogeneity-seeking 6th grade modeling curriculum, comparing commitments to epistemic criteria and considerations.

Objectives and significance

Research about modeling in science classrooms highlights the importance of heterogeneity in science learning (Rosebery et al., 2010), emphasizing the complexity involved in developing scientific expertise (Pierson et al., 2021; Jaber & Hammer, 2016; Manz & Suárez, 2018). At the same time, a growing body of scholarship seeks curricular pathways for convergence of epistemic and representational practices (Barzilai & Chinn, 2017; Berland et al., 2016; Reiser et al., 2021). In this paper, we amplify the productive tension between heterogeneity and convergence with two constructs. *Heterogeneity-seeking curricula* emphasize multiple perspectives of phenomena across representational forms. Though we acknowledge shared understandings are essential for classroom praxis, in a heterogeneity-seeking classroom, knowledge products constitute an emerging, shared vocabulary that gives voice to students' ideas and questions rather than being end-points of inquiry. *Commitments* offer a lens for exploring the values that motivate and inform students' interactions with models and with one another. Our notion of commitments, paralleling epistemic cognition, focuses on students' values. However, whereas epistemic criteria (Pluta et al., 2011) and considerations (Berland et al., 2016) look for disciplinary practices in students' modeling, commitments take students' values as a starting point, mapping them to disciplinary resources that are sometimes overlooked in classrooms. These constructs offer lenses for noticing and capturing the discursive life of models in a classroom community by emphasizing students' values and ideas, problematizing how phenomena have been positioned as objective and external to students' modeling work (Reiser et al., 2021), instead showing them to be a production of the classroom's discourse.

Conceptual framework

Though "commitment" has been used in varying ways (e.g., Chinn et al., 2011), we conceptualize commitments as fine-grained resources (Hammer et al., 2005) that shape how students use, value, and learn from models. From a resource perspective, commitments are activated and expressed by individuals in response to conceptual and social contexts (Elby et al. 2016). Yet, commitments do not reside solely in individuals; at a group level, emergent epistemologies are jointly constructed and reconstructed from resources within communities of practice (Goodwin, 2018). As a result, individuals can enact and display sometimes-conflicting commitments (Clark, 2006; diSessa et al., 2004), including those that represent their membership in multiple communities (Bang & Medin, 2010). We propose that commitments can function in some similar ways to the "ideals" of the apt-AIR epistemic cognition framework (Barzilai & Chinn, 2017), though their role for researchers and for students extends beyond epistemic cognition. As an analytic lens, epistemic cognition frameworks take disciplinary values as a starting point, searching for forms of these values in students' work (e.g., Berland et al., 2016). In contrast, commitments take students' values as a starting point (identifying students' values and mapping these commitments to disciplinary constructs). This perspectival shift opens analysis to a wider range of students' resources that may not align with science education's normative conception of disciplinary values. We distinguish between these lenses in three ways. First, because commitments emerge from students' modeling activities, they include material and phenomenological aspects that are backgrounded in research about epistemic ideals. Second, while some commitments in our data aligned closely with primary epistemic ideals, others would be considered "secondary," "vague," "nonepistemic," or "less sophisticated" using existing frameworks for epistemic criteria (Pluta et al., 2011) and practical epistemologies (Berland et al., 2016). Third, commitments played different roles for students' modeling than epistemic ideals; rather than only being used to evaluate models, commitments were also used (a)

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to explain why or how one model should inform another, (b) to position models as complementary, and (c) to relate models to broader contexts. In the context of this heterogeneity-seeking curriculum, we use a resource-focused lens to ask two research questions: What commitments emerged that influenced students' modeling? and, How can a lens of commitments help science education researchers identify and analyze students' values and their role in modeling?

Method

We analyze data collected during a design study (Cobb et al., 2003) that iteratively refined a modeling curriculum about ecosystems. This study was conducted in a public middle school in a small suburban school district in the southeastern US in collaboration with a STEM teacher, Ms. S. Six of Ms. S's 9-week 6th grade classes participated (August 2018 to March 2020, 105 students total). From each class, 5-6 students were selected by the 6th grade teaching team as representative of their peers, and these students were interviewed about their experiences in the unit. All iterations of the curriculum foregrounded modeling. Throughout the unit, students were instructed to create diagrammatic, physical, computational, and embodied models. The unit was framed by two design challenges: students designed a biosphere, a closed-system physical model that included plants, snails, and guppies (a typical pet fish in the US); and they programmed a computational model that represented a larger ecosystem of plants, snails, guppies, and guppies' competitors and predators. Throughout the unit, the students gathered information and iteratively re-represented the guppies' environment with increasing complexity. We analyze focal student interviews and whole class discussions to identify students' commitments and how they shaped students' modeling using inductive coding (Charmaz, 2006). To identify commitments, we transcribed interviews and whole class discussions with turns of talk as the unit of analysis. We created initial coding categories in part based on students' language (e.g., "real world"). We compared these categories to studies of professional science and to research about epistemic ideals in science classrooms. In this paper, we have grouped commitments into categories (see Findings). This structure is not hierarchical (no commitment is considered more "sophisticated" than the others), and these commitments could be named and organized in a variety of ways; thus, rather than focusing on the relationship between these four commitments, we focus on the nature of these commitments and their role in a heterogeneity-seeking modeling curriculum.

Finding: Commitments

In interviews, most focal students (26 out of 33) valued connecting their models to the **"real world."** This commitment maps to several epistemic criteria. From Pluta et al. (2011), it maps to the primary criterion of "accuracy" ("how faithfully the model depicts the target") and the secondary criterion of "realism" ("use the word real"). In prioritizing representing the real world, some students' responses also map to the primary criterion of "explains-2" (Pluta et al., 2011), because they value models that "show how and why" (Carlos: "how a giant biosphere works"). From Berland et al. (2016), valuing models that "show how and why" addresses the question, "What kind of answer should our knowledge product provide? (Nature [of account])" (p. 9). Explaining "how and why" suggests a mechanistic account, which Berland et al. have characterized as "more powerful" for constructing and evaluating knowledge" (p. 13) compared to a descriptive account (Carlos: "tell how it looks like"). In contrast, in our data, students did not always prioritize mechanistic accounts; for example, Caleb wanted to explore a descriptive question: how much oxygen a guppy needs.

A majority of focal students (24 out of 33) also valued models that could **"show"** phenomena to themselves or others. The commitment to seeing and showing phenomena maps to several epistemic criteria. Like the commitment to real-world, seeing and showing in some cases connects to "explains-2" (Pluta et al., 2011) and "Nature of Account" (Berland et al., 2016), because students valued models that showed mechanistic explanations (e.g., Nora: when algae are spread out, guppies die faster) although they sometimes also appreciated descriptive accounts (e.g., Nora: "more environmental" food web representation). This commitment also connects to "clarity" ("model is easy to understand;" Pluta et al., 2011, p. 496) and "audience" ("Who will use our knowledge products and how?"; Berland et al. 2016, p. 9).

Several focal students also valued models that enabled them to **"control"** variables by holding them constant or to "change" variables by manipulating them (15 out of 33). This commitment overlaps with several epistemic ideals about evidence; however, whereas these epistemic ideals are primarily evaluative, students in our classroom typically foregrounded controlling and changing variables when they were designing models. In a convergence-seeking curriculum, students might evaluate a model by considering the quantity and quality of evidence that was included ("quality of support" and "accuracy" in Pluta et al., 2011; "Nature of account" and "Justification" in Berland et al., 2016). In retrospective reflections, students' commitments functioned in a similar, evaluative way (e.g., Carlos: "it was kind of like testing soil differently"). Yet, as they were designing or using models, students more often emphasized affordances for investigations (e.g., David: "the computational model

won't go wrong unless you tell it too"). This forward-looking stance toward models positions models not only as "knowledge products" that can be evaluated but also as generative tools for exploring ideas.

Over half of the focal students (18 out of 33) voiced a sense of responsibility to **care** for the plants and animals in their biospheres or for the species or environments represented by their models. Caring for model components and their referents influenced how students thought about designing, using, and learning from models. There is no analogous epistemic ideal in Pluta et al. (2011) or in Berland et al.'s (2016) epistemic criteria or considerations. While Barzilai and Chinn's epistemic cognition framework includes affective and ethical dimensions (e.g., "caring about… epistemic performance" and "aspiring to epistemic justice;" 2017, p. 13) based on research that demonstrates that science learning is inextricably intertwined with students' *epistemic* affect and *epistemic* motivation (Jaber & Hammer, 2015), these aspects are narrowly focused on the production of (disciplinary) knowledge rather than broader axiological dimensions of learning.

Discussion: Nature and role of commitments

In these classrooms, commitments functioned as resources (Elby et al., 2016; Sandoval, 2005). Students' commitments were pressing but unstable (interpreted and enacted differently by different students and by given students at different times). Commitments were also linked to models in a perspectival, rather than an inherent, way (took on different meanings for different students in relation to models). As a result, commitments were not a "property" of models or of students – they instead influenced how students valued and interacted with their models. In our data, commitments functioned in *some* ways like epistemic ideals by acting as evaluative resources during modeling. Yet, because each of these commitments connects to different, yet overlapping, aims, commitments were not hierarchically ranked. As a result, we would not expect to see students' progress toward "sophisticated" (Krist, 2020) or "primary" (Pluta et al., 2011) commitments, as they might with epistemic ideals. And because commitments were not stable across models, we also would not expect to see students develop a shared set of criteria that could be used to evaluate models generally, an activity common in convergence-seeking curricula (Pluta et al., 2011; Ke & Schwarz, 2021). Instead, a lens of commitments emphasizes making connections across multiple representations and ways of knowing (Warren et al., 2020).

First, students used commitments to justify one model informing another. For example, Karla suggested using the plant investigation to inform the computational model. She explained that students "did not really use [the plant investigation] as much as they needed to" to make the computational model "accurate with real life." In other words, she wanted to use the plant investigation to strengthen connections between the computational model and the ***real world***. In other cases, students saw the computational model as informing the design of "real" models. For example, Nataly used her computational model to imagine the guppy in her biosphere jar; her commitment to ***caring for*** the guppy helped her empathize with the guppies. Because she was concerned that the computational guppy looked lonely, she suggested her group include two guppies in their jar.

Second, students used commitments to position models as complementary–by connecting their own models (of different types, e.g., computational, food web), and also by connecting their models to their classmates'. For example, Lacie characterized all her models as "helpful because, like, you can find out different things." She described how she could ***change variables*** in the computational model ("make guppies do what you want them to do) and explained how she could ***show phenomena*** in the food web ("helps you show, like, what they're gonna eat"). Students also positioned models of the same type as complementary. For example, when Nora and Sean presented their food webs, rather than positioning one model as correct, they described how each group's model ***showed*** different perspectives of ecosystems (Nora's "energy pyramid" and Sean's "more environmental" model). Just as commitments were not ranked hierarchically, models were not seen as competing with or replacing other models. Instead, each model offered new perspectives that contributed to an assemblage of representations that became more valuable as models and perspectives were incorporated.

Third, students used commitments to relate their models to other experiences. For example, Wade wanted to give the plants "a chance at life," and Dolores and Hunter suggested that the biospheres could teach guppies how to "survive on their own in the wild." In these cases, a commitment to ***caring*** guided how students interacted with their models. Commitments also helped students think about why models might be used to investigate phenomena. For example, Micah explained that a scientist would need to "test the stuff on the computational model and do it in real life [in a biosphere] to see how the effects would turn out… so you don't mess up the river," explaining how the models could be used to protect ***(care for)*** populations in a river. As in these examples, students' commitments helped them consider the roles of models in the outside world.

In summary, while commitments aligned in some cases with epistemic ideals, their roles in these classrooms extended beyond those of epistemic ideals. Epistemic ideals are used to evaluate models. They support convergence-seeking aims by providing students with agreed-upon standards for developing and assessing knowledge. To this end, they guide students in creating mechanistic and "gapless" explanations (Ambitious

Science Teaching [AST], 2014, p. 3), producing abstract and generalizable knowledge (Berland et al., 2016), and justifying claims with evidence (Krist, 2020; Pluta et al., 2011). These are important goals for epistemic education (Barzilai & Chinn, 2017) that can help students appropriate powerful disciplinary practices. However, exclusively foregrounding these goals for epistemic education could limit the values that students use to navigate their STEM learning. Our data indicate that students can draw on a broad range of values to guide modeling, which sometimes resemble professional practices that are backgrounded in science education.

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Multimodal Data Fusion to Track Representational Flexibility of Adolescents with Autism Spectrum Disorder during Virtual Reality-Based Training

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Abstract: We implemented multimodal data fusion to develop a prediction model tracking representational flexibility (RF) of adolescents with autism spectrum disorder (ASD) in virtual reality (VR)-based training. RF is a key competency related to individuals' capability to select, coordinate, and create alternative representations inherent to STEM subjects. To promote ASD adolescents' RF development, research has used VR-based 3D simulation design tasks. However, it remains a challenge to track ASD adolescents' RF development during VR-based training. Using supervised machine learning, we implemented decision-level data fusion with RF evidence from multiple data sources. To train the model, we used a total of 178 audio- and screen-recorded VR training sessions of eight ASD adolescents. We compared model performance metrics of several candidate classifiers. Methodological details, findings, and implications of multimodal data fusion will be discussed.

Keywords: Multimodal data fusion, virtual reality-based training, autism spectrum disorder, representational flexibility

INTRODUCTION

Adolescents with autism spectrum disorder (ASD) are underrepresented individuals in STEM education. ASD features developmental delays that include cognitive and social skill challenges that cause difficulty in STEM education. ASD learners typically lack representational flexibility (RF), which is a competency related to individuals' ability to choose and execute various representations inherent to STEM subjects. Researchers stated that RF leads to deeper understandings of multifaceted and complex tasks in STEM education. However, they have difficulty in developing RF. Recent research has introduced virtual reality (VR)-based training to foster ASD adolescents' RF development. VR enables students to experience various 3D design tasks and these design tasks can foster students' representation practices. However, it remains an open question regarding how to track ASD adolescent's RF development during VR-based training. Given that ASD adolescents' cognitive-affective states are dynamic, it is essential to track their needs to provide ASD adolescents with timely and adaptive learning supports during VR-based training. There is a lack of empirical research tracking ASD adolescents' multimodal interactions during VR-based training. This study aims at developing a prediction model that tracks ASD adolescents' RF development using a multimodal data fusion approach. The primary research question is: how does multimodal data fusion predict ASD adolescents' RF development during VR-based training?

Literature Review

Representational flexibility in integrated STEM education

RF is an individual's cognitive capability to switch attention and choose different modes of representations for knowledge comprehension (Herbert & Hayne, 2000). RF enables an individual to understand, reproduce, and apply knowledge to adjust problem-solving behaviors and solutions to surrounding circumstances. STEM practices typically require students to perform knowledge synthesis and application through multiple rounds of problem-solving. Enhanced RF enables students to better select and compare various representations aligned with design tasks. Researchers state that ASD adolescents' low RF explains their difficulty in academic achievement in STEM education (Moon, Ke, & Sokolikj, 2020). It relates to their difficulty in identifying, executing, and evaluating design task features during problem solving. It may subsequently lead to disengagement, as evidenced by ASD individuals' dynamic cognitive-affective states.

Virtual reality-based training for learners with autism

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Virtual reality (VR) has been used to promote cognitive and social skills development of ASD individuals, by fostering ASD learners' engagement and immersion (Parsons & Cobb, 2011). VR can act as a promising platform for promoting ASD learners' RF development. VR enables ASD learners to choose and compare various representations as 3D stimuli at a high degree of learner control. Recently, Moon et al. (2020) implemented VR-based cognitive skills training that engaged ASD learners in a variety of virtual engineering design quests (i.e., designing elevation bridges to fulfill different environmental and social contexts). In another study, Ke and Lee (2016) provided ASD learners with VR-based design-problem solving tasks. They examined whether and how the tasks promoted design-oriented interpersonal discussions to develop ASD children's perspective taking skills and RF. Despite the emerging uses of VR-based interventions for ASD youths, there is a lack of empirical research on VR-based learning assessment. Because VR-based learning interventions are dynamic, it is vital to track students' real-time behaviors. Considering ASD adolescents' developmental features, they are likely to experience dynamic cognitive-affective states during VR-based training. Automatic assessment will then help to drive adaptive learning support.

Data fusion in education research

Research has increasingly proposed the usage of data analytics to track students' learning. Research demonstrated a variety of computational techniques for the automatic assessment to track behavioral evidence of learning. For example, Moon et al. (2020) developed a prediction model that detects ASD adolescents' RF development using supervised machine learning. They collected ASD adolescents' verbal utterances related to RF facets and trained a classification model. Several other studies used computer logs to build a prediction model. However, there is a limitation with the current prediction models tracking learner states. They relied on mostly a single data source. Considering that VR is designed to foster students' multimodal interactions, predicting students' learning states from a single data channel appears limited. Research reported the advantage of multimodal learning analytics (MMLA) to track students' behaviors in highly-interactive digital learning environments (Worsley & Martinez-Maldonado, 2018). MMLA aims at leveraging and predicting student learning by merging and interpreting multiple data inputs with computational techniques (Worsley & Martinez-Maldonado, 2018). Among many approaches in MMLA, multimodal data fusion is a method systematically integrating more than two different data sources. Henderson, Rowe, Paquette, Baker, and Lester (2020) conducted multimodal affect detection by collecting and fusing different types of student trace data in game-based learning for medical training. However, little research explored the feasibility of multimodal data fusion design, integration, and implementation in VR-based training.

Method

Data

We used a total of 178 audio- and screen-recorded 1-1.5 hour VR training sessions of eight ASD adolescents. Study participants participated in VR-based training (Moon et al., 2020) that contains multiple design quests (i.e., elevation bridge design and non-player character design) aimed to promote ASD adolescents' RF development. We sampled students' behavior data from two VR-based training modules (Figure 1). In the first module the participants were requested to build a mechanical bridge that allows island residents to move their cargoes without ships. In the second module the participants developed interactive NPCs by editing block-based computer scripts. The participants joined multiple rounds of training sessions and their behaviors were automatically logged in the virtual environment. In each training session, students had to investigate the surrounding natural and social contexts in the virtual scene, decompose design problems, prototype 3D design solutions, and conduct iterative tests. We collected two types of data: (1) video recordings of students' avatar behaviors during VR-based training, (2) computer logs that recorded students' training actions.

Data Wrangling

We carried out multimodal data fusion by blending two different types or modalities of data when predicting the states of RF enactment. Specifically, we used a late fusion approach (Meng, Jing, Yan, & Pedrycz, 2020) that classifies each modality results before fusing the outcome results. A late fusion approach merges the average confidence values of sub-decisions on classification and then determines the final classification result.

There are four data-wrangling steps for the multimodal data fusion. Figure 2 portrays the data fusion process implemented in this study. First, we collected two types of data: (1) speeches and (2) behavior logs collected from study participants. Student speech data was their verbal utterances in relation to RF development during VR-based 3D design activities. To collect students' speech data, we audio- and screen-recorded every training session. Computer logs of students' behaviors in VR were also automatically recorded. Second, we

conducted expert labeling to create benchmarking classification results of students' RF enactment prediction. There are four facets of RF enactment: (1) attention switching/cognitive shifting, (2) alternative representation, (3) pattern development, and (4) pattern contextualization (Table 1). We used a coding scheme that was iteratively tested and validated through multiple studies (Moon et al., 2020). The coders independently labeled RF facets, then compared and discussed their results until reaching 100% interrater agreement. Third, we converted students' speech and behavior data to a dataset for the training of the prediction model. Using a speech-to-text converting application, we transformed students' entire speeches to text data. For data conversion, we also used the LightSIDE that conducted text vectorization (Mayfield & Rosé, 2013). In terms of behavior logs, we converted students' behavior data to the frequency of each behavior feature. Based on the expert-labeling results, we conducted separate machine-learning classifiers with the two data sources (i.e., speeches / behavior logs) to compute the estimated probability scores of RF facets. Throughout candidate classifier evaluation, we chose random forest because it showed the best average prediction performance than the other classifiers. Fourth, we arranged the metadata of the collected data sources by time interval during VR training. Students' entire training session data was divided by the time interval, resulted in a total of 1,441 data instances for model development. We then implemented the classifiers using confidence-based fusion from respective data sources at sub-decision level. We then computed the final prediction results of RF by averaging the confidence scores from the sub-decision classifiers of two data sources. We pre-set a threshold condition as higher than 50%. Last, we evaluated the prediction results between the two respective data sources and the fused one to investigate whether multimodal data fusion improved the prediction performance. We evaluated each classifier's performance using the metrics as follows: AUC, F1 score, and precision. AUC is a performance metric to check whether a model can accurately distinguish between positive and negative classes. F1 score is a weighted average value of the precision and recall. Precision is the ratio between the number of positive cases correctly classified and the total number of positive cases. We have also tested several methodological features to refine the classifier settings—data imputation and splitting when training and testing a model. In terms of data imputation, we use the algorithm k-nearest neighbor (kNN). The goal of data imputation was to replace missing values of the input data in the prediction models. We set the ratio of training (80%) and testing (20%) data for model training. During the data fusion process, we found a potential imbalanced data issue in the training data set. Data imbalance indicates that data distribution is skewed so it is necessary to deal with imbalanced features through a computational technique. We used a synthetic minority over-sampling technique (SMOTE) that performs resampling by creating new data points of minority class.

Figure 1

Training Module Examples (Left: Elevation bridge design, Right: NPC design)

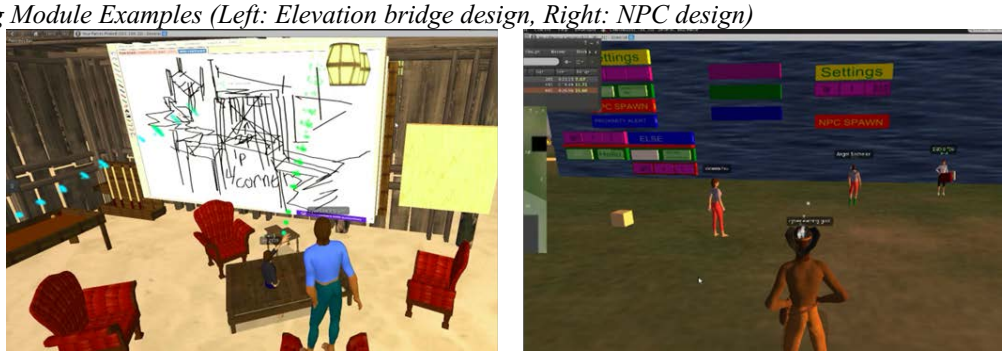

Figure 2

Multimodal Data Fusion Implementation

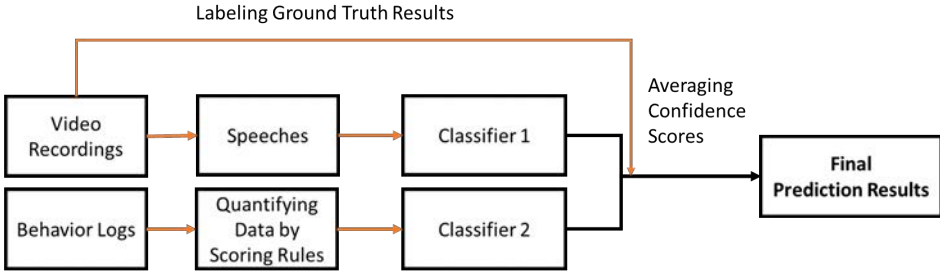

Table 1

RF Facets (Moon et al., 2020)

RF Facets	Definition
Attention Switching / Cognitive Shifting	Ability to switch attention or action based on changed rules and contextual demands
Alternative Representation	Ability to identify and apply multiple representations
Pattern Development	Ability to identify and delineate a pattern / rule during design problem analysis and solving
Pattern Contextualization	Ability to identify an implementation context of the endorsed pattern or customize the pattern based on a novel implementation context

Results

The results show that multimodal data fusion improved the overall performance results of the fused classifiers. Specifically, the fused classifier yielded the best performance scores (i.e., AUC, F1 Score, and Precision) in tracking all RF facets. The fused model performance in the NPC design module was generally better than that of the elevation bridge design module. A possible reason of this result is that the training data set in the NPC design module contains more student speech and behavior log data than that in the elevation bridge module. When examining the methodological features of the selected classifiers, we found the optimized number of trees in random forest classifiers (n = 20), pruning condition (confidence level = 30%), and oversampling parameters (the number of neighbors = 20) yielded the best prediction performance.

Conclusion and Future Research

The result of this study suggests the usefulness of multimodal data fusion in tracking RF during VR-based training. This study finding should inform on the design and implementation of MMLA in immersive learning environments. There are multiple future research directions. First, we will examine the applicability of dimension reduction techniques in developing a prediction model. Although the current prediction model has integrated multimodal data fusion, we did not evaluate which data features are best predictive of different RF facets. Therefore, it is worthwhile to implement dimension reduction to avoid data noises to make a prediction model efficient. Second, the present prediction model of this study only focused on detecting the positive occurrence of RF facets. Future research will build a prediction model that tracks both positive and negative cases of RF in VR-based training.

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Analyzing the Influence of Student Problem Solving Approaches on Learning Through Teaching in Mathematics Education

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Abstract: While previous research has examined what students learn as they agentically solve mathematics problems, less is known about what teachers learn through this process. We use this paper to address this oversight by analyzing interviews, lesson plans, and video observations of five novice elementary and middle school math teachers as they taught between six and eight lessons each. Findings reveal that teachers who rely on prescripted approaches more regularly developed knowledge related to classroom management and climate. Alternately, teachers who allowed students to agentically solve problems more routinely developed a deep understanding of students' mathematical thinking. This study therefore contributes to extant learning through teaching literature by illustrating how pedagogical choices directly affect what teachers learn within these approaches.

Introduction

As Nieminen et al. (2021) and others argue, allowing students to solve well-designed mathematics problems on their own (rather than teachers frontloading solution processes for students) leads to deep and meaningful student learning related to both mathematical content knowledge and socioemotional skills. However, less is known about what teachers learn when engaging students in this process. In response, we use this paper to address the following research question: what types of knowledge do teachers develop when using prescripted or open-ended pedagogical approaches? To address this question, we present empirical data from a study of early-career elementary and middle school math teachers. Our emergent analysis of this data reveals that teachers who employ student-driven problem-solving approaches more frequently develop knowledge related to the mathematical thinking of students while teacher-driven approaches primarily result in knowledge development related to general pedagogical concerns. This paper therefore contributes to extant learning through teaching (LTT) literature by providing a nuanced understanding of learning that occurs through these divergent pedagogical approaches.

Theoretical context

According to Sherin (2002), LTT exists as a critical and at times intractable aspect of developing as a teacher. Previous studies have uncovered a wealth of value within LTT as teachers have developed both discipline specific content knowledge (CK) (Elmendorf, 2006; Leikin, 2006;) and pedagogical content knowledge (PCK) (Perkins et al., 2015; Zazkis & Mamolo, 2018) through this learning process. In terms of the mechanisms through which LTT occurs, Schön (1987) describes a simple three-part framework that encompasses LTT: planning some sort of lesson or learning experience, implementing that plan with students, and then reflecting on the results. Since its publication, multiple scholars have elaborated on these three steps and provided a greater sense of detail within each element. Simon (1997), for instance, describes the planning stage as one in which teachers produce prospective learning trajectories for students that involve learning goals, proposed tasks, and hypotheses as to how the learning process will unfold.

Focusing on mathematics education specifically, LTT research has interrogated all phases of Schön's process to better understand how math teachers develop both CK and PCK when teaching. In doing so, Leikin (2010) notes that not all pedagogical tasks embody the same potential for LTT. Instead, some math lessons, especially those that create space for students to respond in new and unexpected ways, create significantly more opportunities for teachers to learn through the act of teaching. Additionally, Leikin (2006) found that teachers often develop both CK and PCK by creating new lessons and anticipating students' responses. These two practices within the planning process enable teachers to deeply engage with content in often unexpected ways. Yet despite these findings, what teachers learn when enacting lessons that rely on either student-driven problem solving or whole-group instruction, and how that learning compares, remains under explored in the literature. In response, we turn towards new empirical findings related to LTT within both pedagogical modes.

Methods

We collected the data used in this study for a larger project that investigated how novice middle school and elementary mathematics teachers' PCK develops through teaching (see Table 1 for demographic information).

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The teachers created 3 to 4 sets of 2-day lesson plans to teach a math concept. This 2-day lesson plan included teaching and assessment tasks, anticipated solution strategies from students, the underlying mathematical thinking for these strategies, and expected instructional strategies. By asking for these components, we aimed to capture teachers' knowledge of students' mathematical thinking and their mathematics teaching, two important elements of pedagogical content knowledge (e.g., Ball et al., 2008; Shulman, 1986). We then conducted a set of three structured interviews for each cycle of 2-day lesson plans (one pre interview and another interview after each lesson) as a means of investigating teachers' learning from their teaching. Additionally, we asked teachers to videotape themselves teaching one of the planned lessons. By including lesson plans, interviews, and videos of classroom practice, we were able to check the alignment between the planned lesson and the enacted lesson and ensure validity of our analysis through triangulation (Denzin, 2012).

Table 1
Background Characteristics of Participants

Teacher ID	Gender	Race	Years of Math Teaching Experience	Years of Teaching Experience	Lesson Plan Cycles Included in Study
Xavier	Male	Black	2	2	3
Daniella	Female	Multiracial	2	3	3
Linda	Female	White	1	3	4
Hanna	Female	Multiracial	0	0	3
Mike	Male	White	2	2	3

Once collected, we coded all of the data using the coding scheme developed by Fredericksen et al. (1998). In their analysis of teacher assessment practices, the authors divided the criteria for high quality teaching into four broad categories: pedagogy, climate, management, and mathematical thinking. For the purposes of this initial analysis, we consider teacher knowledge and self-reported learning related to each of these (for instance, do the teachers show evidence that they possess knowledge of their student's mathematical thinking?). Additionally, we coded for evidence of student-driven problem solving and teacher-driven instruction (i.e. the teacher shows the entire class how to solve the problem). Definitions of each code can be found in Table 2. To ensure reliability, we employed the consensus building process described by Harry et al. (2005): all data was coded by both members of the research team independently and then any disagreements on code applications were "debated and clarified until the group agreed on appropriate usage of the set of codes" (p. 6). Although we do not include analysis of the lesson plans or video observations here, we used these other forms of data to verify our coding of the interviews. More specifically, we looked for both moments of alignment and disagreement between what teachers were describing and what they showed in their lesson plans and while they were teaching. No significant disagreements were found. We therefore believe that the interview data accurately represents participant knowledge.

Table 2
Code definitions and examples

Code Name	Definition	Example
Knowledge codes		
Pedagogy	"The teacher shows a mastery of different instructional techniques and adapts them to students' backgrounds and abilities." (Frederiksen et al., 1998, p. 233).	"The solutions are presented to build upon students' conceptual understanding of the relationship between multiplication and division. The first solution is most accessible to students because it provides a visual model and as the solutions build upon each other, they eventually lead to the learning goal of explaining the relationship between multiplication and division and applying it to fractions."
Climate	"The social environment of the class empowers learning" (Frederiksen et al., 1998, p. 233).	"We talked about perseverance with difficult problems, and always trying to learn more. In their reflection, they drew little blobs, like 'fixed mindset: it's like a burned out-lightbulb,' and then 'growth mindset: it keeps on shining.'"
Management	"The class runs smoothly and efficiently." (Frederiksen et al., 1998, p. 233).	"I was walking around the room while they were doing the partner activity in addition to redirecting. I was also watching what they were doing. And I was seeing if they were setting up their ratios correctly and I also collected their work as well."

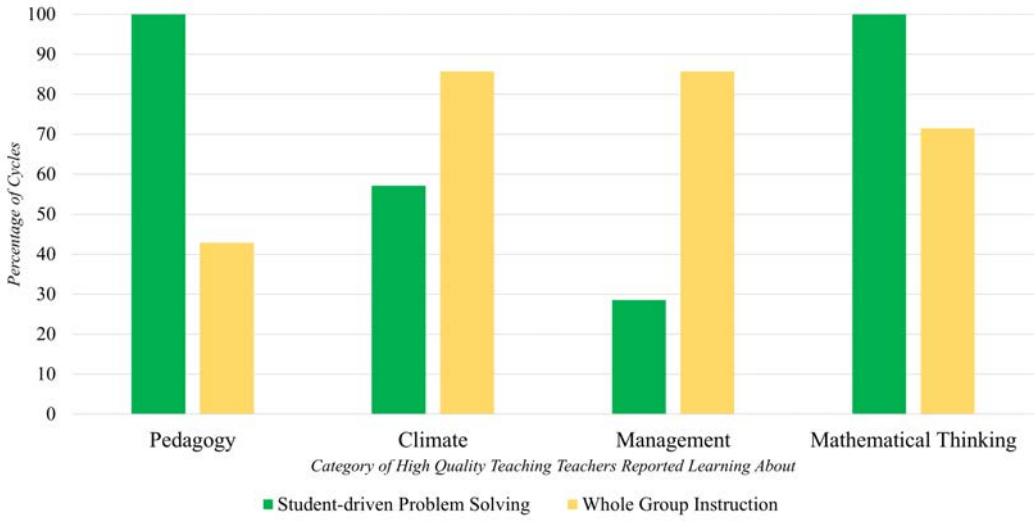
Mathematical Thinking	"A central goal of the class is to promote mathematical thinking among all participants" (Frederiksen et al., 1998, p. 233).	"Regrouping is really hard for 5th graders. I'm still learning how difficult it is for them to connect the same concept across different types of numbers. They can explain regrouping with whole numbers brilliantly and they can even do that with decimals. I think just because it's not a set place, like the fractional part, they're just not making that connection.
Problem solver codes		
Student-driven problem solving	When working on a new problem, students are able to try and solve the problem however they see fit.	"I like them to see what they know on their own and really investigate before I tell them how to do it. It just kind of lets them make connections on their own then."
General teacher-driven problem solving	The teacher shows the entire class how solve the problem presented to the class.	"The biggest thing is the process and multiplication. Are they following the process? Are they doing it exactly the way we have it on our note sheet? When we reference those notes, all they have to do is put in their numbers."

Findings and discussion

Through this analysis, we found evidence of teacher's knowledge development related to all four criteria for high quality instruction defined by Fredericksen et al. (1998) (see Table 2 for examples). Additionally, we found that 2 of the teachers (Linda and Hanna) overtly relied on student-driven problem solving while the other 3 teachers (Xavier, Daniella, and Mike) primarily used whole-group instruction in each class. In comparing these two sets of codes, however, we also discovered that how teachers reported learning related to Frederiksen et al.'s (1998) four categories were not evenly distributed (see Figure 1). In particular, the teachers who structured their classes around student-driven problem solving reported learning about pedagogy and mathematical thinking during all 7 of the 2-lesson cycles they taught during this study (100%). By contrast, teachers who focused on whole group instruction only reported learning about pedagogy during 3 of their 9 cycles (42.857%) and mathematical thinking during 5 of their 9 cycles (71.429%). In considering the other two categories, the relationship reversed. Teachers who focused on whole-group instruction reported learning about both management and climate during 6 of their 9 cycles (85.714%). The student-driven teachers only reported learning about management during 4 of their 7 cycles (57.143%) and climate during 2 of their 7 cycles (28.571%).

Figure 1

Evidence of Self-reported Learning by Pedagogical Approach



Based on these findings, we contend that a teacher's choice to position either the student or the teacher as the problem solver within a classroom environment could hold significant implications for what teachers learn when teaching. This study then builds on Leiken's (2010) assertion that teachers have greater opportunity to learn when students can respond to problems in new and unexpected ways. Specifically, our analysis provides a focus to previous research by unearthing the kinds of knowledge that teachers construct (and recognize as learning) in

these interactions: by allowing students to complete tasks on their own (and guiding students through that process), teachers more frequently develop PCK and learn how students think about mathematics. Conversely, the teachers who relied on whole group instruction more prominently recognized the learning they did related to general pedagogical concerns (management and climate). One possible cause of this diversion may be that teachers who merely present solution processes to students do not engage in interactions related to mathematical CK (or do so with lesser frequency) and instead focus on general pedagogical processes unrelated to content.

Taken together, these findings extend the work of Schön (1987) and Simon (1997) by considering how the act of planning not only engages teachers in LTT but shapes future contexts where LTT occurs. In choosing between a teacher-driven and student-driven approach to problem solving, teachers also decide between what they can expect to learn. In future iterations of this project, we will continue to refine our analysis by further specifying the types of knowledge teachers gain in different teaching contexts while simultaneously unearthing learning mechanisms that allow for this development. Future research should also continue to develop a nuanced understanding of the relationship between pedagogical models and LTT.

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Investigating Students' Memory for Feedback in a Naturalistic Classroom

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Abstract: The purpose of the present study was to examine students' memory for academic feedback in a naturalistic classroom setting. We investigated whether introductory applied psychology students had differential recall for four types of feedback. Students completed an activity, were given authentic feedback on their assignment, and recalled that feedback one week later. Findings suggest that students had the lowest recall for the two types of feedback that theoretically stand to benefit them most. Overall, students' recall across all feedback categories was very low compared to the amount of feedback units given by the instructor. We also saw a pattern of students "transforming" the more generalizable feedback they originally received to more task-specific feedback at recall. Practical implications of these findings are discussed.

Introduction

Feedback is an integral part of the academic process. Its purpose is to provide students with information that can propel them forward from their current state of knowledge/skills to a superior goal state (Hattie & Timperley, 2007). Literature in this area has highlighted the factors that may impact the cognitive and affective responses to different types of feedback and, consequently, the uptake and implementation of that feedback (e.g., Fyfe et al., 2015; Reeve et al., 2014). Even though such studies on feedback are plentiful, little is known about students' *recall* of the feedback they receive. This is surprising, especially as learners' memory of their feedback could influence whether the feedback is ultimately implemented, modified, or ignored (see Winne & Butler, 1994).

In their systematic review of the literature, Hattie and Timperley (2007) identified four main types of feedback students can receive: *Task Feedback (FT), Process Feedback (FP), Self-Regulation Feedback (FR), and Praise/Self Feedback (FS)* (See Table 1 for defining features and examples). Because *Process Feedback* is more generalizable and encourages deeper learning, it is seen as more beneficial and longer-term than *Task Feedback*. Arguably, the most beneficial type of feedback is *Self-Regulation Feedback* because it instructs students on how to self-assess their work and develop the skills necessary to become better self-regulators. *Praise/Self Feedback* can have ironic consequences for future motivation because it does not encourage students to invest further effort. Thus, it tends to be the least effective at improving academic performance.

Overall, Hattie and Timperley (2007) conclude that feedback's efficacy depends heavily on the level at which it was aimed. In the current study, we use this framework to categorize the feedback that students receive and recall receiving on a *real classroom assignment*. Much of the previous research on feedback has been done in laboratory settings, where feedback is manufactured and unrelated to the actual performance of the student on a given task (e.g., randomly providing positive/negative feedback to participants *without* considering their actual performance). The current study, which follows up on preliminary results from one lab section, aimed to fill these gaps in the literature by examining how much feedback students remember from an actual classroom assignment and whether students' memory differed as a function of feedback type.

Methods

Participants

The present study was conducted in a first-year introductory applied psychology college course. The class had an enrollment of 102 students, 76 of whom consented to participate in the study (M_{age} = 18.98, SD = 1.36). The students were split into four different lab sections, where they completed weekly projects in groups of 3-4.

This IRB-approved study was designed to blend into the course with minimal disruptions to its natural flow. Students completed an applied activity on the human body's response to stress in their groups. After submitting their assignment, the course instructor and four teaching assistants (TA) met to discuss grading procedures, ensuring consistency in grading and making sure the same detail of feedback was provided across labs. All assignments were graded before the following laboratory session. At the beginning of that lab session, students were given 10 minutes to individually read through their group's assignment feedback. This was the one

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major modification to the course (i.e., typically students did not get class time to review assignment feedback). One week after the feedback read-through in the lab, all students were given a surprise free recall task.

Materials

Students' recall of feedback

Participants were asked to complete an online survey about their thoughts and attitudes towards academic feedback and recall as much of the feedback given to them on the stress activity as possible. This was an open-ended question with no additional prompts about the activity or what type of information should be included in their response. From informal conversations with students, we learned that many were unlikely to revisit their previous feedback before starting a new assignment, even if they knew it had the potential to be beneficial. Therefore, we opted to avoid recall cues because their unsupported recall of the feedback would best represent their awareness and "use" of past feedback in a typical classroom situation.

Codebook

Feedback and recall of the feedback were broken into units. Feedback units were defined by a comment/recall that contained one unique idea about the work submitted (see Table 1). Feedback provided by the TA and students' recall of that feedback were coded into the four types of feedback presented in Hattie and Timperley's (2007) paper. In the instances that a piece of feedback could not be placed into one of the four categories, it was assigned to "Other." Responses were then examined for similarities; no patterns within the "Other" category emerged. All authors created and refined the codebook as well as co-coded all of these data, reaching a consensus for each unit.

Results

The average number of feedback units for each feedback category were calculated at the classroom level for both TA comments and student recall (see Table 2). As stated above, the course instructor and TAs met to discuss grading procedures, ensuring consistency in the quality and focus of the feedback. TAs in all lab sections gave feedback that represented all four feedback types outlined by Hattie and Timperley (2007). However, the amount of feedback provided differed significantly across the lab sections, therefore we could not collapse the data. On average, TAs gave FT and FP most often and an approximately equal number of feedback units in both categories (although this varied slightly by TA), whereas FS was given least often. In line with this, FT and FP were recalled most frequently by students, on average. However, students were more than twice as likely to recall FT than FP, despite being given both types in almost equal measure. FR was recalled least often by students, on average. Notably, students' recall (across all feedback categories) was very low compared to the amount of feedback units received from the TA. Overall, findings suggest that students have differential recall for the four types of feedback.

Discussion

This study demonstrates a noteworthy discrepancy between the types of feedback that educators *give* and the way students *understand, classify,* and *remember* that feedback. We observed that students recalled little of the feedback they received, and when they did, it was primarily the marginally beneficial task-based feedback. Theoretically, it would be most beneficial for students to remember FP and FR feedback, as these types have the greatest ability to generalize and be useful on future, novel learning tasks. Findings suggest that even if students are *receiving* the types of feedback that have the potential to be most impactful, they may not be drawing out the key elements to understand and remember their feedback in the ways that stand to benefit them most long-term. We saw examples of this "*transformation process,*" where students received process-based feedback but actually remembered it in a specific, task-based way. Due to space constraints of the current paper, we have provided only two examples (see Table 3).

Prior research demonstrates that critical constructive feedback, which scaffolds students to improve on tasks, often remains untapped (Tärning et al., 2020). Our findings begin to shed light on *why* this might be. Students may not be purposefully ignoring or not implementing feedback; instead, it might be a product of not understanding it in the same way that educators intend for them to, altering how they store and recall feedback. Additionally, Máñez and colleagues (2019) observed that sixth-grade students spent more time attending to feedback after failure than after success. Therefore, future analysis of our data could explore whether students were differentially remembering positive versus negative feedback.

Practically, these results beg the question: *how can we train students to better locate, remember, and use self-regulatory feedback (or at least prevent students from transforming useful, generalizable process-based feedback into more specific task-based feedback in their long-term memory)?* If we successfully accomplish these aims, we stand to better prepare students for future learning and improve course performance outcomes.

Table 1
Defining Features and Examples of the Four Types of Feedback

Feedback Type	Defining Features	Examples of Teaching Assistant Feedback	Examples of Student Recall of Feedback
Task (FT)	Provides task-specific information: ● Clarifies whether information in assignment is correct or incorrect ● Offers directions to get to correct information for the specific task (i.e., not intended to generalize) ● Direct text-level edits without explanation (e.g., track changes)	"You should add more information here." "Correct." "This is a helpful explanation for how this strategy directly addresses stress."	"I remember that my TA told us that one of our previous Biological processes, the Thalamus is does not really relate or affects our body when being stress." "Make sure we were citing correctly was a key point."
Process (FP)	Aimed at improving students' understanding of the learning processes required for successfully or more thoroughly completing the task (or similar future tasks - i.e., potential to generalize) ● Offers a strategy to create a product, find a resource, or complete a task more effectively	"...I recommend choosing one main idea for each paragraph. Make the main idea of that paragraph the first sentence (aka "topic sentence") of the paragraph. Then flesh out the main idea with relevant definitions, explanations, and examples…. Using this technique should help you to identify where you are being repetitive or adding unnecessary detail."	"I remembered the feedback talking about how some paragraphs needed to be split into two paragraph for a more coherent flow." "We needed to unify our conversations more in order to show more of a flow in our writing."
Self-Regulation (FR)	Feedback aimed to help students self-assess and, subsequently, boost confidence and motivation to engage further by investing effort to clarify or incorporate suggestions ● Reassures a successful previous procedure/process or demonstration of students' relevant content knowledge to motivate their further expansion on the topic ● OR feedback demonstrates how their writing might be interpreted by an outside reader, asking them to clarify and self-correct	"Make sure to relate these [definitions] back to the context (such as you do in paragraph 2)." "For reference, it sounds to me like stress is experienced through external factors that enact defense systems. Is this what you mean? Do you mean that these external factors trigger defense systems?"	"What I could recall is that our feedbacks for the biological process is a bit bad for we did not fulfill the require thing." (*Note*: In this case, the "require thing" was referring to the assignment rubric, knowledge that the student could/should use the rubric will allow them to self-assess in the future)
Self/Praise (FS)	Personal evaluation directed at the student (can have a positive or negative valence) but *without* a direct connection to task performance ● Typically does *not* motivate students to invest further effort	"Well done!" "Great effort"	"Overall, good job" "Written well"
Other (O)	Any instance of feedback that did not fit into the categories above	"If you would like to revise and resubmit, please do so by lab on Tuesday, 2/18/2020."	"Unfortunately, as I write this down, the only feedback I can really remember was 'negative.'"

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Table 2

Average Number of Feedback Units given by the Teaching Assistant and Students' Average Recall in each Feedback Category for each Lab Section

	Task Feedback (FT)	Process Feedback (FP)	Self-Regulation Feedback (FR)	Self/Praise Feedback (FS)	Other (O)
Lab 1 (*n* = 16)					
TA Feedback	10.29 (*3.30*)	10.71 (*3.99*)	1.14 (*1.07*)	0.57 (*0.53*)	1.17 (*0.76*)
Students' Recall	1.81 (*1.68*)	0.75 (*0.93*)	0.06 (*0.25*)	0.13 (*0.34*)	0.00 (*0.00*)
Lab 2 (*n* = 22)					
TA Feedback	9.86 (*3.89*)	8.57 (*3.21*)	1.86 (*0.69*)	2.71 (*1.25*)	2.71 (*1.25*)
Students' Recall	2.45 (*1.82*)	0.55 (*0.67*)	0.05 (*0.21*)	0.09 (*0.29*)	0.32 (*0.48*)
Lab 3 (*n* = 21)					
TA Feedback	13.50 (*4.04*)	7.17 (*1.47*)	3.33 (*1.51*)	0.67 (*0.82*)	0.00 (*0.00*)
Students' Recall	2.86 (*1.49*)	0.86 (*1.06*)	0.10 (*0.30*)	0.14 (*0.36*)	0.00 (*0.00*)
Lab 4 (*n* = 17)					
TA Feedback	10.50 (*7.09*)	7.17 (*2.40*)	0.50 (*0.84*)	0.67 (*0.52*)	1.00 (*1.10*)
Students' Recall	1.35 (*1.00*)	1.41 (*1.23*)	0.00 (*0.00*)	0.06 (*0.24*)	0.29 (*0.77*)

Table 3

Examples of Students Transforming Teaching Assistant Feedback at Recall

Teaching Assistant's Comment (Type of Feedback)	Students' Recall of Feedback (Type of Feedback)
"Even though it may be beneficial for the hypothalamus, how is this related to stress?" (FR)	"Some others things are just my Ta telling us to explain more about what we wrote and elaborate on it." (FR → FP)
"I think this can be significantly condensed if you remove repetition and unneeded details." (FP)	"Long paragraphs" (FP → FT)

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Design Thinking as a Structure for Collaborative Project-based Learning in Multiple Disciplines

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Abstract: This study examines the design thinking process as a structure for collaborative project-based learning in undergraduate courses ranging from biomedical sciences to teacher education. Our aim in this design-based research study was to understand how design processes are experienced and to develop a set of design principles. Individually written reflection papers were coded in categories including design aspects that worked well as well as student struggles. Code co-occurrence correlations were calculated and a network map created. Findings in each set of relationships were translated into design moves. One important finding was that learning through design thinking requires truly collaborative work where team members work collectively throughout the design process. The learning experience should also be designed to emphasize building relationships of interdependence. The innovative analytical process used provides valuable insights to improve the use of design thinking for collaborative project-based learning in multiple disciplines.

Background

Project-based learning and collaborative learning are generally acknowledged in the literature as evidence-based high-impact practices (National Academies, 2018). However, there are a number of issues educators face when attempting to implement these practices in their own courses. A common issue is lack of scaffolding structure, leading to inconsistency of effectiveness, students trying to do all the work at the last minute, and breakdowns in interpersonal communication within student groups (Barron et al, 1998). Furthermore, many projects are structured such that the teacher determines the problem, process, and nature of the solution rather than helping students develop skills in problem identification, creative problem solving and managing productive failure through focused tinkering and exploration (Svihla & Reeve, 2016). Finally, project-based learning in academia often involves designing artifacts or solutions which are only seen by the teacher and peers within the course rather than pushing students to interact with real-world stakeholders and design solutions for real-world problems (Kincheloe, 2008). To address these and other related issues, we have been conducting design-based research study across multiple university courses in which students engage in the design thinking process.

In the current study we are using the Design Thinking for Engaged Learning model (Donaldson & Smith, 2017) which consists of a 10-stage process broken down into 5 phases, with each stage intentionally crafted such that students develop skills in designerly ways of knowing (Cross, 2006). For instance, in order to help students develop the "wicked problem framing" designerly way of knowing, small groups of students identify and frame a wicked problem within the disciplinary scope of the course (Donaldson et al, 2022). To help them develop the cognitive, affective, and conative empathy designerly ways of knowing, students go into real-world contexts in which their wicked problem exists and conduct observations and interviews to understand stakeholders' experiences of the problem—especially the experiences of those at the margins (Jamal et al, 2021). In order to facilitate truly collaborative (Chi, 2009) learning, groups are expected to complete all stages of the process together rather than splitting up tasks to be accomplished by individual members (Odom et al, 2021). In this study, we were seeking to understand how such design processes are experienced by students and to develop a set of principles for using design thinking as a structure for collaborative project-based learning in higher education.

Methodology

This design-based research study (Sandoval & Bell, 2004) investigated the use of design thinking for collaborative project-based learning in the second iteration in undergraduate courses. Students in agricultural leadership, bioenvironmental sciences, tourism studies, animal sciences, and teacher education courses engaged as small groups in the design thinking process over a period ranging from 10 to 14 weeks. The process was broken down into 5 design thinking phases. For analysis of the first iteration (not reported here) we used simple frequency analysis of weaknesses and strengths of the design found in 381 reflection papers. For analysis of this second iteration we developed an innovative analytical process through which to leverage multiple statistically significant

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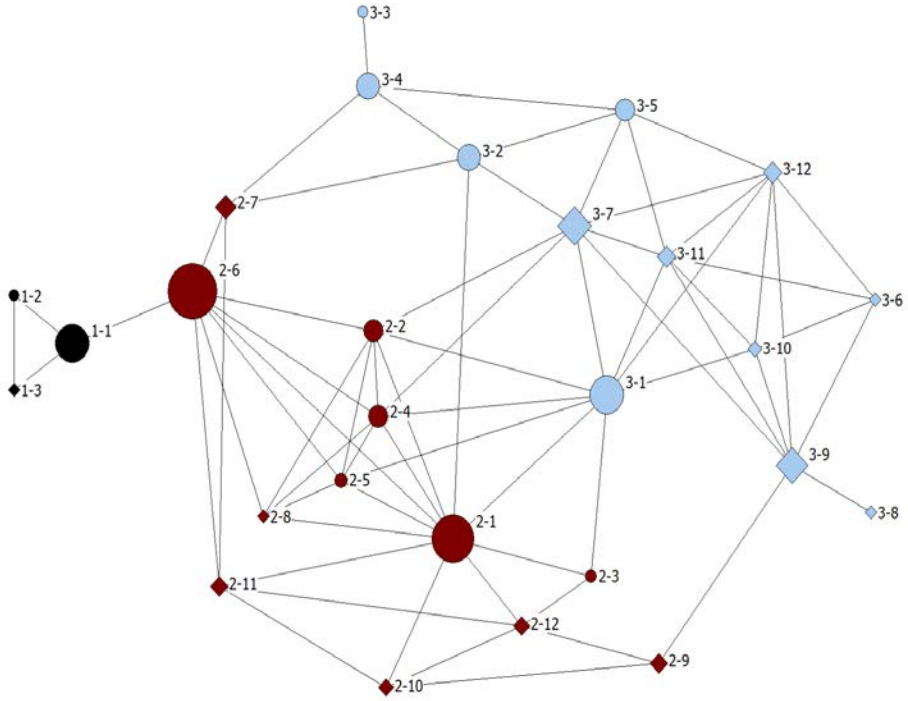
correlations between student struggles and design strengths as a means of developing data-driven design moves for improving the third iteration. Throughout the second intervention, students individually wrote reflection papers which were collected for data analysis (163 documents). We coded the data in MAXQDA Analytics Pro for emergent themes in a number of categories including design aspects that worked well as well as student struggles, resulting in 174 codes covering 2,257 coded segments. We then calculated code co-occurrence correlations to create symmetrical matrices which we imported into the UCINET and NetDraw network analysis software to create a network map of struggles and design features that worked with correlations of $p<0.001$. We used Girvan-Newman cluster analysis (Girvan & Newman, 2002) to identify clusters, calculated eigenvector values, and set node sizes according to betweenness centrality measures to identify the most salient strengths and weaknesses of the design. Because this is the second iteration in a design-based research study, we were primarily interested in crafting design moves to improve the next iteration. To do so, we selected the category of student struggles to indicate aspects of the design that were weak and the category of design aspects that worked well to suggest possible solutions which leverage strengths to address weaknesses. We analyzed the relationships between each of the student struggles and the related design strengths, and translated findings in each set of relationships into design moves.

Findings

In our network analysis of correlations at $p<0.001$ we found 3 clusters with Q=0.372 through Girvan-Newman analysis (see Figure 1) indicating the network of relationships between student struggles and aspects of the design that worked well. We set the node size such that nodes with higher betweenness centrality measures were larger. Diamond-shaped nodes are student struggles, and circles are aspects of the design that students experienced as beneficial.

Figure 1

Network Map of Design Strengths and Student Struggles



In the red cluster in the middle of Figure 1 we found that students who struggled with logistics (node 2-11) also tended to struggle with technology use (node 2-7), understanding what to do (node 2-8), divergent thinking (node 2-12), idea generation and coming up with new ideas (node 2-10). What worked for these students included interacting and developing relationships with team members (node 2-1), collaborative documents and technologies (node 2-5), teamwork times (node 2-6 - recurring meetings devoted to the team project), and idea generation (node 3-1). What these students also found beneficial was rehearsing and sharing projects with peers (node 2-2), and the development process (node 2-4). This suggested that a potential solution for the struggle with technology was to have teams hold workshop times with their teams during team work time where time was set aside specifically for troubleshooting problems. This design move was supported by the connection to the team work times, which worked well. A final design move this analysis suggested was to address student struggles with

logistics by providing students with opportunities to obtain feedback from outside perspectives on logistics of the projects.

There also appears to be a connection between students' personal struggles (Figure 1 - red cluster: node 2-9) and their struggles with divergent thinking (node 2-12), ideation (node 2-10), and collaboration, interpersonal interactions, and relationships in the group (node 3-9). These struggles were addressed with a design move of advising students to seek new perspectives and to be open to new perspectives outside of their group. Another design move that was developed and implemented was to emphasize the value of self-reflection and helping students recognize their own assumptions regarding a challenging team, team member, or situation. For this we added a prompt to a reflective assignment that asked students to think about managing personal and interpersonal relationships for optimal teamwork.

In the blue cluster on the right of Figure 1 we found that student struggles with time management (node 3-7) were connected to struggles with collaboration and relationships (node 3-9), adapting to change (node 3-12), and following instructions (node 2-11). What worked for students who struggled with time management was interest alignment in teams (node 3-5) and increased communication (node 3-2). To leverage these strengths to address the time management weakness, a potential solution is to encourage students to include timing expectations and status updates in their existing communications with each other so that they can leverage their current strengths with communication frequency. Modeling this behavior may be necessary to augment assignment instructions as these students also expressed struggles with following instructions in general.

There is also a connection between those who struggled in time management and success in generating a large number of ideas (Figure 1 - blue cluster: node 3-1). This suggests that they started the design process off well in generating many ideas (possibly because they had aligned interests within teams), but then struggled with collaboration and relationships (node 3-9), following instructions (node 2-11), and adapting to change (node 3-12). A design move and potential solution for this struggle was to add specific instructions for each of the team activities to instruct teams to spend only 40 minutes working collaboratively in the activity, complete the activity within the allotted time, and not delegate other outside individual work after the team meeting.

In the small black cluster on the left of Figure 1 we found that student struggles in problem finding (node 1-3) were related to strengths in scientific and conceptual understanding (node 2-1), and project framing and orientation activities (node 1-1). This led to the development of two design moves. First, the project framing and orientation activities were revised to include discussion of the scope (boundaries) delimiting what types of problems were within the disciplinary scope of the course (guided by the course learning outcomes) and what problems were outside the scope of the course. Second, the problem finding activity instructions were changed to ask groups to have discussions in which they narrowed the scope of their problem while discussing the ways in which the range of problems they were considering tied in with the scientific and conceptual material they had been studying thus far in the course and in previous courses in the discipline.

Using network analysis of correlations between student struggles and design strengths (aspects of the design which students found beneficial) not only allowed us to identify the multiple interdependencies between struggles and strengths in order to leverage those relationships to develop design moves, but also allowed us to identify overall leverage points in the data. Because betweenness centrality measures indicate the degree to which a node is "important" in connecting other nodes, we were able to interpret larger betweenness centrality measures of particular nodes as leverage points. In other words, changing that aspect would impact many other aspects. The design feature of requiring groups to set up weekly teamwork times (Figure 1: node 2-6) had the highest betweenness centrality measure (79.73 with an eigenvector of 0.27). Interacting and developing relationships with team members (node 2-1) had the second highest betweenness value (65.74 with an eigenvector of 0.36). Coming up with many ideas (node 3-1) had the third highest betweenness (48.97 with an eigenvector of 0.34). These three leverage points were design strengths. One area of student struggle had a high betweenness value (46.78 with an eigenvector of 0.28): time management (node 3-7). Taken together, this suggests—as supported by the earlier data-grounded design moves described earlier—that design thinking projects will be most powerful if we place an emphasis on building team relationships through regular working meetings in which all team members work collectively and collaboratively (rather than splitting up tasks and letting members work individually) over an extended period of time. This group functioning will further be optimized if we provide specific guidance and structures for time management.

Discussion and Implications

Design thinking can be used to structure collaborative project-based learning (Carroll et al, 2010). This study investigated the details of how to optimize such structuring of the design thinking process in learning contexts through analysis of the second iteration of a design-based research study. We hope to gain deeper insight in

subsequent iterations. One of our most important findings was that learning through design thinking requires truly collaborative work in which members of each team work together collectively to engage in all aspects of the design process, and that the learning experience should be designed such that it emphasizes building relationships of trust and interdependence within the team. We also found that it may be beneficial for design thinking teams to routinely share and discuss their work with peers outside their teams, as well as with others outside the educational context with an emphasis on reflection, perspective taking, and questioning assumptions. Another strategy suggested by our analysis was that learning through design thinking may be most effective if teams are taught and encouraged to engage in frequent metacognitive practices such as reflection-in-action (Schön, 1992), so that their discussions are not only focused on completing the task at hand, but also focused on review and refinement of logistical and technical issues, processes, and ways of thinking about the task at hand. Finally, the innovative analytical process we developed provided valuable insights grounded in the data, which we then leveraged to develop design moves to improve the implementation of design thinking for collaborative project-based learning. We believe that this analytical method may be applicable in a wide range of design-based research projects in multiple disciplines.

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Teachers' Use of Resources for Equitable Integration of Computation in Science Classrooms

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Abstract: While computation is a crucial aspect of modern science, students rarely have opportunities to engage in such work. In this study, we designed a series of professional learning opportunities for 12 physics teachers to support their enactment of equitable computational pedagogies. We asked how and why teachers utilized two primary resources of the PLS when making decisions about computational pedagogies. We analyzed multiple data sources using lenses from a situative learning perspective to examine teachers' critical pedagogical discourses. We discuss how teachers' critical discourses shaped the way the resources were utilized when designing computational learning opportunities for their students and the implications for future equity-oriented computational professional learning opportunities for teachers.

Purpose of the Study

Modern science increasingly rely on computation to explore and to understand the natural world; however, computation is largely absent in many high school science courses. Science teachers, then, must plan, enact, and reflect on opportunities for students to engage in computational practices. However, two challenges arise when considering how to support science teachers in designing opportunities for computational practices. First, current high school science teachers have likely not engaged in computational practices, nor have they considered how to plan, enact, and reflect on students' participation in computation. Second, merely providing students with opportunities to engage in computational practices does not necessarily result in equitable participation (Ensmenger, 2012).

Both challenges demonstrate that science teachers need support to provide equitable computational opportunities for students. In this study, we report on a series of professional learning opportunities for 5 secondary physics teachers. In this professional learning series, we provided teachers with a suite of resources to support their enactment of equitable computational pedagogies. By resources, we mean physical and intellectual commodities that teachers use to solve problems of practice (Stroupe, 2016). For this study, we asked:

1. *How did teachers attend to equity when planning, enacting, and reflecting on computation practices?*
2. *What resources were useful in supporting teachers' planning, enacting, and reflecting on equitable computation practices?*

Theoretical Framing

The above research questions are informed by sociocultural theories of teacher learning. When using resources, teachers engage in complex forms of intellectual activity that might otherwise be too difficult without some form of assistance. Note that teachers do not use resources absent of a context. As teachers use resources in their school, the community reciprocally reshapes the resources and their function to better serve valued goals (Cole & Engeström, 1993). While most science teachers use students' ideas, and other resources, to shape instruction, how and why they use the resources could vary. Therefore, we wanted to understand how teachers recognized and used resources to make decisions in concert with multiple voices from various instructional settings.

To unpack how and why teachers recognized and used resources, we examined their *critical pedagogical discourses* (hereafter, critical discourses). Critical discourses describe an individual's developing personal theories about what counts as productive teaching and learning (Flores, 2006; Rex & Nelson, 2004; Thompson et al., 2013). What makes these internal discourses critical is that they are consequential to an individual's actions and learning. Such discourses mediate learning and can influence how teachers think about practice and resource use across contexts (Sfard & Prusak, 2005). For this study, we used critical discourses to understand teachers' resource recognition and use, and we argue that teachers' instructional decisions using resources depends on what they see as problems or opportunities in

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practice. The explanatory power of critical discourses can broaden when the field understands why science teachers select particular resources to reason with and about, how their personal theory of teaching and learning shapes their resource use, and why their personal theory of teaching and learning helps them mediate contextual pressure to teach in specific ways.

Methods

The Professional Learning Sessions and Participants

With the goal of equitable integration of computation in secondary science classrooms, our professional learning sessions (PLS) had three major components: (1) a week-long workshop held in the summer, (2) workdays that occurred every two months during the school year after the initial workshop, and (3) informal communication between teachers and different workshop facilitators. The participating teachers were White with roughly even gender distribution. Over the course of the PLS, we introduced multiple resources to support teachers' implementation of equitable computational pedagogies. In this study, we focus on two primary resources (Table 1) from the PLS, minimally working code (MWC) and Equity QUantified In Participation (EQUIP, Reinholz & Shah, 2018). From the start of the week-long workshop, we introduced computation using MWC to make computational tasks accessible to both the teachers and students with minimal background in coding (Caballero, Kohlmyer, & Schatz, 2012). Together with teachers, we used EQUIP (Reinholz & Shah, 2018), a participation tracking tool, to analyze video recordings of students' small group collaboration on computational tasks. During workdays, each teacher debriefed the EQUIP analytic with a teacher educator.

Data and Analysis

To examine how the teachers took up these resources, we drew from two data sources. First, we interviewed six teachers who consistently participated in the PLS for two years. The semi-structured interview focused on the use of resources shared/promoted during the PLS, intended to provide insight into resource use (e.g., which were framed as useful/not useful, what resources were used by most teachers). Second, we analyzed recordings of debrief sessions. These recordings allowed us to see how resources were used with students (teachers talked about their resource use throughout the debrief session), particularly in terms of resources related to equity.

Based on thematic analysis, we identified how and why the two primary resources were used by teachers and each teacher's critical discourses. We triangulated our findings by drawing on both interviews and debrief data. Similarly, we identified each teacher's critical discourse that is consistent across their interviews and debriefs. These themes were specific to particular teachers, although there were some similarities across some of the teachers. In findings, we focus on two primary resources (MWC and EQUIP) and present teachers' critical discourses.

Findings

Our analysis showed that depending on teachers' critical discourses, they took up MWC and EQUIP differently. We compare and contrast how pairs of teachers applied these resources.

Responding to Students' Frustration with MWC

When the teachers talked about using MWC for their lessons, one salient theme was managing students' frustration because of students' unfamiliarity with computational tasks. More detailed analysis showed that the teachers managed this issue differently by either prioritizing *comfort* or *perseverance*.

> I don't mind that the students get frustrated. But I don't want them to spend the hour on that same frustration. Because they don't. They give up. They turn to another group or something like that. (Ms. Miller, interview)

> It feels good. And I think that's a really valuable thing to expose students to. Remember the last time you were frustrated at the beginning, and you just kept at it, and you kept working, kept working, let's try that again. Let's see if you can't do it again. (Mr. Ross, interview)

Although both Ms. Miller and Mr. Ross attended to students' level of frustration, the teachers interpreted the high level of frustration differently. Ms. Miller, based on her critical discourse of comfort, talked against the prolonged frustration that students might experience. On the other hand, Mr. Ross, based on the critical discourse of perseverance, spoke positively about students experiencing challenging computational tasks.

Their contrasting critical discourses also shaped different instructional decisions. Ms. Miller used the comment features (texts followed by # in VPython, computation-related pedagogical technique) to guide students during the task.

> It was too big of a jump for them. They needed, I have already gone in and done a bunch of commenting because there was no commenting in there. (Ms. Miller, interview)

Mr. Ross on the other hand allowed students to struggle for a longer period of time and presented his solution toward the end of the lesson when his students ran out of time to complete the task.

> I'd love to be able to spend time with this, but we've got to move on. And let me just show you a couple of – I'll show you the approach that I used. And so, I'll take a minute and do that. (Mr. Ross, interview)

Interpreting Inequitable Participation Using EQUIP

Teachers' critical discourse shaped how they interpreted disproportionate participation patterns shown in EQUIP analytics. We found two broad critical discourses of *individual mindset* and *systemic influence*.

When the facilitator asked Mr. Taylor about the marginalized pattern of participation for Manny, a male Latinx student, Mr. Taylor shared his explanation about the perceived fixed mindset that Manny held.

> Facilitator: So there are times when Manny is brought in there, but maybe it's just a sampling that happens to be [showing] this extreme pattern...or do you think that's more normal?
> Mr. Taylor: I've been fixated on growth versus fixed mindsets lately...encouraging students, kids to adopt a growth mindset because it's true. The idea that we can continue to grow throughout our life is true. ... So I am very much focused on the fixed mindset that Manny has, that all of us can adopt at a moment's notice. ... So it's not surprising to me that he gets into that fixed mindset quite often, and he isn't trying to grow, and become better, and accept the challenge, and work through the difficulties, and come out the other side being better because of the struggle that he goes through. So it's not surprising to me at all. (Mr. Taylor, debrief)

Mr. Taylor consistently portrayed Manny as not trying to grow and challenge himself, rather than considering how his race (i.e., a systemic influence) may be affecting Manny's opportunities to participate in small group learning settings.

Ms. Collins below shared an alternative critical discourse of systemic influence. When the facilitator asked Ms. Collins about equity-related patterns before reviewing the EQUIP report together, Ms. Collins offered her gendered experiences as a woman being positioned as the secretary in a small group setting, and she applied her critical discourse of systemic influence to interpret why she might see disproportionate participation by her marginalized students.

> I guess I expect that my minority students, whether that's in their academic level or their ethnicity or things, I'm sort of expecting to see that those are the students that are gonna end up asking questions more than they're gonna be doing explanations and answers. ... I'm expecting a lot of the time that those are the students who are gonna get put in the, "Here, just calculate this for us, run the calculator." … And not the ones who are reasoning. Mostly because I'm thinking about my time, when I was in college, as one of the few girls in the group, do I get relegated to the secretary position all the time? So I'm wondering if it's a similar thing in terms of my students of color and my lower academic-achieving students. Is that the same thing happening to them? (Ms. Collins, debrief)

Her critical discourse also shaped what she attended to in EQUIP analytics, such as who is asking questions or explaining and answering questions.

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Contributions of the Study

Our analysis showed how the teachers took up two primary resources (MWC and EQUIP) differently based on their critical discourses. This leads to three main contributions of the study. First, the range of how the teachers managed students' frustration with computational tasks highlights the importance of supporting teachers to meaningfully navigate the tension. Offering too much scaffolding nor leaving students in a helpless position would not be ideal. Explicit discussions on what and how much teacher support would encourage students to engage in disciplinary practices is a critical component of integrating computation in science.

Second, the contrasting interpretation of disproportionate participation by minoritized students showed that offering an equity-oriented tool is not enough. In particular, Mr. Taylor's interpretation of Manny's disproportionate participation concerns us because he attributed the issue to the perceived deficit of the marginalized student. His critical discourse also showed that the common frame of reference (e.g., growth mindset) could be twisted to place the blame on the marginalized students.

Lastly, the study largely highlighted the crucial role of teachers' critical discourses in the process of professional learning. Teachers' personal theories of teaching and learning represented in their critical discourses shaped the way they used two primary resources offered in PLS. We found that equity-oriented tools, such as EQUIP, may even be counterproductive when teachers' critical discourses reinforce deficit views on marginalized students. This warrants further research on how the computation- and equity-oriented professional learning contexts can be modified to explicate and reshape teachers' critical discourses.

Table 1: Two Primary Resources

Resources	Descriptions
Minimally Working Code (MWC)	Pre-made VPython codes that model particular science phenomena. The codes are working; meaning, they execute without an error. However, the codes need modifications to accurately represent the desired phenomena.
EQUIP Web App (EQUIP)	Classroom observation tool that generates quantitative analytics on student participation patterns based on students' social markers, such as gender and race (Reinholz & Shah, 2018; https://www.equip.ninja).

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A Dialogue on making use of constructionism in different scenarios as a leverage for empowerment, motivation, and learning.

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Abstract: The coronavirus pandemic forced Brazilian schools to move to an online environment rapidly. Consequently, many schools just took the traditional classroom approach to screens. This paper aims to reflect on our practices and share an innovative pedagogy that is adaptable to different scenarios and engages all learners. We will describe two cases to illustrate how a constructionist approach has sparked student agency and learning. We observed how a maker workshop contributed to a child with learning loss to complete his literacy process in the first one. In the second, we share the affordances of The Circle of Inventions practice, which allows for the implementation of constructionist moments in any learning environment. Ultimately, we aim to spark interest in more widespread constructionist practices in diverse learning contexts and leverage collaborations for new investigations, design, and implementation of innovative pedagogies in this field.

Introduction

This paper was born from an encounter at the Winter School of Learning Sciences in São Paulo, in August 2021. Exchanging experiences regarding our work as teachers, during the Covid-19 pandemic, in a private school, an afterschool maker program, and in a project designed to mitigate the problem of the lack of accessibility to online learning for students in a vulnerable community, led to the observation of a few patterns and the desire to think further and research issues regarding technology, making and the engagement in learning. Observing the clear need for adaptable strategies and routines to engage all students in education and seeing evidence that a constructionist approach, developed in these very diverse settings, has had a positive impact on students engagement, confidence and learning led us to ask ourselves, "how might we think together and design pedagogical innovations that allow for simple and purposeful constructionist learning opportunities in any learning environment?" With this question in mind, we began exchanging ideas. We decided to write this paper as a spark to an ongoing process of co-creation to develop, implement and test practices that promote more constructionist learning in any learning space. We use constructionist learning based on Seymour Papert's definition as a process where children are invited to create and construct meaningful and sharable objects to think with and play with. (Papert & Harel, 1991).

Like the rest of the world, the coronavirus pandemic forced Brazil to implement new forms of teaching and learning as schools rapidly moved online and to other forms of education according to connectivity and accessibility to technology. In this context, many schools just took the traditional classroom approach to the screens. Some tried to innovate and create engaging online learning. Others had to work around technology and deliver physical materials to students' homes. As Brazilian educators from different educational settings, this "new normal" has highlighted the need for innovative pedagogies that do not simply replicate the traditional classroom to screens. We also saw the need for learning strategies that are adaptable to different scenarios - online, blended, at school, or home - and that promote each learner's engagement. This paper will share two cases, that compose this dialogue, to illustrate how a constructionist approach has sparked students' agency, collaboration, and learning. In the first case, Edelstein observed how an afterschool maker lab workshop contributed to a child with learning loss completing his literacy process. The second, by Ricci, is regarding the practice of the Circle of Inventions, which allows for the implementation of constructionist moments in any learning environment. The ultimate goal of this paper, and this dialogue, is to spark interest in the topic to other teachers and researchers and leverage new investigations, design, and implementation of pedagogies that may support teachers in bringing more meaningful making into their classrooms no matter their context, access to technology, and curriculum.

The Constructionism of Seymour Papert (1991), the ideas of cultivating creativity in learners from Mitchel Resnick (2017), the concept of making in the classroom from Martinez and Stager (2019), the Agency-By-Design Project Zero framework (Clapp et al., 2017), the work on meaningful making developed by Paulo Blikstein and the Transformative Learning Technologies Lab (2019), the constructivism of Jean Piaget (1970), the critical pedagogy of Paulo Freire (1998), and the literacy process of Emilia Ferreiro (2011) are the main conductive threads and theoretical pillars that sustain and guide our work and the thinking behind this paper.

Intrinsic motivation as a necessary ingredient for the genuine engagement of children in learning processes is vital when thinking about the implementation of constructionist learning experiences. To reach such

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motivation, a sense of competence, autonomy, and belonging must be present, according to research in psychology and differentiation, and logically, the presence of meaning lies at the root of it all (Bondie, 2018). Constructionist learning, or maker-centered learning, is often connected to STEM (Science, Technology, Engineering, and Math) learning. In this paper, we will emphasize the importance of constructionist learning from the perspective of motivation and look at the positive impact generated in terms of social and emotional health for students involved. The Covid pandemic with the consequent social isolation of children highlighted, more than ever, the need for the design and implementation of learning experiences that have social and emotional wellbeing at the forefront. The cases that follow shed light on how constructionist learning experiences supported children in different contexts to be motivated and engage in learning and aim to provoke other educators and teachers to consider innovative strategies and routines to bring more constructionist learning into any learning environment in a way to trigger motivation, social and emotional safety, and learning.

The maker space as a facilitator for a child with learning loss

At the beginning of 2020, T., a 7-year-old male, a 2nd-grade student at a private school inspired by Reggio Emilia's approach and Paulo Freire's constructivism, found obstacles in his literacy process. T. was way behind his group, which worried his teachers. However, the family did not accept help for T. to participate in recovery classes offered within the school. At the same time, in a school of innovation and technology, T. attended maker workshops in weekly meetings. He was considered by the coordinator as highly capable, having already started his experience as a programmer. Faced with such different performances in these environments, I was interested in following him and understanding if maker education could collaborate with his literacy process. Therefore, I conducted interviews with the educators, with the management, did document analysis, observed the workshops, and experimented with the project carried out by T.

At first, I understood how the literacy assessment had been done at the School. The school was generous in its multiple probing resources and room configuration, free of tables and chairs. However, it is necessary to inquire and assess the development of each child to understand what the expectations are about them and the group. The school, aware of his learning gap, offered recovery classes. In this first moment, the family was resistant to the offer. Parallel to school activities, the starting point of the innovation and technology school for T. was different. The assessment process was formative, and the work developed individually, not depending on the pace of a group composed of so many children. Thus, it caught my attention that in an environment where assessments took the form of feedback, T. shows competence and realizes that he has resources and tools to develop his project, motivating and empowering him beyond that space.

The maker space is a literate environment, where its function is presented concretely through hands-on projects. Literacy begins with the process of understanding the world, so innovation, technology, and hands-on experience allow this reading to be concrete, with sense and sensitivity. Literacy needs to be understood as a personal project and the child's desire to access the world in which they are inserted. In this way, the involvement and path taken within the innovation and technology space should be analogous to the child's literacy project.

During the pandemic, T. was away from the school of innovation and technology for some time. Nonetheless, it was fascinating to observe the work he did when he returned. He elaborated his ideas and made them exist in his thoughts, despite the absence of hands-on experience in the makerspace. Upon returning, T. was full of ideas and desires. Although he did not realize that he already had enough knowledge to carry them out, these were quickly resumed with the help of his mediator, showing that the inner practice continued to take place, even if abstractly, during this period of absence. T. is a child who had difficulties with abstraction, as his teacher put it, but at this moment, he had the opportunity to notice that what he worked on in the abstract could be transposed to the concrete. This event empowered him and contributed to the development of the necessary abstraction for the literacy process. Such a fact demonstrates that we can work from a new perspective to empower the individual as a whole. Although there is no confirmation of any organic issue for T.'s difficulty, going through this experience helps him become more potent as an agent capable of learning and understanding that his difficulty is punctual.

The fact that T. successfully developed in the makerspace was also an opportunity for empowerment for the whole family. The space's coordinator, V., says that despite not having much contact with the family, "they are always very excited about T's projects. We always receive very positive feedback about his participation here in the lab, and the same is happening now with the brother, which reflects his great identification with our type of proposal". At first, the family told T's School that they trusted T.'s process in his own time, not understanding the need for the recovery class. I hypothesize that, by witnessing the growth through constructionist activities and by recognizing that T thrived in another environment, the family felt more comfortable accepting help to tackle T's difficulties related to literacy. In this way, the makerspace also acted as emotional support for the family.

T. is a child that does not give up on his desire to learn and gives importance to the space that school occupies in his life. With the help of the teachers, he understood he was capable of learning. This characteristic

of resilience also appeared in the makerspace. T. was deeply involved with his projects in a focused way. It was possible to see him devote hours to programming an Arduino, and in the end, when he saw that his result was not what he expected, he was satisfied with his learning and created new strategies for the following workshops. In the observations, it was clear that T. had a difficult time asking for help. However, the mediator in the makerspace made sure to prompt him and constantly asked questions and offered feedback, which he accepted. As he grew in the makerspace and learned from the modeling of the mediator, he felt confident to start helping a new classmate. From the maker's perspective, that the student may also occupy the position of teacher (Martinez and Stager, 2019), it is noticeable that T., as he began helping his new classmate, build his self-esteem, and understood himself as a mediator. When he understood that he could help his colleague with doubts, he started looking for a mediator to resolve his issues, leaving his passiveness behind.

At the end of 2021, T. was already successfully finishing his 3rd year at the elementary school. The difficulties in his literacy process had already been overcome. Within the makerspace, T. already occupied leadership roles and felt empowered and controlled his learning. Although not all fronts were in dialogue, for sure, it was a path of joint efforts between T., his family, his school, and the maker space.

The Circle of Inventions

Maker-centered learning promotes maker empowerment by developing a sensitivity to design through the creation of meaningful and shareable artifacts (Clapp et al., 2018). This path can be interesting for deep learning as children are actively involved in the learning process, are engaged in authentic real-world projects, have a chance to reflect on processes, articulate their understandings and collaborate with peers. However, implementing inclusive constructionist learning experiences that reach and engage all students can be a challenge for educators, especially in school contexts with time, material, professional development, curriculum, and technology constraints. This type of implementation made itself even more complex during the pandemic. In this section of the paper, we will share some examples of how the Circles of Inventions framework can help bring maker-centered learning into diverse classrooms, both online and in person. The Program Circles of Inventions (CoI), an initiative by the Brazilian non-profit Instituto Catalisador, began as a constructionist activity in public libraries in Brazil. After reading sessions, children engaged in the creation of meaningful personal narratives through the construction of artifacts to be played with and shared. Today, the program has evolved to include diverse non-formal educational spaces as well as schools. The framework developed for Circles of Inventions allows for a learning practice that fosters the thinking and sharing of narratives, ideas, and 3-dimensional drafts (artifacts) that are culturally responsive and meaningful. It may be integrated into different curriculum and pedagogical intentions (Camargo et al., 2019).

In March 2021, as we moved to online learning with less than a week to adapt and prepare for the "new normal", my goal was to continue with the constructionist learning experiences we were developing in the makerspace where I worked as a design thinking teacher in a private school in São Paulo. Due to the new context, the school reorganized the teaching teams into cohorts where all teachers would co-teach and support students' learning more integrally. The focus would be on literacy, math, and projects, especially in 2nd grade, where I was teaching. This new organization allowed me to partner with homeroom teachers in planning the writing workshops when we decided to adapt the writing workshops to the project we were developing and use the CoI framework as an opportunity for constructionists learning in the context of online learning. The framework, which includes a Circle of Reading, a Circle of Making, and a Circle of Narratives allows for multiple structures and thinking routines to be embedded into the practice, with the potential to scaffold group work, individual work, reflection, and articulation into realms that are meaningful for students. The core of the CoI is the creation of personal narratives after engaging in making a shareable artifact that translates thoughts and stories. The possibility of these personal narratives to emerge and find a safe space to be expressed is an essential aspect of this culturally responsive practice that fosters a sense of belonging. The CoI was an interesting and feasible way to spark motivation for writing workshops in an online context as: 1. The read-aloud (Circle of Reading) was possible, and children seemed to enjoy this moment, 2. Students could then move on to make artifacts (Circle of Making) sparked by a provocation born from the read-aloud with whatever materials they had access to at home, 3. They would later return to zoom to share their artifacts and stories (Circle of Narrative), a moment of high participation online. With this structure in place and children engaged, we would then give them the writing mini-lessons and send them to write inspired by their artifact and the narrative it generated. During journaling reflections, it became evident how much children had been engaged and were proud of the first book they managed to write throughout the term. The CoI that allowed for a constructionist learning moment, even online, seems like a practice that catalyzed more writing for this group.

Another example of the use of the CoI, in a different context, as a way to spark motivation and learning through constructionist experiences happened as an effort to continue the work of the maker-centered after school program of the Espaço Catalisador Pirituba, which works with students from a low-income community in São

Paulo. The student's lack of internet and device accessibility led the educators to organize maker kits for students' at home with guidelines for the activities. The app Whatsapp was something that most families managed to access on at least one family members' device, so this was the medium used for communication with students. Most activities proposed in the kits began with a story/narrative shared through Whatsapp, or in the Kit. Children were then provoked to make something and then share their creations and narratives via WhatsApp. Accounts by the team tell of high student engagement and family involvement, and where 80% of the children who were enrolled pre social isolation continued in the program.

In the Jd. Panorama community, a vulnerable housing settlement in the city of São Paulo, the CoI was also used online, thanks to a project to take the internet to students in the community. The goal was to give continuity to the work of the Creativity Studio, an afterschool program centered on art, making, and building agency in students. After receiving a kit with basic craft materials, the students of the Creativity Studio also engaged in a series of CoIs on zoom, one of which was a cycle of 4 encounters. The Circle of Reading used the book "What do you do with an idea" by Kobi Yamada (2013), which sparked a creative process that led the children to create innovative ideas regarding imagining the world after Covid. Students also gave each other feedback and submitted proposals to the Interaction Design and Children Conference Design Challenge. These examples show us how the CoI is a practice that may be used in different contexts to spark constructionist learning. It may take the form of a provocation for a project, as a community-building strategy, as the project itself, as a spark for a design process, and explore multiple contents depending on the books read, questions raised, and thinking routines implemented.

Conclusion

The cases exposed above reflect how a constructionist learning approach, that takes into consideration the student as a whole, that is culturally responsive and sensitive, where active listening by educators and peers is present motivates and engages students in such a way as to foster learning. In the first case, the possibility of the individual choosing his project, feeling able to carry it out and help his colleagues, collaborated to consolidate his literacy process. The whole experience gave him agency and empowered him to manage socio-emotional issues that previously paralyzed him. In the second case, the Circle of Inventions was a way to spark learning during social isolation in very different contexts, through read alouds, the making of meaningful artifacts, and, most importantly, the sharing of important personal narratives inspired by the artifacts created. This dialogue established by the authors through this paper reveals the relevance of constructionist learning experiences for meaningful and successful learning to occur. In light of the need for more motivation and consequent learning in diverse environments, constructionist possibilities designed to be easily implemented and culturally responsive, no matter the learning context, is a goal for us as educators. We take the opportunity of this paper to invite other educators and researchers to partner with us in the development of such innovative pedagogies, strategies, and routines that could facilitate the implementation of constructionist learning by any teacher in any environment, promoting agency in students, motivation, and learning.

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Encouraging children to envision futures through learning in career development classes: Focusing on the case of Japanese elementary schools and "social scaffolding"

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Abstract: This study analyzes what children in Japanese primary schools learn through career development classes carried out by volunteers who continuously participate in school-community partnerships, clarifying the influence of these classes. We analyze children's compositions describing their impressions of career development classes, utilizing a text mining tool (Tiny Text Miner βversion, or TTM) to analyze our data. Using TTM, we divide text data into words or phrases and analyze tendencies of word usage. Children, as a result, learn how long they will work during their lives, how society at present is constructed, what their future will be like, and what they work for in career development classes. Most children imagine what will happen in their future and future society, so these classes might provide them with the triggers to think about their future and offer "social scaffolding".

Major issues addressed

Education in schools is connected loosely to society, and children are always incorporated into it. Although many of them will work on it after graduating from high school or university, they cannot sufficiently learn the processes of viewing their future, thinking about their dreams, and realizing these future ideal perspectives. According to an investigation by the Japanese Cabinet Office, 60.6% of Japanese young people answered they had bright expectations for their future, which is the lowest rate among investigated countries (Japanese Cabinet Office, 2018). These results signify that it is difficult for Japanese young people to envisage a bright future and to form expectations about their future. To tackle these difficulties, in 2013, the Japanese government presented "4 Basic Directions about Educational Administration", and one of these directions signifies a "nourishing capability for surviving present society", which promotes career development. Career development in Japan, in general, is recognized as a way to nourish the ability to live. At the same time, career development aims to generate self-esteem and a sense of work based on children's curiosity, and to promote children planning their future and considering how they want to spend their lives.

Observing research on career development all over the world indicates that career development in the educational field can be seen to provide effective ways of nourishing children's perspectives on the future (e.g. Peila-Shustera et al., 2019). Previous research mentions that children must acquire the basic perspectives of career adaptability to envision their future and make educational or vocational decisions (Hartung et al., 2011). There is, however, not enough research on childhood career development, especially in non-Western cultures, despite studies on adolescence and adulthood (Liu et al., 2014). Career development is regarded as a way to promote children understanding their world, considering alternative goals, and planning courses of actions to meet goals (Magnuson & Starr, 2000). Children's aspirations and expectations for an occupation change dramatically during the elementary years (Auger et al., 2005). These results, however, do not specify how children concretely think or learn from career development classes, and they cannot clarify how children learn alongside career development providers or through comparing themselves at present to themselves in the future. Moreover, although the importance of connecting schools and society is recognized widely in Japan, there is not enough research about career development and about what children are learning through it. Regarding career development in elementary school, it is not an exaggeration to state that there is no analysis. This study thus seeks to analyze what children in Japanese primary schools learn through career development and to clarify the influence of it.

Methods

Participants and data collection

In this study, we investigate career development in Japanese public primary schools (called A school and B school). One volunteer in his 70s (called Volunteer O) engaged in conversation with A school and B school's principals, and they decided to hold career development in their schools. Volunteer O also participated in other activities held

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in these schools with fellow volunteers, so he continuously kept in touch with these schools, and he and the children knew one another. Ninety 5th grade children at A school and Fifty-eight 6th grade children at B school took career development classes in July 2021. These classes were held in such a manner as to prevent transmission of COVID-19, so Volunteer O consciously stood in front of the children while maintaining social distance, using PowerPoint and video (see Figure 1). He had been working at a company relating to communication, so he made presentations about 1) what his job was like, 2) why he began to work at that company, 3) how long we have to work, 4) what we work for, 5) how learning in schools can connect to our jobs, and 6) how to broaden our curiosity. This class contained Volunteer O's talking and videos relating to his jobs, showing a drone so that children would not be bored (see Figure 2). After finishing classes, teachers encouraged children to write what they learned when they participated. This study analyzed these children's compositions describing their impressions of the classes.

Figure 1
The situation of career development classes

Figure 2
How to introduce the story of the drone in classes

Method of analysis

Words and phrases that children often use can be clarified through text mining tool called Tiny Text Miner βversion (TTM), developed by Naohiro Matsumura and Asako Miura. Papers describing the impressions of career development classes of 148 children are analyzed. Before analyzing word usage, we designated the words that should be treated as noise in order to remove words not directly relating to children's impressions of career development classes. We also specified some words as synonyms that are combined through the analysis. We consequently filled the boxes of nouns, adjectives, and adverbs to designate objects of analysis. As part of the procedures stated above, we clarified 1) the tendency of word usage, and 2) relations between modification and re-modification through dependency parsing that can be ascertained by TTM. After clarifying the tendency of word usage and co-occurrence relation among words, we picked up some words or phrases from the analyzed results and observed concrete whole sentences containing these words or phrases. Through the above analysis, we tried to clarify how children learned and felt through career development classes.

Findings and implications

Tendency of word usage

As a result of analysis, 21 nouns, adjectives, or adverbs, which were abstracted more than 10 times, were designated: "job (noun)"= 73 times, "future (noun)"= 67 times, "movie (noun)"= 55 times, "interesting (adjective)"= 51 times, "drone (noun)"= 42 times, "class (noun)"= 29 times, "wonderful (adjective)"= 29 times, "study (noun)"= 27 times, "now (adverb)"= 26 times, "surprising (adjective)"= 24 times, "telephone (noun)"= 21 times, "school (noun)"= 18 times, "past (adverb)"= 18 times, "half (noun)"= 16 times, "development (noun)"= 16 times, "life course (noun)"= 16 times, " adult (noun)"= 13 times, "people (noun)"= 11 times, "dream (noun)"= 10 times, "society (noun)"= 10 times, and "like (noun)"= 10 times (see Table 1). These results refer to children who took career development classes and wrote about things relating to their jobs, their futures, their school lives, what they saw through the classes, and their feelings about the classes.

We then analyzed relations between modification and re-modification through dependency parsing. The results of analysis are as follows in descending order: "life course + half", "future + dream", "future + movie", "drone + manipulation", "class + interesting", "movie + interesting", "future + development", "drone + interesting", "job + like", and "job + money" (see Table 2). These results about relations among words signify that the words "half" and "life course", which were abstracted above, were used in relation to each other; we can predict that children mentioned something that happened through their half of the life course. The word "future" qualifies "dream", "movie", and "development", so children might imagine future developed society or their future dream through watching the movie, which was provided by Volunteer O, relating to future technologies. The word "drone" is often used in "manipulation" and "interesting"; thus, children may be surprised by the

manipulation of drones in the career development classes and find it interesting. These children also thought "class" or "movie" was "interesting", so they might experience a degree of interest, though there is the possibility that the impressions stated here are somewhat superficial. The word "job" is used in the same context as "like" and "money", so children may mention future jobs relating to their preferences or monetary conditions.

Table 1

Word usage: more than 10

job	73	study	27	development	16
future	67	now	26	life course	15
movie	55	surprising	24	adults	13
interesting	51	telephone	21	people	11
drone	42	school	18	dreams	10
class	29	past	18	society	10
wonderful	29	half	16	like	10

※1 Left sides: words

※2 Right sides: the number of words

Table 2

Relations of modifications and re-modifications

life course+half	movie+interesting
future+dream	future+development
future+movie	drone+interesting
drone+manipulation	job+like
class+interesting	job+money

※ "modification"+"re-modification"

How children learned in classes: observing concrete contexts

The results of dependence parsing, as stated above, clarified how some words are related to one another; nevertheless, they cannot signify the concrete contexts of the word usage. In this study, we therefore focus on "life course + half", "future + dream", "future + development", "job + like", and "job + money", which might strongly relate to career development, but the nuances or contexts of which are still ambiguous. We analyzed the original data, which comprised 148 papers on which children wrote their impressions of career development classes, and checked how the words "life course + half", "future + dream", "future + development", "job + like", and "job + money" were used in the concrete sentences. 1) "life course + half": Most children who used this combination mentioned that they were surprised at how long they have to work through their lives. Some children were motivated by the length of commitment to their jobs; others, however, felt that length was very long, with this feeling potentially fostering negative images of jobs (concrete sentences as follows).

> Boy 1: I was surprised that I have to work at a company for more than half of my life course, even if I have something that I want to do.
> Boy 2: I want to do the job which I like because I will be bored if I work for getting money.

2) "future + dream": Most children who used this combination mentioned their future dream. Some of them said that they had already decided on their future dream, and others said that they had not decided yet. Many of them found that career development classes had become triggers for imagining their future dreams.

> Girl 1: I have a dream that I want to do this job. People who were mentioned in the movie and classes today realized their dreams, so if I do not give up my dream and do my best to achieve it, my dream will come true. I therefore want to realize my dream, which I have had since I was a little child, and I want to feel that my job is very interesting.

3) "future + development": Most children who used this combination mentioned their curiosity about future development, and they imagined what would happen in their future.

> Girl 2: What I had the strongest impression of today was future development. Our society gradually develops, so it will become a different one in the future. I felt that this social change from present to future is very curious.

4) "job + like" and "job + money": Most children who used these combinations mentioned that they want to embark on their jobs because they want to continue their work for a long time and have a great life. Moreover, they expressed that they want to do their jobs not only to earn money but also to utilize their abilities.

> Boy 3: I thought about how important working and studying are though this class. Before taking the class, I thought people work only to get money. Taking this class enabled me to realize another purpose of working, so I will sometimes recall things that Volunteer O taught today when I am working in the future.

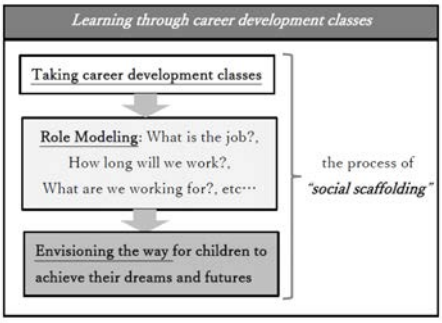
Conclusion

Children who participated in career development classes, in this study, were surprised at the reality of what a job entails, and were impressed by the reason for work. This very simple awareness can be said to be characteristic of career development in elementary schools because children in this age rage have a tendency to look to the near future according to development stages. These children's purity of perspectives about the future may enhance their feelings that these classes were very interesting. Children, as a result, learned how long they will work during their lives, how society at present is constructed, what their future will be like, and what they work for in these classes. Most children imagined what will happen in their future and future society, so these classes might provide them with triggers to think about their future perspectives, which inevitably contain positive and a few negative images of the future. Some tools used in these classes—for example, movies or drones—could offer a medium for children to look at the future. In addition, this study signified the possibility of collaboration between teachers, school counselors, and volunteers to realize career development classes, which broadens the range of jobs that children can learn.

Of course, the career classes analyzed in this study could not provide children with instructions on how to realize their futures; these classes could, however, illuminate children's futures and potential life courses. Providing young people with role models in the future encourages them to produce their ideal futures or to consider ways to realize their future. This process can be called "social scaffolding" in this study and may be related to intergenerational learning (Nakano, 2021). Children learned through relationships with volunteers or people who provided career development classes, and the behaviors of these people and the classes themselves became "social scaffolding" for children because career development, in this study, provided children with opportunities to learn and consider their future, promoting role modeling of children's futures and envisioning ways for children to achieve their dreams (see Figure 3). This study has importance in highlighting that career development classes present children with triggers for learning how study at school could connect to their futures and imagining more concrete images of these futures.

Figure 3

Learning through career development classes



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International Society of the Learning Sciences

How the Learning Sciences Can Help Improve Corporate Training

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Abstract: This conceptual paper describes contemporary issues in one corporate professional development program. Culture, practices, modes of delivery, and external influences are all factors that contribute to the lack of innovation in corporate training. Although the learning sciences community does address learning in many contexts, including corporate training, this area is also underserved in research and the literature. This paper describes how the learning sciences might have a greater impact on corporate training by preparing learning and development practitioners to create more effective learning experiences and communicate more effectively about those experiences. Instructional designers in the corporate world must be able to efficiently create technology-enhanced learning experiences, while still advocating for the adoption and inclusion of relevant theories of how people learn.

Introduction

Many businesses in the United States have an employee training and development program. Typical categories of training include new employee orientation, compliance or regulatory training, job-specific skills improvement, and "soft skills" training (Colman, 2020). Research has shown a connection between employees' satisfaction with training and their overall job satisfaction (Jaworski et. al., 2018; Schmidt, 2007). However, these studies also found that employees are often dissatisfied with training options and companies can be reluctant to offer any training to part-time employees or those who are lower in the corporate hierarchy.

Although learning scientists have long advocated for a shift in how businesses view training (Barab & Plucker, 2002; Schank et. al., 1999) to focus more on contextualized experiential learning, much of the work in this area continues to be centered on schools or programs that are education-adjacent, such as university-business-partnership training programs (Bergner & Farad, 2021; Mambrey et. al., 2002; Raes et. al, 2017).

This conceptual paper, using an example from my experience as an instructional designer at a clinical service organization, argues that the learning sciences can help instructional designers and other corporate training practitioners to re-envision training in the workplace and create better learning experiences for all employees, resulting in greater job satisfaction and more fulfilled workers.

Theoretical Perspectives

Broadly, I am arguing for the learning sciences to examine how we can prepare instructional designers to work in corporate, non-educational settings. Learning scientists could apply principled practical knowledge, in those settings, to create "a ladder leading to sometimes radical design improvement" (Bereiter, 2014, p. 4). In addition, I am suggesting that we need to train instructional designers who are also "learning sciences communicators," similar to the Data Communicators proposed by Wolff et al. (2016), to broadcast the benefits of LS theories of learning and design frameworks throughout the corporate world.

To make this argument less abstract, I will discuss a specific case using the Social Infrastructure Framework developed by Bielaczyc (2006, 2013) to both design learning experiences and evaluate those learning experiences. The SIF focuses on four dynamic and inter-related elements: culture, practices, socio-techno-spatial relations, and interaction with the outside world (Figure 1). Previously, this framework was used in a single instructional design (ID) project for corporate training at a service organization for individuals with moderate to severe autism (Duvall, 2020). Although the SIF was originally focused on schools, the elements can be repurposed and refined to provide an approach to improving corporate training experiences as well.

Methodology

In this conceptual paper, I seek to address the question "How can perspectives from the learning sciences help instructional designers in corporate training programs? To do this, I provide an example of an organization where I worked as an instructional designer. Since 2004, X Autism Services (XAS), located in the northeastern United States, has served individuals with moderate to severe autism. The business's programs include early intervention for children from one to six years old, an educationally integrated behavioral services program for K-12 students who cannot be adequately served in the public school system, outreach programs embedded in public schools, and community integration and employment services for adults. XAS uses an applied behavior analysis (ABA) approach for treatment. In the last five years, the company's number of employees has more than doubled, resulting in an initiative to reframe the corporate training program. The goals for restructuring were to improve

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training in terms of resources needed, availability of courses, and impact on employee and business performance. In the next section, I will explain how I applied the SIF to the company's training program.

Results

Analyzing the context using the Social Infrastructure Framework

Cultural beliefs

Corporate learning programs often include discussions of adult learning theories (Colman, 2021; Gutierrez, 2021), modes of delivery (Masalimova et.al, 2016), and effectiveness (Strother, 2002). XAS is no exception. However, in practice there was little connection between theories of learning and practical implementation. In 2020, the business purchased and implemented a new learning management system (LMS) after evaluating several options. All of the systems touted individualized learning, peer-to-peer collaboration, and achievement recognition, but there was no discussion in the promotional materials about how these connected to various paradigms of learning. At XAS, as in many corporate training programs, there was not a well-defined overall paradigm for learning—especially surprising, given that the activities of the organization are centered on a behavioral approach to learning.

Often, training design and development requestors had little idea of which learners should be included or how learning should be assessed. There were also different categories of training: regulatory requirements, knowledge acquisition or "best practices," practical knowledge for specific jobs, and so-called "soft skills" training around interpersonal interactions.

Despite opportunities for innovation, the corporate training program at XAS often ended up focusing on things such as completion tracking, particularly for regulatory requirements, and return-on-investment versus costs (Rothman, 2002). There was also a focus on knowledge/learning as a product that could be purchased from others or, if developed internally, sold (Campbell, 2010; Taneja & Goel, 2014).

With the introduction of a Quality, Training, and Research (QTR) department in 2018, the organization indicated that it was attempting to shift its culture and training practices.

Practices

Because XAS began as a small company with fewer than 100 employees, corporate training most often occurred through direct instruction – lectures to all employees that were run by higher level employees in the organization. Typical materials included PowerPoint presentations and paper handouts. More informal training occurred on the job, in the moment and in context.

The goal of the QTR department was to implement an LMS and provide more streamlined instruction, including computer-based, self-guided training. However, early efforts merely replicated the existing practices, with videos of lecturers presenting PowerPoints.

Socio-techno-spatial relations

The practices of instructor-led training caused an issue as XAS grew. All-employee trainings for a company of 100 staff members require much fewer logistics and resources than for a company of almost 400. But initially there was no LMS to offer electronic delivery of training, which meant that other technology had to be adapted and repurposed. At the same time, the idea of "instructorless" training was such a cultural and practical shift that it impacted how employees, and executive leadership, viewed the relationship between learners/instructors/computers. Many discussions centered on how to ensure that learners were actually "doing" the learning. The most common questions were about how to prevent them from skipping ahead in videos or looking up answers for assessments.

Interactions with the outside world

The population that XAS serves, and the services it provides, means that there are significant regulations, particularly from the state government, that impact how its training programs operate. Yearly audits of each program require evidence of achieving training requirements. XAS also has consultants from private ABA practice and a graduate program at a local university who conduct professional development opportunities. These are primarily, but not singularly, offered to clinicians as opposed to direct support professionals or other support staff.

Instructional design using the Social Infrastructure Framework

Bielaczyc (2006) describes the elements of the SIF as interconnected, with the culture serving as the "substrate" (p. 306). That is, culture is infused throughout the practices, socio-techno-spatial relations, and interactions with

the outside world. Given this, to make significant changes in designing learning experiences, the culture also needs to change. There is a challenge here, because changing the culture requires both some form of intervention and the participation/acceptance of the members of the culture. It is a careful balancing act between pushing too far, and not pushing far enough, and requires communication tailored to the culture. Hallmarks of the learning sciences such as application of principled practical knowledge (Bereiter, 2014) and an iterative design-based approach can ameliorate these issues.

Next, I will discuss two ID projects and how they connect with the elements of the SIF as well as how the broad, corporate level understanding of the SIF elements, especially culture, informed these specific examples.

Software simulation training

In 2018, XAS adopted a new electronic health record software system. Executive leadership wanted to conduct training for all employees who would be entering client demographic and service records in the system. The original request was for an instructor-led session with an "I do – We do – You do" approach. I suggested an automated step-by-step simulator training, given that individuals often only need such training resources when they are actually using the system as novices. However, as a non-profit with limited financial resources, the only technology available to implement this training design was PowerPoint. Nevertheless, both the learners and executive leadership viewed the resulting "training module" favorably. This project involved and impacted culture (expectations of what comprised training), practice (method of training), socio-techno-spatial relations (use of software and how/when/where learners used it), and interaction with the outside world (knowledge of how to use PowerPoint to create a software simulator). As a result, it made a small but noticeable shift in how the company viewed training and helped make the case for investment in more advanced ID software. At the same time, an early suggestion that we needed no training at all – that users could learn how to use the system on their own from other employees and the materials available online from the software company itself—was unacceptable. Because of the ABA background of the company and its executive leadership, not having some XAS-developed form of a "task analysis" describing, step-by-step, how to complete data entry into the system was not viewed as a tenable solution.

Compliance and ethics training

One regulatory requirement was for employees to receive compliance and ethics training. While this is a pro-forma expectation at many companies, XAS wanted to customize its training due to the company's cultural precedents, as well as the unique population it served. The initial prototype was a brief welcome video from our compliance officer, followed by a recording of a PowerPoint presentation with a voice-over narration. The stated objective for the training was primarily to make employees aware of the compliance program and comfortable with identifying and reporting possible issues. I developed a second version of the training, a board game adapted from the classic Clue game. Learners would consider ethical principles through the lens of employees from the various program lines, generate ideas about what unethical behavior might look like, and discuss ways that they could report lapses (phone, email to compliance officer, website, and so on). In a trial of the two approaches, there was a statistically significant difference between the end-of-course knowledge assessments, with those who played the game performing better. In this case, one interesting feature was the socio-techno-spatial relations. The original request envisioned employees completing the training on their own with a computer, a departure from the corporate training culture. However, the game design allowed for sharing of multiple perspectives and discussions about ethics, which was more in line with the training's actual objectives. Another factor, related to interaction with the outside world, was that the compliance officer was in an external mentorship program on corporate compliance, which encouraged businesses to adopt novel approaches for their training programs. Finally, this case demonstrates how even "check the box" regulatory trainings can become more meaningful learning experiences if businesses want them to be.

Discussion

The SIF provides one example of how the learning sciences can improve corporate training. There are other theories (such as activity systems) or specific frameworks that could also be applied. Bereiter (2014) argued for the importance of principled practical knowledge in improving education. With corporate ID, practice is often emphasized, while principles – the theories underlying learning – are overlooked. Regardless of the aesthetic quality or technical aspects of corporate instructional materials, there is little connection between learning theory and practice.

At the same time, corporate training programs are a significant source of adult learning. They require businesses to invest resources and hopefully lead to more fulfilled and more competent employees, which benefits

both the employees and the company. However, corporate training often views learning as a product and focuses on metrics like time spent in training or multiple-choice questions answered correctly.

The learning sciences has much to offer corporations to improve learning. To achieve this potential, though, we must pay careful attention to factors that influence the acceptance of different approaches to learning. We must also equip practitioners, such as instructional designers, with research-based approaches to design that can facilitate their work. Most importantly, we must prepare them with the communication skills necessary to advocate for the use of learning theories and design frameworks that reflect what we know about how people learn.

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International Society of the Learning Sciences

Sources of difficulties in reading comprehension in adults with ADHD

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Abstract: Academic success is highly dependent on students' ability to comprehend written texts. Students with Attention Deficit/Hyperactivity Disorder (ADHD) often struggle with reading comprehension, but the source of their difficulties is unclear. The current study compares reading comprehension, as well as linguistic and cognitive skills in adults with and without ADHD. Results show worse reading comprehension in adults with ADHD and an association between reading comprehension and sustained attention. Implications for reading comprehension instruction are discussed.

Introduction

Academic success is highly dependent on students' ability to read and comprehend written texts. Individuals with Attention Deficit/Hyperactivity Disorder (ADHD) often struggle academically (Barkley, 2000), and reading comprehension deficits, although not considered a primary deficit in ADHD, may contribute to these academic difficulties. It is currently unclear whether individuals with ADHD have reading comprehension difficulties and what underlies these difficulties if they exist. Some studies found that children and adults with ADHD have reading comprehension difficulties (Brock & Knapp, 1996; Samuelsson et al., 2004; Stern & Shalev, 2013), while others presented inconclusive findings (Ghelani et al., 2004). These inconsistencies may be related to individual differences in readers with ADHD, as well as to the tools that assess reading comprehension. Reading comprehension may vary as a function of cognitive and linguistic skills. In addition, the texts that assess reading comprehension differ in length, complexity, the degree to which they are meaningful and engaging, and their attentional demands, thus posing differential challenges to individuals with attention deficits. The type of reading comprehension questions can also affect the findings.

Most studies on reading comprehension in ADHD focus on identification of difficulties in reading comprehension. Little is known, however, about the nature of these difficulties. Reading comprehension is an active process in which the reader simultaneously extracts and constructs meaning from the written text, thus creating connections between the ideas presented in the text, and forming a coherent mental representation of the general message (Graesser et al., 1994). This process involves linguistic and cognitive abilities (e.g., vocabulary, memory, and attention), motivation (e.g., purpose of reading and interest in the content), and knowledge (e.g., topic knowledge and knowledge of comprehension strategies; Snow, 2002). Other critical components of reading comprehension are meta-comprehension, a special case of metacognition, and self-regulation. Meta-comprehension is the knowledge that readers have about their own comprehension (Flavell, 1979; Poissant, 2005). Self-regulation is the experiences, feelings, and thoughts that occur during reading, or any other ongoing cognitive activity. These experiences give individuals an internal feedback about their comprehension and allow them to use strategies to solve comprehension problems. Readers who are less confident in their comprehension may use more strategies to compensate for their poor understanding (Temelman-Yogey et al., 2020).

Individuals with ADHD have deficits in executive functioning (Pennington et al., 1993), and these deficits can affect each of the skills necessary for reading comprehension. For example, students with ADHD can struggle with remembering the text, with maintaining constant level of focus (i.e., sustained attention) during reading (Stern & Shalev, 2013), or with monitoring comprehension. Indeed, reading abilities of students with ADHD are often technical, with no deep semantic processing, and students may read an entire chapter but have no idea about its content (Levine, 1987). Students with ADHD may also be less motivated than students without ADHD, due to their earlier negative experience with reading comprehension. Understanding the cognitive mechanisms underlying reading comprehension will help create better assessment tools, and will help refine research-based instruction methods to promote the development of proficient comprehenders (Snow, 2002). The current study aimed to compare reading comprehension in students with and without ADHD and to characterize the source of reading comprehension difficulties in students with ADHD, if they exist.

Methods

Participants

Fifty-nine students from the Open University of Israel took part in an on-line study in exchange for course credit. Twenty-five participants (19 women, *M* age = 28.04 years, *SD* = 4.70) comprised the ADHD group, and 34 participants (*19* women; M age = 27.10 years, *SD* = 4.51) comprised the control group. All participants were born

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in Israel, they were native Hebrew speakers, and they reported no developmental or learning disabilities besides ADHD. The groups differed neither in age, t (57) = .78, p = .442, nor in years of education, t (57) = .22, p = .813.

Tasks

Neuropsychological testing

Participants answered some basic demographic questions and then completed a continuous conjunctive performance test (CCPT) to measure their sustained attention. In the CCPT, participants were presented with 320 geometric shapes and were asked to press the space bar when the target (a red square) appeared. The standard deviation of reaction times was used as a measure of the ability to keep a constant level of performance during the task, so that large SDs reflect poor sustained attention (Tsal et al., 2005). After completing the CCPT, participants performed the reading task, followed by an immediate recall task (Segal et al., 2019), as well as a Hebrew vocabulary test (Kavé et al., 2022). In the immediate recall task, participants named 12 pictures and were then asked to recall the names of the pictures. The memory score is the percent of items recalled correctly. In the vocabulary task, participants were asked to choose the correct meaning of 12 infrequent Hebrew words out of four alternatives. The vocabulary score is the percent of correct responses. Next, participants provided some more background information regarding their development and their language history, and then they rated the level to which seven ADHD symptoms characterized their behavior on a 1 (never) to 7 (very often) scale (Konfortes, 2010).

Reading tasks

Each participant read one of two informational texts: a text about the Taj Mahal (417 words) or a text about Babylon (426 words). Participants were asked to read the text and then to rate their comprehension ("how well did you understand the text on a scale of 1 (did not understand) to 4 (understood perfectly), as well as to judge their learning ("what are the chances that you will answer comprehension questions correctly on a scale of 25-100%?"). Then, they were presented with seven multiple-choice questions about the text. The accuracy score is the percent of correct answers to these seven questions.

Results

As shown in Table 1, participants with ADHD did not differ from control participants in memory and vocabulary, but they reported having higher levels of ADHD symptoms and their sustained attention was worse.

Table 1: Cognitive measures by group

	ADHD		control		t	p
	M	SD	M	SD		
Memory [a]	64.67	17.23	69.36	13.41	1.18	.244
Vocabulary [b]	48.33	22.18	54.17	21.64	1.01	.316
Sustained attention [c]	95.78	41.25	73.72	31.64	2.26	.028
ADHD symptoms [d]	21.00	5.07	15.85	3.69	4.51	<.001

[a] Percent of items recalled; [b] Percent of correct responses; [c] SD of reaction time to targets in milliseconds; [d] Level of reported symptoms.

Accuracy levels were similar across texts, t (57) = .46, p = .648, and therefore all further analyses were conducted for the two texts together. As shown in Table 2, participants with ADHD provided lower ratings of their comprehension than did control participants. They also judged their learning as less effective. Accuracy scores were lower in the ADHD group relative to the control group.

Table 2: Meta-comprehension and comprehension measures in the reading task, by group

	ADHD		Control				
	M	SD	M	SD	t	p	Cohen's d
Comprehension rating	2.92	1.04	3.38	.70	2.05	.045	.52
Learning judgement (%)	72.44	18.72	84.12	11.01	3.00	.004	.76
Accuracy score (%)	78.29	18.03	89.50	14.63	2.63	.011	.71

Table 3 presents the correlations between accuracy scores on the one hand and memory scores, vocabulary scores, sustained attention, and level of ADHD symptoms on the other hand. Sustained attention correlated significantly with accuracy scores as well as with ADHD symptoms.

Table 3: correlation analysis

	Memory	Vocabulary	Sustained attention	ADHD symptoms
Accuracy score	.23	.09	-.41**	-.07
Memory		.31*	-.04	-.20
Vocabulary			.05	-.10
Sustained attention				.36**

* $p < .05$, ** $p < .01$

Discussion

The present study explored whether adults with ADHD show difficulties in reading comprehension compared to age-matched students without ADHD, as well as the cognitive underpinnings of these difficulties.

Participants with ADHD reported higher levels of ADHD symptoms, they had significantly lower sustained attention, and their reading comprehension was worse relative to aged-matched controls. Participants with ADHD also rated the texts that they read as more difficult, and demonstrated lower confidence in their ability to answer comprehension questions than did participants without ADHD. The two groups did not differ in memory or in vocabulary.

These findings support previous reports of reading comprehension difficulties in adolescents with ADHD (Stern & Shalev, 2013), and suggest that reading comprehension difficulties persist into adulthood. These difficulties can also explain why students with ADHD often struggle academically (Barkley, 2000). Participants with ADHD have most likely dealt with reading comprehension difficulties since childhood, thus developing decreased confidence and increased awareness of their comprehension abilities over time. Nevertheless, they were probably unable to implement strategies to improve their reading comprehension.

Importantly, accuracy scores were not related to the level of ADHD symptoms, but to sustained attention, suggesting that inability to keep a constant level of focus impairs reading comprehension. Lapses of attention may impede the creation of connections between the ideas presented in the text, thus limiting the ability to understand the general message.

In the current study, there were no associations between memory and vocabulary scores and reading comprehension. This does not mean that memory and vocabulary are not important for reading comprehension. Instead, the findings suggest that these abilities do not suffice for reading comprehension and that sustained attention also plays a critical role in the process. Assessing sustained attention in poor comprehends will allow us to construct a more personalized educational plan for each reader according to the reader's specific cognitive functions, and to prevent frustration and increase confidence in reading and academic success.

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"It disrupts power dynamics": Co-Design Process as a Space for Intergenerational Learning with Distributed Expertise

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Abstract: This paper examines co-design as a space for collaborative learning with distributed expertise across generations and roles. We address a fundamental need in co-design spaces: to develop and surface expertise relevant to the design task across a team. We examine how knowledge building is experienced in a design process that has asymmetric expertise among youth, educators, and researchers. We used co-design to engage educators and youth in collaboration towards designing an Artificial Intelligence unit that centers equity and justice. We structured for joint inquiry to facilitate collective learning. We conducted interviews with participants to understand how they experienced codesign. We found our approach allowed for collaborative learning and interactivity among participants with different kinds of expertise.

Introduction and Background

Successful codesign requires a range of expertise and perspectives; just how to do so in a way that disrupts and transforms existing practice presents every co-design team with a challenge. Two motives for co-design are (1) to create conditions for design where diverse expertise can be surfaced, leveraged, and transformed (e.g., Bang & Vossoughi, 2016) and (2) to redistribute social power (Huybrechts et al., 2017). Co-designers have devised different strategies to accomplish these aims, such as creating novel activity structures for eliciting multiple perspectives (Matuk et al., 2016), mapping values of co-designers (Ryoo et al., 2015), and structuring participation to center perspectives of marginalized groups and communities (Ishimaru et al., 2018).

We build on the need to address such issues in research on co-design within the context of an effort to broaden participation of historically marginalized communities in STEM through the design of a unit focused on the sociocultural, ethical, and political dimensions of artificial intelligence using a storyline approach (Reiser et al., 2021). This paper aims to contribute to literature of participatory design, by focusing on co-design process as perceived by participants, towards understanding how we might design intentionally towards creating a collaborative learning where distributed expertise is developed in an intergenerational context that includes youth, educators, and researchers and where there was limited domain knowledge across all role groups.

Organizing for Intergenerational Codesign to Build Shared Expertise

To support codesigners in building expertise that could be distributed across the team, we created multiple specialized activity structures within the context of a week-long design workshop and the preparation for it (see Table 1).

Table 1
Co-Design Workshop Activities Aim and Structures

Aim	Activity Structures
Clarifying purposes	Engaging with everyday technologies Unpacking the AI goals together (subgroup)
Organizing for intergenerational design	Course to learn how to write storylines Organizing small groups where youth worked together as a group
Learning about AI	Identifying AI experts to join space Stations for learning

In this paper, we present the analysis of interviews conducted with participants to investigate how participants experienced the distribution of expertise and being in an intergenerational environment in co-design.

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Methods

In this section we describe the context of this study and participants, procedures of activities, instruments we used to examine participants' experience in co-design activities using interviews as an instrument, and the analytical approach used to examine their experience. We addressed the following questions: *How were participants' values reflected in their experience of co-design? What relationships did this co-design process afford or constrain for participants? How did their experience compare to other experiences involving building with others and youth?*

Participants

In this co-design workshop, eight educators and five young high school students (TS = teacher and student participants) participated in a five-day co-design workshop aimed at developing and designing an artificial intelligence unit that centers issues of equity and justice in artificial intelligence. Teachers' backgrounds and disciplines varied, and included High School English Language Arts (ELA), Middle school World Geography, Middle School Math, History, and after-school education programs focused on Media Literary and Agency. We invited high school students to join this co-design process as we wanted to attend to young people's voices and at the same time co-construct knowledge with them. Two months after the co-design workshop was completed, we invited all TSes for interviews. Twelve of 13 TSes were interviewed for addressing the research questions of this study. We also invited AI and AI Education experts to share their expertise in the workshop, two representatives from the district partner and four AI researchers who are experts in technology and artificial intelligence education. Four facilitating researchers led the co-design workshop to develop a storyline.

Data source

To address questions raised in this paper, one researcher conducted 12 interviews with teachers (n=7) and high school students (n=5) two to three months after the completion of the workshop. The protocol included questions designed to elicit participants' experience of the workshop, how it compared to other activities like it, key moments of the workshop, and the ideas they were exposed to or developed as part of the workshop. In addition, we asked participants about needs for teaching and learning if the units were used in their classrooms. All interviews conducted using an online conference application due to COVID-19. The interviews were recorded and transcribed using professional transcription services. One researcher reviewed the transcription for accuracy.

Analytical approach

To address our primary research question, we centered our analysis of interviews on (1) values participants reflected about their experience, (2) relations they described as were afforded or constrained in the co-design workshop, and (3) how this experience compared to other experiences they had in relation to work with others and building collaboratively. We conducted an inductive analysis that aimed at identifying themes and categories related to the three research questions.

Findings: Participants' Experience of Co-Design Workshop

Values and care in co-design

Throughout the workshop participants and researchers discussed norms and guiding equity-oriented principles in the co-design process and the ends towards which this learning space was organized (e.g., designing ethical AI literacies curriculum). We found that values and acts of care were enacted in different ways by teachers, researchers, and students, according to interviews with participants.

Multiple participants described that the co-design space was one where participants *showed respect for one another, felt welcomed, and positioned as valued co-designers.* Participants said that care and respect were values evident among teachers, researchers, and young students in ways that ideas were taken into consideration and invited in the space, and participants' backgrounds and prior experiences even as non-experts in the subject matter were respected. For example, one teacher mentioned "we were treated like professionals the whole time....it felt like it was leaning into everyone's different expertise." Notably, this teacher was someone who did bring significant expertise as a technology instructor in their school, specifically related to AI.

Relationality in co-design

Participants observed that relationships evolved in the space, and they said that co-design was a safe space to build relationships across people with different kinds of expertise and ages. These relationships developed between participants also included thinking collectively and individually about communities they work with (e.g, teachers, parents, students, communities of color).

When *building relations* in the space, participants said facilitators encouraged and designed for communication among all participants. Such interactions supported participants to learn about one another and build relations with one another. For example, a student asserted, said "I really liked how we could interact with other people and learn more from them [working together in groups]." Participants said that the co-design workshop was a *safe space* where they could "take risks without feeling embarrassed." A key part of that for participants was that participants felt they could seek help and pose questions, without the risk of judgment. One teacher who acknowledged they do not have expertise in AI, said "it gave space for everybody else who didn't know and knew they didn't know and felt uncomfortable by the fact they didn't know, to kind of grow."

As described earlier, the space brought participants with diverse and varied expertise and experiences to the space. We found that this diversity and variety allowed for fluid positionalities to be enacted and at the same time disrupted relations between teachers, students, and researchers. In other words, *the positionality of participants in relation to others* took different forms depending on type of activities and discussion topics, that is, participants described their role in relation to others in different ways taking different positionalities.

Uniqueness of experience: comparing this experience with other experiences

In analyzing how participants compared co-design to other experiences, we focused on how participants experienced the redistribution of power in the context of knowledge building compared to other experiences. Participants' experience of the co-design process and outcomes was described as different from other experiences in educational settings or professional settings (like curriculum design, professional development) when it comes to who is involved in the co-design process (e.g., diverse people including students) and the intentionality in co-design method (e.g., using storyline approach).

Participants described co-design as offering an opportunity to think about educational possibilities that were different from their previous experiences. For them, the co-design process was *disrupting the status quo* for what counts as design of curriculum and learning environments. For example, one teacher said, when asked if they would recommend this session to other educators, "Because it disrupts...it disrupts power dynamics. It disrupts our notion of what curriculum can be and look like. And then I think ultimately it infects the K-12 space with something that actually seats or has the potential to seat young people as co-conspirators in developing their own learning." This alternative possibility was also shared by students, who experienced the opportunity to build with teachers and have a say on the curriculum design process as a unique learning opportunity in which, "they [the teachers] were learning from us as we were learning from them" reflecting on the difference between power dynamics they often have with teachers versus during the co-design session.

Building collaboratively as a process and outcome

Participants described the co-design space as one where they were *building together*. Participants described the co-design space as affording collaborative building and thinking with others and building relations among participants through interactions during activities. Interviewees recognized that the process of building together involved them exchanging and navigating their varied expertise, experiences, and voices towards engaging in activities. Importantly, building together connected to who is in the room is enriching to the teachers and students experience. That is, the presence of participants of color who shared common cultural practices as expanding of what counts as diversity beyond the expertise in the space. One teacher, for example, described that an essential aspect of building with other participants was having people with varied expertise yet also a representation of people of color, "I also think, there were quite a few people of color in the room. I personally, as a person of color like when I'm designing, I like to be around other people who look like me and who have other experiences like me and it always enriches the session just like immediately." One student described an example where participants constructed an idea when exchanging perspectives and discussing, this example not just illustrate the notion of building together, but also building together with youth ideas in particular, "The discussion boards we did on the Jamboards, we all put our thoughts into it and we could see clearly our different perspectives of it. When we were saying stuff, the adults branched off what we were saying. So they understood where we were coming from and they started discussing more about it, so we added more into the conversation."

Participants described different types of ideas that were constructed with other participants and researchers. The participants described content related ideas (e.g., learning about racism in games), learning about co-design structure and process as a methodology, and ways to use materials and tools used in activities. One idea that resonated with multiple participants is learning about sociocultural dimensions of AI, such an idea was constructed in discussions among participants and researchers. For example, one teacher said, "the way there was that woman who did this research about how the facial recognition software mostly only worked on white faces, because of the data set was from only white faces and things like that. The way because the data that the AI uses

is from our racist history, it is reproducing that racism in a way that's neutral, because it's a computer program, that was a big take away from me."

Conclusion and Future Work

Several intentionally designed activity structures supported the development and elicitation of expertise in an intergenerational context. We found that these activity structures helped create a "safe space" for collaboration and knowledge building among participants around justice centered topics that matter to participants. In addition, positioning all participants as "not expert" in AI facilitated participation across generations and across the research-practice divide. For young people, the intentional design of the space did not require youth to think like adults; rather, intentionally designing spaces where they can maintain who they are, and assert their childhood/youth-hood as to express their perspectives (e.g., Cortez & Lizárraga, 2020).

Such findings are an invitation for co-design researchers to attend to equitable participation and ethics in structuring collaborations in co-design processes. Such a lens can disrupt power dynamics among participants and create a possibility for varied positionalities and ways of knowing and being to build knowledge collaboratively. In this paper we attended to the experience of educators and young participants in the co-design process as it is narrated by them. Future work we aim for will be centered on identifying and connecting between participants perceived experience and the actual engagement in situ.

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Students' changing understanding of psychological evidence: Integrating evidence evaluation in psychology instruction

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Abstract: This study extends the prevailing emphasis on evidence in the natural sciences by offering a novel fine-grained analysis of how undergraduate students evaluate psychological evidence. The study employs the Grasp of Evidence framework to explore psychology students' epistemic ideals and processes for evaluating popular psychological evidence, and examines how these change following a course that included collaborative evidence evaluation and design tasks. Analyses of pre and post evidence evaluation assessments reveal three key shifts in students' grasp of evidence: in perception of the sources of psychological knowledge, in views of scientific objectivity, and in definitions of psychological phenomena.

Introduction

To date, the majority of research on evidence evaluation practices has focused on the natural sciences (e.g., McNeill & Berland, 2017), and relatively little attention has been given to how students engage with evidence from the social sciences in general, and psychology specifically. This is particularly problematic because such evidence has become a staple of popular accounts of human behavior, and often informs public policy (e.g., Einfield, 2019). Moreover, evidence in psychological research has unique attributes as it is based on studying complex and unobservable everyday phenomena in ways that are amenable to empirical examination and replicable by other scientists (Elmes et al., 2011). Attentiveness to these characteristics is particularly challenging as psychology students often struggle to appreciate the scientific foundations of psychology (Balloo et al., 2018). However, we currently know little about how undergraduate psychology students' competence to evaluate psychological evidence can be fostered. Accordingly, this study examined if and how psychology students' ideals and processes for evaluating popular psychological evidence change following an introductory psychology course that provided opportunities for engaging in collaborative online evidence evaluation and design tasks.

Evidence evaluation poses unique challenges to students and laypersons because they lack the extensive disciplinary and methodological knowledge that is needed to understand and evaluate study designs and measures (Duncan et al., 2018). Thus, lay understanding of scientific evidence is inevitably bounded. Accordingly, Duncan et al. (2018) proposed a theoretical framework, called the Grasp of Evidence framework, which unpacks the dimensions of evidence that are relevant for preparing students to engage with evidence as outsiders to science. Duncan et al. (2018) argue that to meaningfully engage with science, laypersons need to grasp two aspects of evidence. The first aspect is experts' evidentiary practices – how experts gather, understand, evaluate, interpret, and integrate evidence. The second aspect is laypersons' evidentiary practices, that is, of how laypersons can use evidence despite their bounded understanding of science.

Within each of these aspects, Duncan et al. (2018) identify specific epistemic aims, epistemic ideals, and reliable epistemic processes for reasoning with and about evidence (Chinn et al., 2014): *(a) Epistemic aims* are the epistemic products or outcomes that people set to achieve. *(b) Epistemic ideals* are the criteria or norms that are used to evaluate whether epistemic aims have been achieved and the quality of epistemic products. For example, some of the epistemic ideals of expert evidence evaluation are the appropriateness of the methods and measures and the validity of the conclusions. *(c) Reliable epistemic processes* are the procedures, strategies, or methods that people can use to successfully achieve epistemic aims. Reliable processes of expert evidence evaluation involve, for example, scrutinizing the appropriateness of the study design. (Duncan et al., 2018).

Though there is a dearth of research on how students evaluate psychological evidence, researchers have identified some overarching challenges for evidence evaluation in psychology. First, students often fail to appreciate, or even actively doubt, the scientific basis of psychology as the study of human behavior (Balloo et al., 2018). Second, students often perceive objectivity in psychology as the negation of subjectivity: science is objective to the extent that it remains value-free (Douglas, 2009). However, objectivity does not require rejecting values, but arises from the using trustworthy processes for interacting with the world, and from social processes of validation, agreement formation, and debate. Third, students struggle to grasp how psychological knowledge is defined and evaluated through the use of valid operational definitions of subjective and complex phenomena.

Introductory psychology courses could provide an opportunity for cultivating such disciplinary epistemic practices. However, such courses are commonly lecture-based and have prioritized the coverage of content

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knowledge in the various domains of psychology at the expense of active engagement with epistemic practices (Gurung & Hackathorn, 2018). Researchers have stressed the importance of explicating the psychology's scientific and offering experiences that illustrate how research findings are underpinned by research methods.

Accordingly, this study set out to examine the following research questions: (1) How do undergraduate students' epistemic ideals and processes for evaluating popular psychological evidence change following an introductory psychology course designed to foster evidence evaluation competence? (2) How are students' evolving evidence evaluation ideals and processes reflected in collaborative evidence evaluation and design tasks?

Methods

Participants and Course Design

The study was conducted in a first-year undergraduate introduction to psychology course in a large university in Israel. The sample included 120 students (24 groups of 5 students, 70% female, 30% male). The course consisted of eight video lectures covering the basic domains of psychology. In addition, to facilitate engagement with psychological evidence, three collaborative online evidence evaluation tasks, and face-to-face meetings that centered around students' experiences in these tasks, were added to the course. The synchronous online tasks were conducted in the chat application on the course's Moodle platform. In each task, students were asked to evaluate popular accounts of psychological evidence and to formulate more scientifically rigorous ways to study these phenomena. The information sources (a newspaper piece, a TED talk, and a podcast) and the subjects discussed (e.g., emotions, approaches to psychotherapy) were intended to reflect psychological evidence students are likely to encounter online in their everyday life.

Data Sources and Analysis

Data sources included an evidence evaluation assessment, administered at the beginning and end of the course, and students' written discussions in the synchronous online group tasks. In the evidence evaluation assessment, participants read three popular reports that presented psychological evidence of varying quality ranging from low quality anecdotal evidence to a detailed report of a well-designed study. The pre- and post-assessments addressed different popular psychological topics (pre: child rearing; post: sleep), but the reports had highly similar source and evidence features and quality. Participants were asked to rate the trustworthiness and quality of each piece of evidence and to justify their evidence ratings in writing. The analysis focused on identifying epistemic ideals and processes of evidence evaluation in participants' justifications of their evaluations. We iteratively developed a coding scheme relying on the Grasp of Evidence framework (Duncan et al., 2018). Interrater reliability for all codes was higher than Cohen's Kappa > 0.78 ($M = 0.90$, $SD = 0.07$), which is a substantial level of agreement.

The goal of our qualitative analyses of students' discourse was to elaborate and refine the quantitative findings. Hence, we first quantitatively identified codes in which there were significant changes between the pre- and post-assessment. We then qualitatively analyzed episodes in which these codes were discussed by paying attention to the meaning of the codes in students' discourse and how this meaning was negotiated.

Findings

Theme I: Shifts in sources of knowledge – Decreasing reliance on personal knowledge

There was a significant decrease (from 69% to 52%, $p = .005$) in students' reliance on the ideal of *personal coherence with experience and intuition* to evaluate evidence ("Conclusions align with the reader's personal knowledge, experiences, or intuitions."). The decrease in personal coherence may reflect a growing recognition of the limitations of lay knowledge and a greater sensitivity to the division of cognitive labor between experts and laypersons. Yet, this decrease could also be due to increased disciplinary skills for evaluating evidence, which may have taken the place of reliance on personal judgments. Despite this decrease, even after the course, half of students still relied on personal coherence when evaluating evidence.

Analysis of the group discussions revealed that students rarely relied on personal information. Moreover, in contrast to the explicit reliance on personal knowledge or experience in the pre- and post-assessment tasks, in the group discussions personal information was auxiliary and implicit. We could not find examples in which students openly appealed to personal experience or knowledge in order to justify their proposals or arguments. This position was reserved for disciplinary knowledge about psychological theories and research methods.

Theme II: Shifts in views of objectivity – Towards procedural objectivity

There was a significant decrease (from 41% to 17%, $p < .001$) in appeals to the ideal of objectivity ("Conclusions are not influenced by researchers' subjective experiences, preferences, or values."), accompanied by increases in

use of the processes of replicating results ("Researchers attempt to confirm the results by running the study again with additional samples etc."; from 24% to 55%, $p < .001$) and using appropriate instruments ("The use of research instruments that can accurately and reliably measure the phenomenon at hand."; from 13% to 23%, $p < .05$). Taken together, we suggest that these shifts indicate changes in students' understanding of objectivity. Pre-instruction, students leaned towards depicting objectivity as achieved when scientific inquiry is unaffected by researchers' subjective judgments, preferences, and perspectives. Following instruction, students appeared to develop a more procedural view of objectivity, with increased mentions of measurement processes. In addition, students attended more to the social process of replicating results.

The collaborative tasks required evaluating evidence and proposing more rigorous means of studying psychological phenomena, which led students to discuss procedural aspects of objectivity. Consider, for instance, one group's discussion on which research instruments could be used to study emotions:

Speaker	Time	Utterance
John	08:33	Using questionnaires?
Dana	08:34	If we identify faces, we can analyze emotions, no?
George	08:35	Measuring brainwaves, measuring heartbeat, and measuring facial expressions could give us some something. If we use a large enough sample it could be quite accurate.
Sara	08:35	Yes, we need to combine different measures because emotions are really complex, and change from person to person.
Dana	08:36	And to construct experiments that include a verbal description and see if they align.

The group wrestles with the question of how to scientifically study emotions via a dialogical process in which they construct and critique each other's ideas. Throughout this discussion, notions of objectivity are not attributed to researchers, but rather to research instruments. Hence, this discussion is underpinned by an effort to identify procedurally objective (Douglas, 2009) ways to measure emotions, i.e., ways that would enable researchers to measure emotions in a systematic, quantifiable, and consistent manner. Nonetheless, issues related to replicating results were infrequently mentioned in the group tasks, which could reflect the fact that students focused on evaluating and designing a single study.

Theme III: Shifts in definitions of psychological phenomena – Towards operational definitions

The third shift involved changing views of the conceptualization of psychological phenomena. Specifically, students focused less on the nature of psychological phenomena and more on how these phenomena can be studied empirically. This shift was reflected in a decrease in the clarity of definitions ideal ("The phenomenon studied, and the variables, should be clearly and precisely defined."; from 44% to 18%, $p < .001$), together with an increase in mentions of valid methods ("Reliance on methods and study design that appropriately represent the phenomenon the researchers wished to study."; from 2% to 38%, $p < .001$). We suggest that these changes expose a shifting understanding of the interplay between evidence and phenomena. Instead of placing the onus on precisely conceptualizing the phenomenon itself, the focus shifts to finding valid ways to empirically study and measure these phenomena – formulating operational definitions that describe phenomena in measurable terms.

In the group discourse, students increasingly discussed the need to develop conceptually clear operational definitions. This was most salient in the third task, in which participants were asked to devise a scientific way to examine which therapeutic approach is "deeper". For example, consider this excerpt:

Speaker	Time	Utterance
Ben	09:05	We need to define "depth" and find a quantifiable way to measure it.
Merriam	09:06	Wait one second, what do we mean by depth? Therapy in which the therapist and patient have a deep relationship?
Ana	09:06	Maybe we can conduct an experiment that will examine whether patients know what the sources for their negative thoughts are.
Merriam	09:07	Therapy that discusses the deep aspects of an individual- the unconscious, events that took place in the past.
Ben	09:07	In my opinion, depth is the "meta-feeling" of the patient towards their own therapy. And not necessarily the outcome.
Merriam	09:07	But can we really know?
Ben	09:07	Maybe we can design a questionnaire.

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The group formulates and criticizes attempts at defining "depth" in treatment (deep relationship, sources of thoughts, unconscious events, etc.). This discussion is tied to quantifiable ways to measure depth. Hence, the request to collaboratively design experiments that test ill-defined psychological phenomena ("depth" of treatment) led to meaningful discussions of how to clearly define and operationalize constructs in valid ways.

Discussion

To the best of our knowledge, this is the first study to map in detail the epistemic ideals and processes are used by students to evaluate psychological evidence. Participants exhibited three main shifts in their evidence evaluation practices. First, there were shifts in views of sources of knowledge, with a significant decrease in reliance on personal knowledge. Nonetheless, even post-instruction, about half of the students appealed to their personal experience to evaluate evidence, suggesting that what develops is the ability to coordinate personal and disciplinary knowledge. Second, we identified shifts in students' views of objectivity – the emphasis shifted from objectivity as a lack of subjective bias to a more procedural view of objectivity, according to which scientific evidence is justified through the social processes underpinning its production (Douglas, 2007). The need to formulate precise and replicable means of studying psychological evidence in groups tasks, led to an emphasis on procedural aspects such as using reliable research instruments. Third, there were shifts in definitions of psychological phenomena, as students paid more attention not to the phenomenon itself, but rather to how it is conceptualized in a way that renders it amenable to scientific study. In the group tasks, students engaged with the challenge of translating everyday psychological phenomena into operational definitions. The necessity to do so in a group, led students to both explicate their own thinking, and to critique and develop the definitions and measures suggested by their group members.

These observations lead us to suggest three emerging design principles for engaging students with psychological evidence. First, providing students with ample opportunities to evaluate psychological evidence from a disciplinary perspective. This positioning encourages students to rely on disciplinary norms and standards rather than personal knowledge. Second, students' evaluation practices could be honed when they encounter evidence of diverse quality such as popular accounts, which include variations both in the evidence's quality and the rigor of its presentation. This may support a more refined understanding of the scientific work due to the need to disentangle unclear and partial accounts of evidence. Third, students stand to gain when they have opportunities to engage in collaborative evidence critique and design: not only explicating their thinking and critiquing others', this process is highly reflective of the nature of psychological research – simulating the processes scientists engage in when aiming to critique and improve existing operational definitions and measures.

Future research could address these issues while also tackling the limitations of the current study. First, as it did not include a control condition (for ethical reasons), we cannot evaluate the contribution of the different components of the course's design. Further, students did not have opportunities to integrate evidence from different sources or engage with more comprehensive bodies of evidence, which would have allowed them to explore more deeply the social and procedural nature of scientific evidence. Also, the tasks' emphasis on positioning students as experts came at the expense of paying more attention to lay evidentiary practices.

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Affordances and Constraints of Online Museum Experiences for At-Home Science Engagement During the COVID-19 Pandemic

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Abstract: Online museum experiences, or OMEs, expand access to museums beyond physical buildings. With limited visitation during the COVID-19 pandemic, many museums increased OME offerings, including those marketed toward families. However, as most OMEs are developed for K-12 audiences, we have yet to understand how OMEs support–or fail to support–families' engagement with science. To investigate how OMEs facilitated or constrained families' engagement with at-home science learning, we conducted semi-structured interviews with parents and used quantitative discourse analysis to identify emergent affordances and constraints. These findings can inform the design of OMEs that effectively support families' at-home engagement with science.

Introduction

During the COVID-19 pandemic, many museums developed distance learning programs to support visitors' engagement and learning in lieu of physical visits (Ennes, 2021). With limitations on physical visits, online programs offered alternative avenues for connecting visitors with museums. These programs, which we refer to as online museum experiences (OMEs), range from digitized collections to recorded tours and live investigations of phenomena (Chong & Smith, 2017). Over 1,200 OMEs are available through an online database curated by the American Alliance of Museums (AAM), with filters for content area, age range, and more (AAM, 2021).

While OMEs are available to the public, including families, we have a limited understanding of the ways that OMEs support families' engagement with science learning. Pre-pandemic, most OMEs were designed for use by K-12 students and teachers (Ennes, 2021). However, the pandemic incentivized development of OMEs for broader audiences (Ennes, 2021). Given the relatively new development of OMEs for families, we have yet to identify how OMEs support families' engagement and learning, including with science topics. We focus on this issue for two reasons. First, parents/guardians (hereafter "parents") play a pivotal role in supporting remote learning during the pandemic (Budhrani et al., 2021; Garbe et al., 2020). Second, designers cannot assume that what works in physical museums will automatically translate to OMEs, or that OMEs should aim to replicate physical visits given the unique affordances of online environments (Din, 2015; Ennes, 2021). In response, OME designers must identify key factors that support ease of use, learning, and enjoyment for families (Lin et al., 2012).

To this end, we analyzed 11 families' participation in science-focused OMEs for at-home learning during the COVID-19 pandemic. Our research questions were: *which characteristics of OMEs facilitated families' engagement with at-home science learning, and which characteristics constrained engagement?* We used quantitative discourse analysis (Mercer, 2004) to develop a coding scheme that identified emergent affordances and constraints of OMEs based on parents' feedback as shared during semi-structured interviews. This paper reports on affordances and constraints for at-home science learning among families, with the potential to inform future design of effective, engaging OMEs.

Theoretical Background

Pre-pandemic, most digital programs designed by museums were intended for K-12 audiences (Ennes, 2021). Virtual field trips (VFTs) are designed as multimedia-rich experiences that reduce financial and logistical barriers, generate access to experts, and emphasize learner-centered pedagogies (Klemm & Tuthill, 2003; Lacina, 2004; Zanetis, 2010). Yet, VFTs can unintentionally recreate barriers to access, such as by requiring English fluency, Internet access, and quiet environments (Klemm & Tuthill, 2003; Stylianou-Lambert & Stylianou, 2010). Also, VFTs differ in quality of design, including alignment to educational standards (Klemm & Tuthill, 2003; Zanetis, 2010). While VFTs offer alternative means of accessing museums globally, they are not without drawbacks.

The pandemic incentivized adaptation of existing digital programs and creation of new programs for wider audiences as delivered through synchronous meetings, social media, websites, and email (Ennes, 2021; Mitchell, 2019). These programs could supplement subject areas de-emphasized by remote learning, such as the arts and physical education (Budhrani et al., 2021). Yet, this benefit was less available to families without resources and/or self-efficacy to use technology (Garbe et al., 2020). Given families' status as a relatively new audience for digital programs, program designers must work with families to identify their needs and establish value, especially for families overwhelmed by remote learning (Flaccus & Gecker, 2020; Garbe et al., 2020).

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To understand how OMEs impacted families' engagement in at-home science learning, we used Gibson's (1986) conceptualization of affordances and constraints to identify positive and negative OME characteristics that affected families' engagement. Gibson (1986) described how the properties of people and their environment allow or prohibit certain actions or interactions (i.e., affordances and constraints0. People must be able to perceive affordances to act on them, including in digital environments where people must interpret the meaning of symbols, text, and multimedia to engage in learning (Greeno, 1994; Norman, 1999). This paper investigates the perceived affordances and constraints of OMEs that impacted families' engagement with at-home science learning toward the goal of informing designs for online informal learning experiences that effectively engage families.

Methods

This study focused on families' use of OMEs during the COVID-19 pandemic, with "family" referring to adults and children in the same household. We studied families because of parents' important role in supporting emergency remote learning (Budhrani et al., 2021; Garbe et al., 2020). We recruited 11 families through social media and e-newsletters and interviewed one parent per household (n = 11). Of 11 parent interviewees, seven identified as female, three as male, and one as genderqueer. Ten parents were white, and one was South Asian. Parents' mean age was 41 years old. Most parents (82%) had completed at least a master's degree. Children included 11 male children, six female children, and one non-binary child. Seventeen children were white, and one was South Asian. Children's mean age was 6 years old. Dependent on age, children experienced remote learning and/or parent-supervised activities in lieu of school or daycare. All families had Internet access at home.

Data sources included 11 semi-structured interviews with parents conducted from Dec. 2020 – Mar. 2021 by the first author. Each parent reflected on at least one self-selected, science-focused OME during the interview. Interviews included the following questions: (1) How would you describe the OME you shared with your child(ren)? (2) What kinds of goals did you have, broadly, when you started that experience? (3) What kinds of science learning goals did you have when you started that experience? (4) What do you remember from your experience? (5) How did you see your children learn during the experience? (6) Have your children mentioned the experience since? (7) Would you recommend this experience to others? (8) In your opinion, what tools in this experience were the most useful for learning? (9) Did you continue to investigate this topic afterward? If so, what other resources did you use? (10) What kinds of experiences or resources would you like to use in the future? Probes to elaborate were used when appropriate. Interviews lasted from 12 to 45 minutes (mean = 23 minutes).

We analyzed interviews using quantitative discourse analysis (Mercer, 2004) to develop an emergent coding scheme from parents' responses. We watched interviews independently to generate possible codes, then developed a coding scheme based on overlapping observations. We checked interrater reliability through independent coding of over 20% of the data (249 turns of 1,004 total turns of talk). Global Cohen's kappa was 0.90, which is considered "strong" (McHugh, 2012). Any differences were resolved through discussion. We independently coded remaining turns, then calculated the percentage of families mentioning each code and the percentage of individual codes within total turns of talk. Details of the coding scheme (including individual kappa values, descriptions, and examples) can be found here: https://bit.ly/3Jj3uHB.

Findings

During interviews, all parents shared their motivation for choosing to interact with a specific OME. Families were most often motivated by content or subject area (91% of families), followed by place or geographic location (64%). Five families mentioned that the study itself motivated them to interact with an OME (45%), while two families (18%) selected OMEs based on school or homeschool assignments.

Parents mentioned 14 characteristics of OMEs that facilitated their engagement (see Table 1 below). All identified affordances were emergent, not predetermined. Parents most frequently described the multimodal, interest-driven, and entertaining nature of OMEs. Four affordances specifically focused on support for engagement with science, such as exposing children to science topics and developing interest. Most parents thought OMEs could promote science and engineering practices, such as developing experiments and making predictions. Parents also saw OMEs as pedagogical supports that helped them to support their children's learning. Several parents reflected on their own experiences with K-12 science education. We observed variety in parents' science backgrounds; one parent received little K-12 science instruction while another had been a science teacher.

Parents also described constraints of OMEs for supporting at-home learning (see Table 2). Many families preferred physical activities and felt that OMEs were lacking compared to physical or outdoor activities. Also, OMEs were not considered to be as good as the "real thing" when visiting museums. Some parents preferred books over OMEs when supporting children's learning about science. Others mentioned concerns over screen time required by digital programs, especially in addition to remote learning, and wished to limit screen time even while recognizing potential benefits of OMEs. Parents also noticed when OMEs provided insufficient instructions,

follow-up resources, or support for varying background knowledge. Last, parents noted when topics were interesting to some, but not all, family members.

Table 1
Relative Frequency of Affordances Mentioned by Parents

% Families	% Turns	Affordances for Participation & Science Engagement
91%	5.6%	Multimodal; OMEs incorporated text and multimedia
91%	5.0%	Interest-driven; OMEs reflected parents' or children's interests
91%	3.2%	Entertaining; OMEs were enjoyable to interact with
82%	3.8%	Accessible; OMEs promoted access to people and places and incorporated everyday resources
73%	3.3%	Hands-on; OMEs featured hands-on activities or experiments
73%	1.9%	Educational; OMEs offer educational content and/or activities
64%	2.7%	Attention-sensitive; OMEs were developmentally appropriate for children's attention spans
64%	2.1%	Flexible; OME topics were switched quickly and easily
64%	1.6%	Shared; OMEs fostered interaction among family members
45%	0.8%	Vetted; OMEs offered research-based information
91%	3.6%	Exposure; OMEs exposed children to science concepts and possible interest
72%	3.7%	Inquiry; OMEs helped children to ask questions about phenomena
72%	2.2%	Parent support; OMEs helped parents to talk about science
45%	1.7%	Parent reflection; OMEs helped parents to reflect on relationships with science

Table 2
Relative Frequency of Constraints Mentioned by Parents

% Families	% Turns	Constraints on Participation
64%	1.2%	Physical activities preferred; OMEs lack the feeling of a physical museum visit.
27%	0.9%	Insufficient instructions; OMEs did not provide enough instructions or resources.
36%	0.7%	Books preferred; books are better sources of information than OMEs.
27%	0.5%	Conflicts over screen time; OMEs increase screen time beyond comfort level.
18%	0.2%	Split interests; OMEs do not reflect the whole family's interests.
9%	0.7%	Lack of parent support; OMEs lack sufficient background content

Discussion & Conclusion

We aimed to understand how OMEs impacted families' engagement with at-home science learning during the COVID-19 pandemic. By analyzing semi-structured interviews, we identified 14 affordances that facilitated families' engagement, with four focused on science, along with six constraints on engagement. These findings have implications for the design of OMEs that support informal learning about science in home settings.

Science content played a major role in families' selection of a particular OME, which we expected based on prior research about families' motivations for visiting museum websites (Lopatovska, 2015) and the general interest-driven nature of informal learning. This study also revealed that a museum's geographic location played a major role in families' selection of OMEs, with OMEs allowing families to virtually travel to places that could not be accessed during the pandemic. Further investigation of the geographic appeal of OMEs is warranted to understand how OMEs can be designed to teach science from both nearby and distant locales. We were initially surprised by the schooling motivation, given our focus on informal learning, but we found that homeschooling families already used OMEs on a regular basis to support their self-directed learning goals.

This study expands on earlier research about museum practices during the pandemic (e.g., Ennes, 2021) by analyzing emergent feedback from parents, rather than predetermined characteristics (e.g., Lin et al., 2012), with attention to constraints, too. Identifying both affordances and constraints expands the field's understanding of "good" design for family-friendly OMEs, with insights for genuinely supportive digital experiences that avoid common pitfalls. Our findings reiterate prior research about family-friendly characteristics, both digital (Lin et al., 2012) and physical (Borun et al., 2008), in that experiences should be multimodal, fun, and social. However, the ways in which physical affordances extend to online environments must be carefully considered, as OMEs present unique possibilities and limitations beyond replication of physical exhibits (Ennes, 2021). As the pandemic introduces new technologies for self-directed learning, designers of informal and/or online learning may benefit from research about technology-specific affordances and their impacts on science education.

This study is limited by a small, narrow sample of parents (who were mostly white and educated with Internet access at home) despite our efforts to recruit a more diverse sample (e.g., advertising free Internet Hotspots). Parents with access to education and resources may be more inclined to engage in learning activities such as OMEs during leisure time (Hood, 1983). To investigate this connection between parents' education and interest in OMEs, we plan to analyze surveys collected during this study about families' use of OMEs before and during the pandemic and their attitudes toward teaching and learning about science. We noted that two demographically similar families had very different experiences with OMEs; we plan to analyze their experiences as contrasting cases. We also plan to examine videos of families' interactions for evidence of scientific reasoning and/or learning. We would like to expand this study with a greater diversity of families, including more homeschooling families, to learn more about OMEs' role in self-directed learning.

In conclusion, this paper contributes emergent insights about the affordances and constraints of online museum experiences for at-home science learning. While families engaged with different OMEs, their interviews revealed common observations about the design of OMEs that facilitated or constrained engagement. This paper also emphasizes the role of families as relatively new and unique users of OMEs. Together, these insights can inform designs for OMEs that effectively support family-friendly engagement and learning.

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A Path Analysis of Gender Differences in Social Presence in Online Course Discussion Forums

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Abstract: *Online social presence*—the degree to which individuals project their identities and personalities into a web-based community—plays an essential role in fostering a connected and satisfying learning environment. The present study's aim was to explore gender differences in behaviors related to social presence in an online course. Using path analysis, we found that students identifying as women or non-binary were more likely than men to use indicators of mood, feeling, and emotion when posting to an online college course discussion forum, holding posting frequency constant. These results have implications for instructional strategies aimed at facilitating social presence in online learning environments.

Introduction

Social presence theorists aim to provide insight about online social interactions by examining the degree to which individuals "project themselves socially and emotionally" in online spaces (Garrison et al., 1999, p. 99). When online learners are socially present, they are perceived as real individuals with histories and fully formed personalities (Kehrwald, 2008). Social presence allows students to overcome feelings of loneliness or isolation typical to online settings by identifying with others (Kehrwald, 2008), which in turn leads to improved course satisfaction and learning (Swan & Shih, 2005). Thus, social presence often makes the difference between an online environment characterized by coldness and isolation, and one characterized by connectedness and interpersonal contact.

However, although social presence can be a critical component of any online learning community (Rovai, 2002), it is possible that not all students contribute to and experience social presence in the same way. As such, "it is unwise to presume that one particular online instructional strategy would affect all students equally" (Rovai & Baker, 2005, p. 32). Thus, to target all students' interpersonal needs, we need to improve understanding of online communicative behaviors from diverse students.

In this research, given our interest in the relationship between identity and technology in learning environments, we examine how online behaviors related to social presence may differ along gendered lines because gender is "created, maintained, and changed through communication" (Houser et al., 2019, p. 36). Survey studies have found that compared to men, students identifying as women perceive the online environment as having greater levels of social presence (Richardson & Swan, 2003), feel more connected to other students (Rovai & Baker, 2005), and are more likely to see the Internet as a tool for interpersonal communication (Jackson et al., 2001). Thus, it is possible that socially constructed conceptualizations of gender that associate strength and independence with masculinity and emotion and dependence with femininity (Morgan, 2021) yield differences in online behaviors that impact social presence.

Existing studies typically measure social presence using self-report scales, which are often inconsistent in their definitions of social presence (Lowenthal, 2010) and unable to assess behaviors relevant to social presence in real time. Therefore, our research is "concerned not just with how people perceive each of the presences *but also with what people … actually do during online courses*" (Lowenthal & Dunlap, 2014, p. 27, emphasis added).

The present study

Our investigation explores gender differences in three defined categories of social presence (affective, interactive, and cohesive) when posting to an online course discussion forum because each of these plays a role in creating a connected learning community (Garrison et al., 1999). *Affective* social presence is "the expression of emotion, feelings, and mood" (Rourke et al., 1999, p.6); *interactive* social presence is evidenced by attentiveness, acknowledgement, and reinforcement from one's peers (Rourke et al., 1999); and *cohesive* social presence is shown by "activities that build and sustain a sense of group commitment" and unity (Rourke et al., 1999, p.8).

This research is significant because students' behaviors when interacting via forums impact perceived social presence (Tu & McIsaac, 2002). Thus, it is important to understand how student behaviors are related to social presence in such settings. Our research question is: *Are there gender differences in the use of affective, interactive, or cohesive indicators of social presence in online course discussion forums?*

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Method

Participants

We analyzed three semesters' worth of discussion forum data in fully online sections of an introductory statistics course at a large public university in the midwestern United States. Data come from the 287 students who voluntarily posted to the discussion forum (1,674 initially enrolled; we removed the 1,381 students who did not post to the discussion form, 1 student with missing gender data and 5 students who enrolled multiple semesters). Our sample included 86 students (30.0%) who identified as men, and 201 (70.0%) who identified as women or non-binary. While we acknowledge that identifying as non-binary is not the same as identifying as a woman, the number of students identifying as non-binary was too small to analyze separately while protecting the privacy of their records (per the Family Educational Rights and Privacy Act).

Measures

The 287 students produced 801 discussion forum posts. We adapted Rourke et al. (1999)'s coding scheme to assess the three social presence categories in students' messages; see Table 1.

Table 1
Indicators of Social Presence (adapted from Rourke et al., 1999)

Category	Indicator	Example	Interrater reliability (Cohen's κ)
Affective	1. Expression of emotion	"IS ANYONE GETTING 'C'?"	.89
	2. Use of humor	"I had 3 tries and 4 options. I got the question wrong. Rip"	1.00
	3. Self-disclosure	"I am beyond lost, even with that video"	.71
Interactive	4. Continuing a thread	Software dependent (e.g., "Subject:Re")	–
	5. Quoting or referring explicitly to others' messages	"what do you mean by 'skewed to the left'?"	.74
	6. Explicitly requesting help	"Can someone explain question 3?"	.86
	7. Complimenting or expressing appreciation	"That helped immensely!"	.89
	8. Expressing (dis)agreement	"I agree, question 7 sounds misleading"	.74
Cohesive	9. Using vocatives	"Thanks, Pal"	.91
	10. Using inclusive pronouns	"We unfortunately all have different numbers"	.97
	11. Using phatics, salutations	"Hi all"	.75

For each forum post, we assigned a value of "0" (i.e., the indicator is absent in the message) or "1" (i.e., the indicator is present in the message). The first and second authors each coded the same 20% of the data and obtained substantial agreement (Landis & Koch, 1977). The remaining forum posts were coded by the first author. To determine students' *affective*, *interactive*, and *cohesive score*, we calculated each student's average number of indicators used per post for each social presence category. To account for the possibility that students who were more engaged in discussion forums were also more likely to use social presence indicators in messages, we also assessed each participant's posting frequency, defined as one's total number of posts written duuring the semester. Gender information was obtained from course data and coded as "0" (man) or "1" (woman or non-binary).

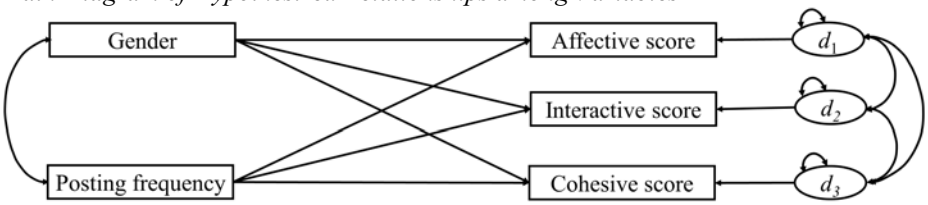
Analysis

We used path analysis to evaluate the direct effects of gender and posting frequency on affective, interactive, and cohesive score using the *lavaan* package in R (Rosseel, 2012); see Figure 1. Gender and posting frequency were hypothesized to have direct effects on affective score, interactive score, and cohesive score. Disturbances were included in our model to represent influences on outcome variables unaccounted for by our predictors. Gender and posting frequency were allowed to correlate, as were the disturbances corresponding to outcome variables.

Results

Interactive indicators were the most utilized category of social presence indicators among participants ($M = 1.00$, $SD = 0.38$), followed by affective indicators ($M = 0.38$, $SD = 0.44$), and lastly by cohesive indicators ($M = 0.16$, $SD = 0.33$). In total, participants used an average of 1.54 social presence indicators (across all categories) per post.

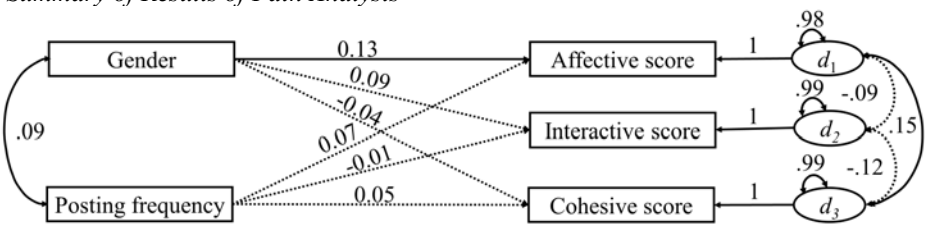
Figure 1
Path Diagram of Hypothesized Relationships among Variables



We used maximum likelihood estimation to estimate path model parameters; robust standard errors were used to correct for bias introduced by non-normal distributions in outcome variables (Browne, 1984). Because our model was just-identified, assessment of overall model fit was not relevant (see Yang, 2018).

Of the estimated direct effects, only the effect of gender on affective score was significant (β = 0.13, p = .02, 95% CI = [0.019, 0.240]), where students identifying as women or non-binary used a higher number of affective indicators per post than men. The effects of gender on interactive (β = 0.09, p = .19, 95% CI = [-0.035, 0.176]) and cohesive score (β = -0.04, p = .50, 95% CI = [-0.121, 0.058]) were non-significant, as were the effects of posting frequency on affective (β = 0.07, p = .11, 95% CI = [-0.002, 0.017]), interactive (β = -0.01, p = .66, 95% CI = [-0.006, 0.004]), and cohesive score (β = 0.05, p = .24, 95% CI = [-0.002, 0.010]). Figure 2 summarizes our results in the form of a path model, with fully standardized estimates reported for all parameters.

Figure 2
Summary of Results of Path Analysis



Note. Solid lines represent significant parameter estimates at p < .05. Dotted lines represent non-significant parameter estimates at p > .05. Variances associated with disturbances represent the proportion of variance in an outcome variable unexplained by our predictors (see Yang, 2018).

Discussion

Our aim was to contribute to ongoing conversations regarding the relationship between identity and technology in learning environments. Towards this end, we explored gender differences in students' contributions to three distinct categories (i.e., affective, interactive, and cohesive) of social presence in an online college course discussion forum. Our findings revealed that students identifying as women or non-binary were more likely than men to express mood, feeling, and emotion when posting online.

This result aligns with previous reports of gender differences in the online expression of emotion (Guiller & Durndell, 2007). We also build on earlier studies by using path analysis to compare the relative effects of gender on three social presence categories, as well as controlling for students' level of engagement in discussion forums. Our results suggest that gender differences in behaviors related to social presence primarily manifested themselves as differences in contributions to affective social presence, rather than to interactive or cohesive social presence.

This study complements previous research reporting that gender may be related to perceived social presence in online courses (Richardson & Swan, 2003; Rovai & Baker, 2005). That is, it is possible that in addition to perceiving other students as being more socially present, women and non-binary students also made more of an effort to be socially present themselves, in part by projecting their affective self into online forum posts. This interpretation is supported by previous research demonstrating that those who perceive greater levels of social presence in online communities are also those who project their personalities into online communities to a greater degree (Swan & Shih, 2005). Future research should simultaneously assess perceptions of and contributions to social presence within a single sample to test this hypothesis.

Furthermore, we can interpret this work through the lens of constructionist theories that see gender as "constructed through communication … cultivated by social institutions" (Houser et al., 2019, p. 34). Specifically, gendered patterns of socialization that identify intimacy and vulnerability as feminine values may have influenced how students chose to enact their gender identity in the discussion forum setting and thus resulted in disparities

in contributions to social presence (Rovai & Baker, 2005). Thus, to foster greater social presence in online learning commnunities, it may be important for educators and students to interrogate cultural norms that conceive of affective social presence as an intrinsically feminine quality.

In conclusion, this work contributes to conversations surrounding identity and learning technologies by exploring social presence in more nuanced ways than past studies. We believe that a promising avenue for future research would be to explore how educational and cultural institutions cultivate gendered communicative practices that in turn yield disparities in students' tendencies to project their identities in a web-based learning community. Such work could play an important role in informing conceptualizations of online social presence, challenging stereotypical gender roles, and informing the development of strategies designed to facilitate social presence in online learning environments.

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The Construction of Mathematical Authority in a First Grade Classroom

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Abstract: This study uses positioning theory to understand *how students come to construct their own and others' mathematical authority.* The study took place in the context of a classroom teaching experiment with 22 first-grade students in a demographically and academically diverse school. We coded the interactions of the eight students who had the most whole class airtime. We also determined airtime for these participants, which involved total talking time during whole class discussions, total utterances spoken during whole class discussions, and the number of times they were talked to. Findings show how one student's airtime contributed to her establishing undue authority and in turn having an incorrect idea endorsed by another student. Findings also reveal some of the interactions that contribute to authority construction over time.

In this study, we explore the following research question: *In what ways do students come to construct their own and others' mathematical authority?* Mathematical authority is "the degree to which students are given opportunities to be involved in decision making and whether they have a say in establishing priorities in task completion, method, or pace of learning." It is specific to math, or "who's in charge" of making mathematical contributions (Gresalfi & Cobb, 2006, p. 51). The question we pose stemmed from our observation of an interaction among a group of first grade students in Lesson 12 out of a total of 16 from an 8-week classroom teaching experiment (CTE).

The interaction occurred during Lesson 12 when a group of students were discussing how to represent two sisters' ages (Janice and Keisha), using variables. In the situation being discussed, Keisha is three years older than Janice. One student, Leo, proposed that Janice's age could be represented with j and Keisha's with k, indicating that these are the first letters of their names. Another student, Nyah, then proposed j for Janice's age and m for Keisha's age, using the order of the letters of the alphabet (e.g., $a = 1$; $b = 2$, etc.) and counting on three more from j. This approach has been documented elsewhere (e.g., MacGregor & Stacey, 1997) as a strategy students use when representing variable quantities. A third student, Zyla, then proposed representing Keisha's age as $j + 3$. A fourth student, Tia, disagreed with Zyla and instead proposed l for Keisha, counting three but including j in her counting (i.e., *j, k, l*). About a minute later, another student, Azaiah, stated that he agreed with Tia and that "I think it's l." When asked why, he referred to a moment earlier in the same lesson, when: "Tia was the right one because she put three on there (indicating that Tia had written "+3" on the shared classroom poster) and that was—and Leo needed help." Tia's mathematical authority and Azaiah's assessment of her idea based on his experience of her past expertise is at the crux of this paper. To investigate this dynamic, we use positioning theory (Anderson, 2009) and build on authors who have used this framing to explore related questions about authority (e.g., Langer-Osuna, 2016; Langer-Osuna et al., 2018), along with Engle et al.'s (2014) influence framework.

Methods

This paper draws data from a larger study carried out in a demographically and academically diverse public school in the Northeast region of the United States. The participants included 22 first grade students who participated in a CTE. The CTE involved eight weeks of classroom instruction organized into two 4-week cycles (with two 40-minute lessons taught per week). Each lesson was video recorded with two cameras and transcribed. The tasks designed for the CTE were based on field-tested tasks developed in previous research by the project researchers. The overarching goal was to engage the students in algebraic thinking, or to support them in

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generalizing, representing, justifying, and reasoning with mathematical relationships (Blanton et al., 2011; Blanton et al., 2015). Students were encouraged to share their ideas and to discuss among themselves the merits of their ideas, to agree or disagree, and share their reasoning. Our goal was to have a distributed sense of authority among all participants in the classroom, and, as teacher-researchers, to share with students both the sources of ideas proposed as well as the decision making around whose ideas should be taken up. Lessons typically began with a whole class (WC) discussion before students broke into small groups (3-5 students) to work on mathematics tasks at their table, and then wrapped up with another WC conversation.

All CTE lessons were videotaped and all written student work was collected. All classroom lessons, from Lesson 1 to Lesson 12, were transcribed verbatim. Lesson 12 includes the interaction in which Tia's incorrect idea was accepted. We are not including Lessons 13-16 in this paper because our study was focused on investigating how, from Lesson 1 to Lesson 12, mathematical authority was constructed. Additionally, while we coded all participants' utterances, we report on eight of the 22 students because these students had the most airtime and in turn had more opportunities to contribute in ways that shaped their positions. If we included data for the remaining students, the frequencies and percentages for each code for these students would be significantly low. Moreover, the five students who were at the center of the Lesson 12 interaction that motivated us to focus on the construction of authority are a subset of the eight focus students. We further selected from the dataset and only include the interactions that occurred in a WC setting because the eight students were present in this setting, whereas these students were separated when working in small groups and cameras did not capture all small group conversations.

We developed our coding scheme by a line-by-line review of the Lesson 12 transcript. We selected this lesson because of the interaction in which Azaiah accepted Tia's incorrect idea. In our line-by-line review and using the constant comparative method (Glaser & Strauss, 1967), we identified lines in which ideas were proposed and how they were responded to because these moments appeared to be linked to how participants were positioned. We define an idea as a thought or suggestion, which can be articulated orally or in writing. Ideas may vary depending on the task and situation at hand and are not necessarily stable or unitary (see Brizuela et al., 2015). Some utterances include one or more ideas, while some utterances do not.

Proposing an idea is a bid, or an opportunity for someone else to respond to your idea. The response typically comes from the teacher and is either neutral, positive (idea was accepted), or negative (idea was rejected). Sometimes the teacher's or student's tone led us to believe their response was neutral, positive, or negative, not the words they said. For example, "okay," said enthusiastically could indicate an idea is accepted whereas "okay" said flatly could indicate a neutral response. In addition to coding transcript lines, we kept track of the total airtime for each one of the students in each lesson, number of utterances spoken by each individual, and the number of times an individual is talked to. We use Langer-Osuna's (2015) definition for an utterance: "what was stated by a speaker when the speaker held the floor, regardless of whether the utterance was interrupted or was a completed turn. In the case of an interrupted utterance, if the speaker gained the floor again to complete the turn, the two turns were each coded as separate utterances" (p. 59). We found the totals for each of these codes across the 12 lessons for the eight focus students. We then ranked students based on the totals for each code. For example, we counted the number of times an individual proposed an idea across the 12 lessons, and then ranked that student in relation to the other eight students. If a student proposed the most ideas they were ranked as the highest for proposed ideas. Since some codes were associated with a negative responses (e.g., an idea is rejected), we reversed the ranking system when necessary. For example, if a student had the fewest instances of an idea being rejected, they were ranked the highest for ideas rejected. To ensure the reliability coders overlapped on 20% of the data. We calculated values for both percent agreement and Fleiss's Kappa to ensure agreement beyond chance agreement. The percent agreement was over 90%, and the resulting Kappa range was 0.58 – 0.71 for all videos.

Findings

In the following we describe observations of the eight students as they interacted over the course of the first 12 lessons in the CTE. The codes we focus on here fall into two overarching groups: airtime in a WC discussion (i.e., airtime, number of utterances, and times an individual is talked to; see top three rows in Table 1) and the number of ideas they propose and the ways in which their ideas are responded to (i.e., number of ideas proposed, responded to neutrally, accepted, explicitly rejected, and not taken up; see bottom rows in Table 1).

Table 1 shows the frequencies for the eight focus students in the two groups of codes described above. For each code, frequency is measured as the number of times a code is observed, except for airtime, which is reported in minutes. The grayscale of Table 1 shows how students compare *across each code* using the ranking method: darker colors indicate a higher ranking. Note that the fewer times an idea was rejected is associated with more authority, so the ranking is reversed for the ideas explicitly rejected and not responded to codes.

Table 1
Heatmap comparing frequencies for students in different categories that relate to authority

	Student							
Category	Azaiah	Leo	Nyah	Syd	Taya	Tia	Tye	Zyla
WC Airtime (in minutes)	8	7	10	7	7	15	9	10
Utterances in WC Discussion	61	55	72	48	53	120	57	86
Times Talked To WC Discussion	84	80	94	71	62	141	83	103
Ideas proposed	50	50	83	49	57	96	45	77
Ideas responded to neutrally	27	32	32	28	23	53	25	37
Ideas accepted	15	8	24	15	21	23	14	24
Ideas not taken up	3	3	3	0	1	3	7	7
Ideas explicitly rejected	0	4	4	0	2	2	3	3

Looking down the columns and across the rows in Table 1, we notice a higher number of darker cells for Tia, indicating her influence based on airtime, utterances, sharing of ideas, and neutral responses to her ideas. Zyla is the next highest in the airtime categories, followed by Nyah. In general, we observed the students who proposed more ideas also have higher frequencies for codes of how their ideas were responded to because in order to have an idea responded to, one must first propose an idea. For example, Tia, who proposed the most ideas, also had the most ideas responded to neutrally; we assume this is because as she proposed more ideas, there were more opportunities for her ideas to be responded to.

To better understand how students' ideas were responded to comparatively we provide percentages in Table 2. The percentages were calculated by taking the total for each idea response category (ideas responded to neutrally, accepted, explicitly rejected, and not taken up) and dividing it by the total number of ideas proposed by each individual. For example, Azaiah had 54% of his ideas responded to neutrally (see Table 2). We found that percentage by dividing the 27 instances of Azaiah's ideas being responded to neutrally (see Table 1) by the 50 ideas that Azaiah proposed (see Table 1). Table 2 is also a heat map that shows how students compare in each category using the ranking method: darker colors indicate a higher ranking. In this case students are ranked based on the percentage, not on the frequency for each category. Note that, once again, the fewer times an idea was rejected is associated with more authority, so the ranking is reversed for this code.

Looking down the columns and across the rows, we notice that, when focusing on percentages, Tia's prevalence in the WC discussions is not paralleled in terms of the percentage of her ideas responded to neutrally, accepted, or rejected. That is, in spite of standing out in terms of the amount of airtime during WC discussions, the number of utterances she made during WC discussions, the number of ideas she proposed, and the number of her ideas that were responded to neutrally (see Table 1), other students' ideas were responded to neutrally or accepted in higher proportions, and another students' ideas were rejected in a lower proportion compared to Tia's. When focusing on percentages, it is Leo who had the highest percentage of his ideas responded to neutrally; Taya had the highest percentage of ideas accepted; Azaiah had no ideas explicitly rejected; and Syd had no ideas explicitly rejected or not taken up (i.e., the lowest percentage). In Tia's case, she had the fourth highest percentage of her ideas neutrally responded to, the seventh highest percentage of her ideas accepted, the second lowest percentage of her ideas explicitly rejected, and the third lowest percentage of her ideas not taken up.

Table 2
Heatmap comparing students in the ideas responded to categories that relate to authority, using percentages

	Student							
Category	Azaiah	Leo	Nyah	Syd	Taya	Tia	Tye	Zyla
Ideas responded to neutrally	54%	64%	39%	57%	40%	55%	56%	48%
Ideas accepted	30%	16%	29%	31%	37%	24%	31%	31%
Ideas explicitly rejected	0%	8%	5%	0%	4%	2%	7%	4%
Ideas not taken up	6%	6%	4%	0%	2%	3%	16%	9%

Conclusion

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By looking at both the frequencies of airtime, utterances, and ideas, as well the ways in which ideas were responded to as a percentage of proposed ideas, we can see that Tia stands out in terms of amount of airtime, utterances, and ideas proposed. However, there were other students who stood out proportionally more than Tia in the ways in which their ideas were responded to.

The incorrect information that Tia provided in the lesson 12 exchange is noteworthy because from her and Azaiah's perspective it was logically sound. Tia was arguing that since Keisha is three years older than her sister, and her sister's age is represented with *j*, that Keisha's age should be represented with *l*. She is actually correcting another student who suggests *m* for Keisha's age. To Azaiah, Tia's argument is intuitive. Relatedly, Lane and Harris (2015), who worked with three to eight year olds, found that children are more likely to accept intuitive claims. Thus, we conclude that the content of that particular claim may have played a role in why it was accepted as valid and in turn resulted in granting Tia undue authority.

Understanding the construction of authority has implications far beyond the first-grade mathematics classroom in which our study occurred. Supporting students in developing a positive perspective on mathematics and their mathematical abilities is deeply intertwined with understanding mathematical authority in a classroom. As we think about how to cultivate positive mathematical mindsets among our students, in which they view themselves as sources of mathematics knowledge, we must better understand students' perceptions of themselves and others as sources of mathematical knowledge.

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The Relations between Motivational Beliefs, Academic Delay, and Academic Achievement in Online Learning Environments

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Abstract: The purpose of this study was to examine the relations between motivational beliefs, academic delay, and academic achievement in an online science course. The sample included one hundred and sixty-eight undergraduate students. We extracted data on timestamps for assignment submissions from the learning management system to capture students' behavioral delay for each assignment over the course of the semester. Using multilevel modeling, the results showed that the relation between academic delay and academic achievement was moderated by motivational beliefs. The negative effect of momentary delay on academic achievement depended on academic self-efficacy, while the negative effect of habitual delay on academic achievement depended on emotional cost. These findings point out that academic delay is not always harmful. Lateness in online courses is particularly detrimental to demotivated students but less consequential for motivated counterparts. Simply focusing on academic delay without considering who is engaging in the dilatory behavior could be misleading for intervention.

Major issues

Academic delay is a common phenomenon experienced by college students. Delay can be understood as behavioral postponement of one's own work and could signify the act of task avoidance (Ferrari et al., 1995). Academic delay is composed of two distinct components. Habitual delay refers to the extent to which an individual has a greater tendency than others to postpone coursework across various situations, while momentary delay refers to the extent to which an individual is engaged in postponement more than usual within a given situation during a certain period of time (Kljajic & Gaudreau, 2018). According to some reports, between 70 to 90 percent of college students engage in unnecessary delay in their coursework (Steel, 2007). This number is daunting given that meta-analyses have consistently shown that irrational tendency to postpone work is negatively correlated with all types of academic achievement, including course grade, quiz, and GPA (Steel, 2007). This tendency can be even more prominent in online learning environments. Although online courses feature autonomy, flexibility, and convenience, students are expected to learn with fewer regulatory cues from instructors and peers and need to override lower and distracting processes often occurring in self-paced learning environments that are competing with long-range goals (Levy & Ramim, 2012). In addition, students may be prone to delaying tasks until the last minute, owing to their frustration and emotional distress from technical difficulties in online courses (Cheng & Xie, 2021). For these reasons, academic delay in online courses is an area worthy of investigation.

Owing to the affordances of school and learning management systems (LMS) to capture various learning analytics, scholars are interested in determining valid measures of academic delay that are consistently associated with student achievement in online courses (Elvers et al., 2003; McElroy & Lubich, 2013). This inquiry is of great value in that it could offer stakeholders and instructors a clear idea in identifying problematic dilatory behaviors in real time and in a less intrusive manner. Although several measures have been examined in the literature, findings are mixed and inconsistent at times. In some instances, a behavioral measure, such as date of first posting in class or days between assignment submissions, was related to student achievement (McElroy & Lubich, 2013). In other instances, it was not (Lim, 2016). As Balkis (2011) has found, the relation between irrational postponement and academic achievement is quite complex and can be moderated by students' motivation. However, this complicated relation has been overlooked in the literature on academic delay. In addition, most of the previous studies have dominantly focused on the relation between students' habitual delay and academic achievement (Lim, 2016; You, 2015); therefore, whether students' momentary delay is related to academic achievement is under-examined and still unclear. For online instructors in particular, it is important and useful to know if and under what condition students' habitual and momentary delay are associated with academic achievement. The goal of the present study is to answer these major issues through a longitudinal data analysis.

Theoretical perspectives

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Academic delay and academic achievement

Several studies have been conducted to explore if academic delay is negatively related to academic achievement. Elvers et al. (2003) found that the difference between the date of first access to course content and the date of exams was negatively correlated with exam scores in an online class. However, in some cases, academic delay is not consistently related to academic achievement. For instance, McElroy and Lubich (2013) showed that although date of registration for class and date of first posting on discussion boards predicted students' grade earned-letter, they failed to predict grade earned-percent. Similarly, a study by Romano et al. (2005) indicated that although exam scores were related to the extent to which students completed learning sessions in one learning unit, this relation was not significant in the other learning units. These studies highlight that academic delay has been operationalized in different ways. In addition, these findings suggest that the association between academic delay and academic achievement is not consistent and, hence, is inconclusive.

Motivational beliefs and academic achievement

Motivation can be defined as "the process whereby goal-directed activities are instigated and sustained" (Schunk et al., 2014, p. 5). This process encompasses different subjective beliefs about engaging in a task, including academic self-efficacy (perceived competence), task value (reasons for engaging in a task), and cost (negative evaluations of what is required to engage in a task) (Eccles & Wigfield, 1995). Research has consistently shown that these motivational beliefs have a significant association with students' academic achievement. Komarraju and Nadler (2013) found that college students' academic self-efficacy and task value were significantly correlated with GPA. Jiang et al. (2018) also found that academic self-efficacy, task value, and cost were significantly correlated with midterm exam scores among 8th graders.

Methodological approach

The design of this study is guided by one central question: What is the relation between motivational beliefs, academic delay, and academic achievement in an online science class?

Sample and procedure

A total of 168 undergraduate students enrolling in an entomology course at a mid-western university participated in this study. About 74% of the participants were female and 26% were male. Eight percent of the participants were African American, 62% were White, 19% were Asian American, 2% were Hispanic, and 9% were other races. On average, participants were 21.23 years old. In terms of academic standing, 8% of participants were freshmen, 17% were sophomores, 34% were juniors, and 41% were seniors. During the second section of the Spring 2019 semester, students enrolled in this course were invited to complete an online survey on their demographic information and motivational beliefs and grant the authors permission to access their learning analytics and course grades.

Measures

Motivational beliefs

Five five-point Likert scale items (1 =not at all true; 5 =very true) adapted from the Patterns of the Adaptive Learning Survey (PALS; Midgley et al., 2000) were used to assess students' academic self-efficacy. A sample item is "I'm certain I can master the skills taught in this course." Cronbach's alpha is 0.93. Six seven-point Likert scale items adapted from the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1993) were used to assess students' task value. A sample item is "It is important for me to learn the course material in this course." Cronbach's alpha is 0.95. Six nine-point Likert scale items (1 =completely disagree; 9 =completely agree) adapted from Flake et al. (2015) were used to evaluate students' negative emotional reaction to putting forth effort to completing academic tasks in a course, such as stress, frustration, anxiety, and worry. A sample item is "This course is emotionally draining." Cronbach's alpha is 0.95.

Academic delay

Timestamps for assignment submissions extracted from the LMS were chosen as the indicator of academic delay. In the present study, timestamp was defined as the difference in days between the submission time and the deadline for a graded assignment. Each timestamp was computed by subtracting the submission time from the deadline. For instance, if a student submitted an assignment on March 6, 2021 at 19:17 PM and the deadline was set on March 6, 2021 at 23:59 PM, then the timestamp for this assignment would be 0.20 days. Since there were 11 assignments in total, each student had a total of 11 timestamps if there was no missing assignment.

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Academic achievement

Academic achievement refers to students' grades for each assignment. Since there were 11 assignments in total, each student had a total of 11 grades.

Statistical analyses

Multilevel tobit regression analysis was employed to assess the relation between motivational beliefs, academic delay, and academic achievement. The tobit model was used considering the ceiling effect of student achievement data in our sample (Twisk & Rijmen, 2009). The strategy for model building was developed in line with Hoffman's (2015) recommendations. Person-mean-centering was implemented for the level-1 predictors to separate the habitual and momentary effects of academic delay (Hoffman, 2015). Fixed effects were evaluated using Wald tests.

Major findings

The results of multilevel tobit regression showed that the relation between momentary delay and academic achievement depended on academic self-efficacy (b = .86, p = .01). Also, the relation between habitual delay and academic achievement depended on emotional cost (b = -.47, p = .004). We further probed the interaction using the pick-a-point approach. The result showed that when academic self-efficacy was at or below the mean level, the relation between momentary delay and academic achievement was significantly negative (see Table 1). The lower academic self-efficacy was, the more negative the relation would be. On the contrary, when academic self-efficacy was one or two standard deviations above the mean, the relation was not significant. Also, the relation turned significantly positive when academic self-efficacy was three standard deviations above the mean. In terms of emotional cost, the result showed that when emotional cost was two standard deviations below the mean, the relation between habitual delay and academic achievement was not significant. On the contrary, when emotional cost was one deviation below the mean or higher, the relation was significantly negative. The higher emotional cost was, the more negative the relation would be.

Table 1

Probing Interaction Effects

Effect of momentary delay on academic achievement	b	*SE*	95%CI	
Academic self-efficacy as moderator				
-3 *SD*	-3.10*	1.03	-5.13	-1.08
-2 *SD*	-2.24*	.71	-3.64	-.84
-1 *SD*	-1.39*	.41	-2.19	-.57
Mean	-.52*	.23	-.98	-.07
1 *SD*	.33	.40	-.44	1.11
2 *SD*	1.19	.69	-.16	2.55
3 *SD*	2.05*	1.01	.07	4.04
Effect of habitual delay on academic achievement	b	*SE*	95%CI	
Emotional cost as moderator				
-3 *SD*	-.02	.62	-1.24	1.20
-2 *SD*	-.49	.48	-1.43	.44
-1 *SD*	-.97*	.35	-1.66	-.28
Mean	-1.44*	.28	-1.98	-.90
1 *SD*	-1.91*	.29	-2.48	-1.35
2 *SD*	-2.39*	.38	-3.14	-1.64
3 *SD*	-2.86*	.51	-3.87	-1.86

Note. * $p < .05$

Conclusions and implications

The present study examined the relations between motivational beliefs, academic delay, and academic achievement. The current findings have important implications for online instructors and the design of course analytics to support online learning. Most of the course analytics currently provided by learning management systems only present a student's timestamp for each assignment submission, which possibly conflates the effects of momentary delay with habitual delay, and, hence, may not be a reliable indicator for early intervention. Our findings suggest that future course analytics should also provide information on 1) whether a student postpones more than usual at a given time and 2) whether a student postpones more, on average, than other students in the

same course. These pieces of information need to be integrated with measures of motivational beliefs to effectively identify at-risk students in an online course. As the present study shows, academic delay is particularly detrimental to demotivated students but less consequential for motivated students. Simply focusing on academic delay without considering who is engaging in the dilatory behavior could be misleading for intervention.

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LF-LKT: A logistic regression knowledge tracing model integrating learning and forgetting

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Abstract: In the process of learning, learning behavior and forgetting behavior are interwoven, and students' forgetting behavior has great influence on Knowledge Tracing(KT). In order to accurately model learning and forgetting behaviors, this paper proposes a learning-forgetting logistic knowledge tracing(LF-LKT) model that integrated students' forgetting factors. Three factors affecting knowledge forgetting, including the time interval of KC, KC presentation sequence (that is, the recency effect), learning opportunities of KC, and students' response of KC are considered in this paper. We also give different level of weights to time interval. The proposed model is compared with other four models on three dataset. Results shows LF-LKT improves the predictive performance as compared to AFM, PFA . Moreover, the ablation study was conducted to investigate the influence of different factors and the result suggest the combination of three factors results in performance improvement.

Introduction

As the "brain" of the adaptive learning system, the learner model undertakes the important responsibility of self-adaptation. Specifically, in the process of learners' learning, the system relies on learners' historical learning data to construct learners' models. Based on structured subject knowledge and diversified learning resources, adaptive learning system provides students with the most suitable learning resources, paths and modes by collecting interactive data of students' learning process and utilizing technologies such as cognitive diagnosis, machine learning and personalized recommendation. The system can also feedback the knowledge mastery level of learners for educators, so that educators can identify the needs of learners, so as to better adjust teaching strategies. Therefore, learner modeling plays an important role in realizing personalized education. How to build a better learner model, how to combine the learner model with the design of teaching environment, and how to use the learner model in the learning environment to achieve personalized education are the core technical problems in the next stage.

Knowledge Tracing, builds the knowledge state model of learners through accurately modeling students' mastery level of a knowledge component over time based on their historical learning trajectories. KT is the earliest and most concerned learner modeling technology, which can provide learners with adaptive teaching support and push personalized learning resources, so as to improve learning effect and efficiency (Wang,2013).The knowledge tracing model is based on the interactive data of learners and the learning system. The theory of educational psychology and the theory of Ebbinghaus forgetting curve(Ebbinghaus,2013; Murre,2015) put forward that students forget what they have learned, and the impact of forgetting is the decline of knowledge mastery. Recent studies have considered students' forgetting behavior. However, how to adopt classical theories in traditional education, such as forgetting curve to predict knowledge state, is still in its infancy. Moreover, there are few studies considering recency effect. Inspired by the recency effect of psychological theory, this paper integrates factors such as the presentation of knowledge component into the model to predict students' knowledge state.

Proposed model

LF-LKT is based on Logistic Regression (LR) model(Kleinbaum,2002), which uses one or more continuous or discrete independent variables to analyze and predict discrete dependent variables. Logistic regression is one of the common methods of data mining and machine learning. LR model converts the dependent variable into correct and wrong binary logical variables (1 is correct, 0 is wrong), and the relationship between the probability of learners' correct response and the independent variable can be expressed as:

$$\mathrm{P}(Y_{ij} = 1|z) = \frac{1}{1+e^{-z}} \quad (1)$$

$$Z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n \quad (2)$$

Where, Y_{ij} represents learner i's response to question j; Z represents the sum of linear weight values after superposition of independent variables; x_n represents each influence factor, and β_n is the coefficient of

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logistic regression. P represents the probability of students correct response under various influencing factors, ranging from 0 to 1.

Students' historical learning trajectories will affect their knowledge mastery, and if the time interval is too long, they will forget. According to Ebbinghaus forgetting curve theory (Ebbinghaus ,2013;Murre,2015), the number of repeated learning knowledge component and the time interval since the last learning knowledge component will affect the degree of forgetting of students. According to the psychological theory of recency effect(Martin ,1991), the order in which information appears has an impact on students' cognition, and recency effect will lead to a deep impression on the recently learned content. Therefore, the following factors affecting knowledge forgetting are considered in this paper:

T: Time interval from the same knowledge component; N: the times of repetitions of knowledge component; θ: Students' response of a knowledge component. It can be divided into correct answers (C) and wrong answers (I).

Historical learning trajectories $x_1, x_2, \ldots, x_t$ in a group of learning tasks containing a specific knowledge component ($x_t$represents the answer situation of the t time step). Assuming that the knowledge component involved in the t-i time step and the t time step are the same, the time interval from the t-i time step to the t time step can be expressed in the following equation:

$$T = \sum_{i=1}^{n-1} \omega_i \cdot t_i \tag{3}$$

Where, ω_i represents the weight of the t-i time step distance from the t time step; t_i represents the time interval between the t-i time step and the t time step; n represents the answer sequence of learning the same knowledge component with the t time step; T is the weighted sum of ω_i and t_i.The weight mechanism stipulates that the model assigns a certain degree of weight value to the answer sequence of the same knowledge component as the t time step. The weight mechanism is based on the power law attenuation function, and the closer the answer sequence is to the t time step, the greater the influence is. Therefore, the weight mechanism can be expressed as the following equation:

$$\omega_i = {t_i}^{-x} \sum_{j=1}^{n-1} \frac{1}{{t_j}^{-x}} \tag{4}$$

The Predictive performance equation (PPE) model holds that the impact of repeated knowledge component and time interval is correlated, so the combined effect of repeated knowledge component and time interval can be expressed by the following equation(Jastrzembski &Gluck, 2009; Walsh et al., in press):

$$M_n = N^c \cdot T^{-d} \tag{5}$$

Where, c and d represent learning rate and decay rate respectively.Considering the three factors affecting forgetting, we can transform the Logistic Regression model according to equation(2) - (5) and the model formula proposed in this study was obtained:

$$P(Y_{ij} = 1 | M_n, C, I) = \frac{1}{1+e^{-(\beta_0+\beta_1 M_n+\beta_2 C+\beta_3 I)}} \tag{6}$$

To sum up, LF-LKT is based on logistic regression function, and comprehensively considers the interval of students' repeated learning of knowledge component, the presentation order of knowledge component (recency effect), the number of repeated learning of knowledge component and students' mastery of knowledge component.

Experimental design and analysis

In order to verify the performance of this model, the test performance of the model was compared with the AFM model, PFA model and R-PFA model PFA-decay model based on logistic regression model on public data set. The results are shown in Table 1(see Table 1):

Table 1

model prediction performance

dataset	performance indicators	AFM	PFA	R-PFA	PFA-Decay	LF-LKT
Fraction	precision	0.848	**0.915**	0.865	0.869	0.870
	recall	**0.981**	0.976	0.971	0.964	0.958
	F1	0.910	**0.915**	**0.915**	0.914	0.912
Tone	precision	0.835	0.836	0.839	0.839	**0.841**
	recall	**0.977**	0.974	0.968	0.962	0.964
	F1	**0.900**	**0.900**	0.899	0.897	0.898
Cloze	precision	0.770	0.779	0.779	0.785	**0.796**
	recall	0.767	0.761	0.755	0.766	**0.772**
	F1	0.768	0.770	0.767	0.775	**0.784**

It can be seen from the experimental results that, on the basis of comprehensive consideration of all evaluation indexes, the LF-LKT model proposed in this paper performs better than other models on Cloze data set, with the prediction accuracy of 0.784, precision of 0.796, recall rate of 0.772 and F1 value of 0.784. It's the

highest in all the models. Comparatively speaking, the prediction effect of LF-LKT on the other two data sets is not ideal, and the value distribution on each evaluation index is not balanced. Furthermore, taking Cloze data set as an example, the factors affecting forgetting are considered separately. The ablation study result is shown in Table 2. It can be seen that the combined effect of each factor is better than the simple effect.

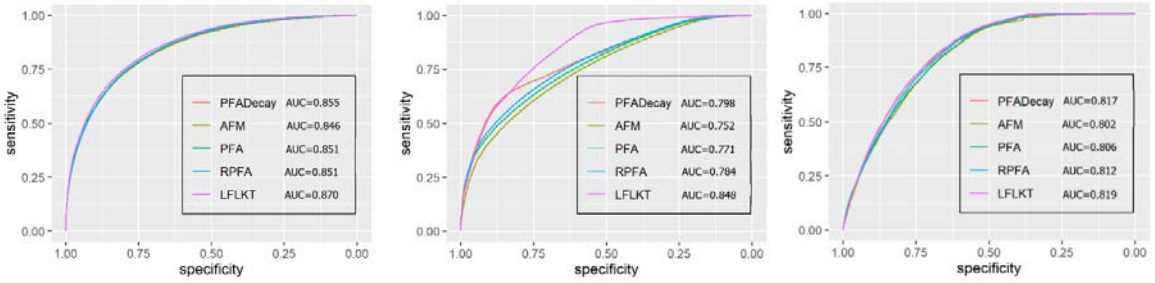
Table 2

ablation study of each forgetting factor

performance indicators	LF-LKT(N,T,θ)	LF-LKT(N,T)	LF-LKT(θ)
accuracy	**0.784**	0.779	0.771
precision	**0.796**	0.782	0.780
recall	0.772	**0.784**	0.764
F1	**0.784**	0.783	0.772

Figure 1

ROC curve



1-a ROC curve on Cloze *1-b curve on Fraction* *1-c curve of all models on Tone*

Table 3

Comparison of AUC values and R2 predicted by the model

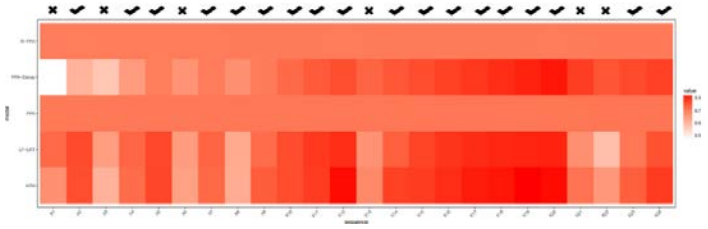
	R^2			AUC		
	Fraction	Tone	Cloze	Fraction	Tone	Cloze
LF-LKT	**0.275**	**0.228**	**0.352**	**0.848**	**0.820**	**0.870**
AFM	0.156	0.203	0.299	0.752	0.802	0.847
PFA	0.186	0.212	0.306	0.771	0.806	0.852
R-PFA	0.201	0.217	0.311	0.784	0.812	0.851
PFA-Decay	0.227	0.220	0.329	0.798	0.817	0.858

One of the basic tasks of knowledge tracing is to predict students' current performance on the next candidate exercise. By comparing the prediction results of the model with the real answer results of the students, the prediction performance of the model was compared (see Figure 1 Table 3).The AUC index of the model proposed in this paper is superior to the original AFM model, PFA model, extended R-PFA model and PFA-decay model on public data set, and the model fitting effect is better than other knowledge tracing models based on logistic regression model. The results show that LF-LKT model is superior to existing models in predicting students' future performance. From the experimental comparison results, it can be seen that AFM has the lowest prediction performance in the data set, which indicates that AFM has limitations in considering students' prior probability at the same time.

Another basic task of knowledge tracing is to output students' mastery of each knowledge component. This paper intercepts a student's learning record in the data set Chinese_tone study over a period of time, and uses five models to track the change of students' mastery of a knowledge component, as shown in Figure 1.In the figure, the abscissa represents students' learning history, the top is students' answers, and the ordinate represents students' mastery of the knowledge component predicted by the model.

The experimental result shows that the tracing effect of PFA and R-PFA model is not obvious. The tracing results of PFA-decay model changed slightly. At the 14th moment, after students correctly answered the exercises corresponding to knowledge component, LF-LKT and AFM models improved the tracing results of students' knowledge component mastery (the output value increased). At the 21st moment, after students made mistakes in the exercises corresponding to knowledge component, the tracing results of LF-LKT and AFM model on students' knowledge component were decreased .The above results showed that PFA-decay, LF-LKT and AFM models would update the corresponding knowledge component according to the answers obtained by students, so as to model the learning process of students.

Figure 2
heatmap of Chinese_tone study dataset



Discussion

In this paper, the time interval of KC, KC presentation sequence (that is, the recency effect), learning opportunities of KC, and students' response of KC are considered. A knowledge tracing model LF-LKT based on logistic regression model is proposed, which takes into account both learning and forgetting factors. The result shows that LF-LKT model improves the predictive performance as compared to traditional knowledge tracing models based on logistic regression model, such as AFM,PFA,R-PFA and PFA-decay models. Moreover, the ablation study was conducted to investigate the influence of different factors and the result suggest the combination of three factors results in performance improvement.

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International Society of the Learning Sciences

Personalized Automated Formative Feedback Can Support Students in Generating Causal Explanations in Biology

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Abstract: The ability to formulate scientific explanations is considered a major goal in science education. However, explaining scientific phenomena is a challenging task, and research has shown that many students are unable to construct proper explanations. And while personalized formative feedback can greatly assist students in closing the gaps between their current and the expected level of reasoning, teachers rarely find the time that is required to provide it. We present a novel framework for designing and providing formative feedback on causal explanations in biology, which can be generated *automatically* using NLP-based algorithms. Results from a controlled experiment showed that applying this framework led to significant improvement in student explanations. Based on these findings, we believe that our framework provides an effective approach for aligning between automated NLP-based analysis and formative assessment of biological explanations in the science classroom.

Introduction

Enhancing students' ability to formulate scientific explanations is considered a major goal of science education (National Research Council (NRC), 2012). However, research has shown that many students are unable to construct proper explanations (e.g., Nehm et al., 2012).

Constructed-response (CR) items are an important tool to elicit students' in-depth understanding of scientific concepts (Nehm et al., 2012), and students were found to benefit from guidance on their explanations and the opportunity to revise them (Ryoo & Linn, 2014; Tansomboon et al., 2017). However, proper assessment of CR items is a costly, time-consuming process, which requires developing grading rubrics and applying them to student responses. Teachers are struggling to find the time to devote to this process, leading to considerable delays in the feedback students receive on their CRs, and affecting its quality (Ariely et al., 2022).

Technology holds much promise for improving this process. Research on automated assessment in science education has shown that machine-learning (ML) and Natural Language Processing (NLP) can be used to construct scoring algorithms and provide immediate feedback to teachers and students (Zhai et al., 2020). However, few studies have attempted to leverage the power of automated scoring techniques for providing feedback on CR items. Moreover, research on the educational impact of formative assessment with automated scoring technologies in real classrooms – where most of the learning occurs – is scarce (Zhu et al., 2020). Our research aims for this gap.

Causal explanations in biology

The majority of explanations in the science classroom are attempts to provide an account that specifies what happened and how it occurred, namely, constructing causal accounts of phenomena (Osborne & Patterson, 2011). Causal explanation should include the sequential stages from input to output of the underlying causal event leading to a phenomenon, and also how one or more factors behave to give rise to a phenomenon (Krist et al., 2019). Depending on the phenomenon to be explained and the context in which it occurs, the underlying causality can be a simple linear relation between contiguous events, or it can consist of complex relations, with several causal factors interacting with each other (Grotzer, 2003). Studies show that students have difficulties in presenting the causal story in which event results from interactions among multiple components (Grotzer, 2003).

Automated formative assessment

Automated formative assessment of CR items in science education is typically based on invoking feedback that aims to close the gap between the expected and observed performance as identified using content-based scoring rubrics (e.g., Tansomboon et al., 2017). Application of ML and NLP are increasingly applied to automated content scoring of CR items (Zhai et al., 2020). Automated scoring techniques have many advantages for assessment such as objectivity, standardization and efficiency (e.g., Nehm et al. 2012; Tansomboon et al., 2017). Also, ML based assessment was found to promote significant learning gains (e.g., Tansomboon et al., 2017; Zhu et al., 2020). This makes ML-based assessment a cost-effective way for assessing students' explanations.

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Research goals and questions

In this study, we present a novel approach and method for designing and providing formative feedback on causal explanations in biology. Our method "breaks down" the expected explanation and reveals the components of the causal explanation. These components are then used to build fine-grained analytic rubrics that are designed for formative assessment purposes and aimed at capturing conceptual understanding.

We recently showed that NLP-based ML scoring models, that were trained on student response data that were human-labeled according to our analytic grading rubrics, can reach a high level of agreement with human experts on the task of scoring scientific explanations (Ariely et al., 2022). In the present study, we applied the automated scoring models to provide personalized feedback to students based on their performance in an authentic classroom scenario. While performed on a case study, our approach is directly applicable to causal explanations in other subjects in biology, and may be relevant to other disciplines as well.

The research questions that we seek to answer are: (1) how do students' responses to open-ended questions change after receiving personalized feedback and- (2) if our feedback on students' response to one item affects their response to a *different* item that measures the same concepts in a different context?

Methods

Participants and data collection

The main data set included 10th-grade students from five classes in the same urban school at the center of Israel (N=115). Due to ethical regulations, answers were collected anonymously, and students were requested to fill only their grade, gender, and geographic location. When needed, the class teacher numbered her students so that she could provide each student their personalized feedback, and track their performance.

Procedure

The constructed response items

Two constructed response items were presented to the students as part of their regular biology studies, and deal with the effect of anemia and smoking on physical activity (hereafter referred to as Anemia and Smoking items). Both items are typical open-ended questions in biology and require a causal explanation to explain the phenomena.

Groups description

The data set (N=115) included two groups as follows: One group included three classes in which the students submitted their responses to the Anemia item, and received personalized feedback on their response ~24 hours after submission. Then, the students were asked to submit their responses to the same item again, and also to another item- the Smoking item. Seventy-three students answered the Anemia item, but 19 of them did not submit their answer to the Anemia and Smoking item after receiving feedback, and were, thus, excluded from the analysis. Therefore, the final sample for this group was N=54 (hereafter the "Treatment group"). A second group included two classes in which the students answered both items one after the other, in a random, unknown order, submitted the items together, and did not receive any feedback on their responses (N=61; hereafter the "Control group").

Automated scoring models and analytic grading rubrics

The students' responses to the Anemia and Smoking items were *automatically graded* using automated scoring models, developed for these items in prior research (Ariely et al., 2022). Analytic grading rubrics were developed by the first author (a domain expert) and validated by a second domain expert and five experienced biology teachers. The rubrics decompose a correct explanation into a collection of binary categories, each representing an essential property that the student explanation should include (see Table 1). A detailed description of the development and performance of the automated scoring models can be found in Ariely et al. (2022).

Personalized feedback on students' responses

The feedback on students' responses (in case they were not fully correct) included a short paragraph followed by a figure that visualizes what is missing from the student's explanation and the student's score out of 5 points. The content of the feedback was predefined according to the different types of reasoning that are revealed by the analytic grading rubric. The feedback was sent to the class teacher who sent it to her students, and also provided a short explanation about the feedback format.

After the students in the Treatment group submitted their responses (following receiving the feedback), they answered a short questionnaire about how they used the feedback, and what part of the feedback was most

useful to them. This questionnaire served two purposes: First, characterizing what the students perceived as being most useful for them. Second, it also provided evidence that students actually read the feedback handed to them.

Table 1.
The categories of the analytic grading rubrics for the Anemia and Smoking items. The (+) and (–) signs represent which category is relevant to each item.

Category – present (+) not present (-)		Anemia item	Smoking item
a	CO-Oxygen competition	–	+
b	Oxygen is transported to the cells by RBC	+	+
c	Change in cell oxygen levels	+	+
d	Oxygen is a reactant in cellular respiration	+	+
e	Change in cellular respiration rates	+	+
f	Use of term (cellular respiration)	+	+
g	Energy is produced in cellular respiration	+	+
h	Change in energy production rates	+	+
i	Use of term (energy/ATP)	+	+
j	Energy is consumed by muscles/cells	+	+

Data analysis

To evaluate the impact of the feedback, we analyzed students' performance in a real classroom situation, by assessing their performance in two different, but conceptually similar, open-ended questions, before and after receiving feedback. This relies on the fact that our assessment and analytic grading rubrics allows us to compare items that measure the same concepts in different contexts.

The students' responses were automatically scored 0 or 1 for each category in the analytic grading rubric, and then these scores were combined to form a composite, holistic score for each item (out of 100%). We analyzed students' performance on the Anemia and Smoking items by comparing their holistic scores for each item. We used the Wilcoxon signed-rank test (for dependent samples), and Mann-Whitney U-test (for independent samples) to analyze differences between students' average holistic scores (followed by a Bonferroni correction, as the Anemia item was compared twice for the Treatment and Control groups).

Results

We analyzed students' performance on the Anemia and Smoking items by calculating their holistic score. We found that while both groups performed similarly on the pretest (Anemia items; two-tailed Mann-Whitney U-test, $z = 0.35305$, $p = 0.72634$, Table 3), the control group did not improve on the posttest (Anemia vs. Smoking item, two-tailed Wilcoxon signed-rank test, *z-score* = -1.2039, $p = 0.2301$, Table 3). However, the treatment group improved compared to its pretest results; the students' performance in the Anemia item improved significantly after they received personalized feedback on the *same* item (Anemia item pre vs. post, two-tailed Wilcoxon signed-rank test, $z = -5.3527$, $p < .00001$; Table 2), and also on a *different* item (Anemia vs. Smoking item, two-tailed Wilcoxon signed-rank test, *z-score* = -2.809, $p = 0.005$, Table 3). Moreover, the treatment group (with feedback) performed better than the control group (no feedback) on the posttest (Smoking items; two-tailed Mann-Whitney U-test, $z = -2.1491$, $p = 0.031$, Table 3).

Table 2.
The Treatment group's average scores in the Anemia item before and after feedback

	Anemia item (before feedback)	Anemia item (after feedback)	Wilcoxon signed-rank test (Anemia pre vs. Anemia post)
Treatment group (N=54)	51.9	80.0 (after feedback)	*z-score* = -5.3527, p <.00001*

Table 3.
The Treatment and Control groups' scores to the Anemia vs. Smoking items before and after feedback

	Anemia item	Smoking item	Wilcoxon signed-rank test (Anemia vs. Smoking)
Treatment group (N=54)	51.9	66.3 (after feedback)	*z-score* = -2.809, p <.01*
Control group (N=61)	54.1	57.2 (no feedback)	Not significant
Mann-Whitney U- Test (Treatment vs. Control)	Not significant	*z-score* = -2.1491, p <.05	

*Bonferroni correction (significant if $p < .025$)

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Discussion

In this study, we present a novel approach and method for designing and providing automated formative feedback on causal explanations in biology. Our analysis shows that after receiving feedback on their response to one item (the Anemia item), students improved their responses to the *same item*, but also to a *different* item that measures the same underlying biology concepts (the Smoking item).

Studies on formative feedback stress that in order to be effective, the feedback should be immediate, individualized, and offer concrete guidance for improvement (Tansomboon et al., 2017). As presented in this study, machine learning algorithms that automatically score scientific explanations can be used to identify gaps in students' reasoning and provide them with timely and individualized feedback. In addition, our grading rubrics were specifically designed for providing *personalized* guidance based on the students' performance, which we believe assisted in students' revisions of their constructed responses.

More importantly, our approach for assessment can provide teachers and students with insights about how to generate and evaluate scientific explanations, because it makes the rationale of the scientific explanation and its components explicit, which can promote students' learning of scientific explanations. It is claimed that crafting complex causal explanations for biological phenomena, promotes students' understanding of the phenomenon and the underlying ideas (Grotzer & Bell Basca, 2003). Also, when students are involved in identifying causal explanations for a phenomenon they are prompt to infer about the underlying causes and to discover the structural connections of phenomena in the world (de Andrade et al., 2019).

Our approach can also provide researchers with a method for developing rubrics and models for automated formative assessment. Nevertheless, as the main limitation of this research is that it is based on a case study with two items on a certain biological phenomenon, further research is required to validate the generalizability of this approach to larger sets of items and of other topics within the biology curriculum.

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International Society of the Learning Sciences

Performing Algorithms: Weaving as Promising Context for Computational Learning

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Abstract: An important aspect of diversifying STEM fields, including computing, is to better understand how tools and materials that are associated with socio-historical practices of underrepresented populations are aligned with disciplinary concepts and what these materials contribute to teaching and learning. Taking a constructionist stance, this study builds on the precedent of electronic textiles in the learning sciences to investigate the alignment of non-electronically augmented fiber crafts with core computer science concepts through the idea of epistemological pluralism. Through an artifact analysis with computer science instructors, the study found that weaving and manipulating fabric are aligned with core computational concepts and that one craft activity requires multiple approaches to computational concepts. The work points to a particular instance of epistemological pluralism and the potential of fiber crafts as a context for understanding transfer of computational concepts across multiple representations.

Introduction

International communities are calling for more sustainable STEM and digital education (European Commission, 2021). One important aspect of this is to diversify STEM fields and to ensure underrepresented groups, including women, persist. Women's persistence in computing can be supported by fostering a sense of belonging that expands dominant computing cultures (Lewis et al., 2017). An opportunity for expanding computing cultures are tangible manipulatives–especially those that consist of materials that are associated with socio-historical practices of underrepresented populations in computing. For example, educational research on electronic textiles, which augment the feminized practice of sewing with electronic components (Buechley, 2006), demonstrated new leadership opportunities for girls (Buchholz et al., 2014), improved learning outcomes for all students (Peppler & Glosson, 2014), and inroads for rupturing dominant computing cultures (Kafai et al., 2021).

Yet, it remains underexplored how fiber crafts in their own right–without electronic components–align with core computational concepts and whether they present relevant contexts for further inquiry of computational learning while fostering a sense of belonging. Building on the precedent of educational research on e-textiles, the present study investigated weaving and manipulating fabric as a context for performing computational concepts, and asked: How do fiber crafts (i.e., weaving and manipulating fabric) align with computational concepts?

The present study builds on constructionist approaches to learning that posit that disciplinary concepts can be practiced through a range of expressive creations of personally meaningful artifacts (Papert, 1993). It also builds on design studies that call attention to the material relationships of digital things (Dourish, 2017). To begin to understand fiber crafts as contexts for computational learning, this qualitative study analyzed artifact analyses sessions with computer science instructors of middle school students' projects. The findings align fiber crafts with computational concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting) and show that fiber crafts require multiple approaches to computational concepts within the same craft activity (i.e., syntax-oriented, spatial, and performative approach). The work has implications for the design of interventions for computational learning of and with fiber crafts and points to an instance of epistemological pluralism and the potential of fiber crafts as a context for understanding transfer of computational concepts.

Potential of fiber crafts for inclusive computer science learning

To counter the trend of early drop-out of women in computer sciences, researchers have called for the recognition of women's leadership skills (Saavedra et al., 2014) and specialized computer science programs for girls (e.g., Pinkard et al., 2019). The movement toward identity-based groups frames computing as a form of community empowerment (Abbate, 2018) and presents a response to research that shows that women's persistence in computing can be supported by fostering a sense of belonging (Lewis et al., 2017).

The relationship of fiber crafts to women and computing promises a starting point for fostering computational belonging. For centuries, fiber crafts have been centrally positioned in the life experience of women (Barber, 1995). In a girl's education, fiber crafts were used to prepare her for domesticity while some women have used their needle work for socio-political expression (Parker, 1984). In early computing, the socio-historical relations of fiber crafts and domestic work were used to recruit women (Abbate, 2012) who went on to profoundly contribute to technology innovation (Essinger, 2004). For instance, the woven memory of Apollo Mission computers was produced by women and derogatively dubbed "little old ladies' memory" (Rosner et al., 2018).

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Within educational research, electronic textiles (Buechley, 2006) have consistently proven to be a cogent context for introducing youth—especially girls—to STEM ideas (e.g., Buchholz et al., 2014). Yet, despite research linking textiles to computing, computing with fiber crafts is frequently focused on adding (programmable) electronic components to textiles. How textile production is in and of itself computational remains an underexplored yet promising starting point for contributing to computational belonging.

A material dimension of epistemological pluralism

The constructionist idea of *epistemological pluralism* theorizes multiple ways of getting to know an idea as a key to domain learning (Turkle & Papert, 1992). Particularly productive for the present study is an underlying ontological dimension of epistemological pluralism. Turkle and Papert (1992) showed that technological innovations of computational materials, such as changes from command-line interfaces to object-oriented graphical interfaces, facilitated relationship-forming and expressive approaches to computing.

This resonates with research related to technology design that calls attention to the underlying material relationships of digital things (Eglash et al., 2020). For example, although often de-materialized, digital concepts, such as bits, are bound to an underlying tangible materiality (Dourish, 2017). Focusing on the materials and the practices they bring to learning, can teach about how materials "contribute to forms of learning and collaborating that are unexpected but that may be fruitful if developed further" (Sørensen, 2010, p. 7).

For example, when looking at weaving as a form of algorithmic doing, the process of programming, in which writers determine the outcome, becomes closer to live coding that produces an unfolding algorithm of person and loom combinations (Griffiths & McLean, 2017). In this case, the socio-material practices of loom and people frame the typical programming approach to algorithmic doing as something very different yet valuable. The ontological threads within constructionist ideas of epistemological pluralism and technology studies prompted the present study to consider what fiber crafts materials bring to computational learning.

Methods

This qualitative study investigated the alignment of computational concepts with fiber crafts. The study facilitated artifact analysis sessions with computer science instructors at research focused universities on whether and how they saw computational concepts in youth fiber craft projects. Computer science instructors were engaged because of their expert understanding of computing and their experience teaching computing to beginners. While this risks to position textiles in a supporting role, the instructors presented a starting point for aligning textiles with computing concepts all along being able to inform understanding of what textiles do that is typically not done in introductory courses. Recruiting happened through snowball sampling and systematic search of university websites. The projects were produced by middle school students during a fiber crafts course (Keune, 2021).

The data sources consisted of artifact analysis sessions and photographs of youth projects. The *artifact analysis sessions* (average 60 minutes long) introduced instructors to the crafts and facilitated analysis of youth projects. The instructors were presented with youth-created projects and were asked to identify how the craft require the use of computational concepts. *Close-up photographs of youth projects*, taken after each course session, captured the project plans and fiber-craft projects from a range of angles to capture project dimensionality. On average, this resulted in 20 photographs per youth per session (1886 photographs in total). The photographs showed details of youth-produced artifacts, including stitches and weaving techniques.

The *analysis of the artifact analysis sessions* followed iterative thematic coding related to K12CS framework (2016) core concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting) to align computer science concepts with fiber crafts. Descriptive codes built on language that the instructors used to capture expressed nuances. To collapse the descriptive codes, the codes were related to core concepts of the K12CS framework and subcategories of core concepts. The codes were discussed for agreement with a fellow researcher and presented for discussion to a research team. This approach made it possible to focus on descriptions by the instructors that elaborated what fiber crafts could bring to computing education.

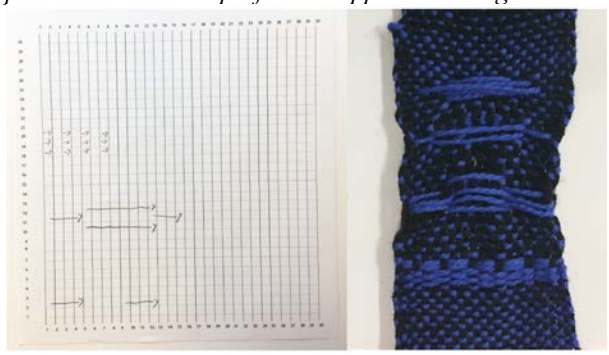
Findings

The analysis of the artifact analysis sessions identified that computer science instructors aligned fiber crafts with five computational concepts (i.e., algorithms, variables, control structures, modularity, and troubleshooting). While the research aligned all five concepts with both weaving and manipulating fabric, in the interest of space, this paper focuses on showing the alignment of algorithms with weaving and what this alignment contributes.

Algorithms are routines that can be performed by people and computers to accomplish tasks. Algorithms require effective communication with a computer by sorting algorithmic tasks and sub-tasks for computers to read and respond to. Across both crafts, instructors mapped algorithms directly onto crafts because of the crafts'

reliable artifact transformation. Artifact transformation consisted for both crafts of opportunities for three types of approaches to algorithms: 1) Syntax-oriented, 2) spatial, and 3) performative approaches to algorithms (see Figure 1 for weaving). Instructors highlighted the need to translate across approaches within the same activity.

Figure 1
Spatial-material and performed approach to algorithms in weaving



For weaving, 92% of instructors (n=11) highlighted the repetitive process of changing heddle positions paired with shuttle directions in a plain weave as algorithmic. A heddle is a flat piece with long and short openings for lifting threads. A shuttle is a carrier of yarn. For example, to create a plain weave pattern, weavers had to lift the heddle to part lengthwise threads and draw the shuttle with yarn between the threads in one direction. Then, to weave another row, weavers had to lower the heddle and draw the shuttle with yarn between the threads in the opposite direction. This pairing of heddle positions and shuttle directions remained for the duration of the weave.

Instructors connected the algorithmic aspects of weaving to a syntax-oriented approach of instructing a computer, like a programming language. One said: "It seems very algorithmic. You could (...) write instructions that [are] pretty robust that could be used to describe the behavior." The instructor's quote leads to the idea that weaving patterns can be described in a formal language, for instance, by writing a pattern down on paper, creating an interactive representation, or automating the functions of the loom through a computer program.

Rather than considering syntactic programming languages as the only way to engage with algorithms, the instructors suggested that algorithms are anchored with coordinate systems. One instructor said:

> Coordinates [in the computer] correspond to the states of the algorithm. To implement [an] operation on a computer, you have to think in terms of coordinates and where [to] put that number eventually (...). This is how the computer thinks.

Instructors also connected weaving with spatial approach to algorithms through the project plans on coordinate paper that youth drew (Figure 1, left). The coordinate grid paper showed warp threads of the loom as vertical lines and youth drew weft threads as horizontal lines. All warp and weft threads were numbered so they could plan personal patterns. Such coordinate patterns graphically represented the steps that would result in the woven fabric. One instructor said: "You just follow it very graphically (...) It's basically a line of code where you do right to left then you just follow it. Right to left, top to bottom." Through its position on the coordinate paper that corresponded to the weft threads of the loom, each drawn line was spatially anchored and could be located on the loom.

Instructors further connected weaving with a performative approach to algorithms. The algorithmic performance (i.e., the repetitive process of changing heddle positions paired with shuttle directions done by the loom and the youth) translated coordinate patterns on fabric into fabric. Instructors recognized the youths' process of weaving yarn into a matrix of warp threads as the way a computer would process a program (see Figure 1, right). Youth performed the algorithm, like how a computer would process a program, rather than communicate it in a machine-readable form for a computer to perform.

Discussion and Implications

Looking across the three approaches to algorithms in weaving, suggests that weaving is a context worth investigating for computational learning. Additionally, because weaving includes different approaches to algorithms in one activity, the craft presents a unique context for transfer. The research highlights the utility of supporting all three approaches (i.e., syntax-oriented, spatial, and performative) within one activity. For example, to foster the syntax-oriented approach to algorithms, activities could include opportunities to articulate the tasks and subtasks of weaving or opportunities to correct or complete pseudocode translations of common patterns. Where the first would be aligned with established weaving practices, the pseudocode activity could highlight

intersections among weaving and computing.

The relationships among approaches to algorithms were nonlinear. Rather than one leading approach, the translations across approaches to algorithms inform each other. For example, while a graphed plan could be implemented one to one by performing the illustrated algorithm, changes to the pattern can happen on the go, resulting in edits to the graphed plan. The fact that weaving fabric can involve multiple nonlinear approaches to algorithms within the same craft presents a particular instantiation of epistemological pluralism. Where weaving provides several ways of engaging with a domain idea that weavers can select from, weaving also makes it possible to engage with more than one approach to algorithms. This leads to considering epistemological pluralism in terms of recognizing multiple ways to approach a domain conceptual understanding simultaneously by one person. Along with the socio-historical promise of fiber crafts as fostering computational belonging for women in computing, the expanded understanding of epistemological pluralism further warrants additional studies that explore the utility of fiber crafts as context for computational learning.

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Silly or Substantive?: How Video Club Can Help Science Teacher Candidates See Strengths in Students' Contributions

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Abstract: Teacher learning occurs at the intersection of practice, critical discourse, and reflection. Yet, the fast-paced nature of teaching makes stepping back to see students' ideas as resources difficult for teacher candidates. Video club (Barnhart & van Es, 2020) affords a collaborative space for teacher candidates to slow down so that they can uncover and challenge underlying assumptions about students and their contributions. This study explores video club as a tool for helping teacher candidates see strengths in students' contributions. We analyze data from science methods courses for teacher candidates, finding that video club can help them to see value in students' contributions that they initially perceived as "silly."

Objectives and significance

Equitable science teaching requires noticing students' strengths (Louie et al., 2021) and building upon students' multiple ways of knowing (Warren et al., 2020). While research has explored how to help teacher candidates (TCs) notice students' disciplinary resources (e.g., Robertson et al., 2015), less is known about how to help TCs take up students' questions and ideas when they do not align with the pathway prescribed by the curriculum (e.g, Reiser et al., 2021). This paper illustrates the power of video as a reflective tool for TCs to notice, value, and leverage student contributions. Specifically, we focus on how video club (Barnhart & van Es, 2020) can help TCs reframe students' "silly" questions and ideas as generative resources for science learning, positioning students as competent inquirers (Keifert & Stevens, 2019). Ultimately, this shift can contribute to an inclusive classroom community where a teacher transitions from "the-one-who-teaches, to one who is taught in dialogue with the students" (Freire, 2018, p. 80). To this end, we ask: How can video clubs help science teacher candidates see strengths in students' "silly" contributions?

Theoretical background

What teachers notice about students' contributions (e.g., questions, ideas, actions) is shaped by the sociopolitical frames through which teachers see their students (Louie et al., 2021). Pervasive deficit ideologies shape teacher noticing (Louie, 2020), constraining opportunities for learning (Horn, 2007) as teachers position students' contributions as not being relevant or appropriate (Flores & Rosa, 2015). Moreover, science education typically draws on exogenous understandings of inquiry, valuing classroom forms of professional practices (NRC, 2012) rather than taking students' contributions seriously (Keifert & Stevens, 2019). As a result, generative resources like students' playful interactions are often dismissed or overlooked in science classrooms (Keifert et al., 2021). Thus, there is a need for teacher educators to understand how deficit perspectives of students' contributions can be surfaced, challenged, and rearticulated (Philip, 2011) in order to help teachers attend to issues of equity and inclusion and see students' resources as strengths (Louie et al., 2021). We propose that video club could be used as a tool to help teacher candidates reframe student contributions (e.g., reframe contributions that they had initially dismissed as "silly" instead as substantive). In video clubs, teachers share and analyze short video clips of their own classrooms (van Es & Sherin, 2007). Through repeated viewing and discussion, video clubs support teachers to consider classroom discourse, curricular materials, and teaching strategies in the context of rich and complex classroom interactions (Borko et al., 2008). We propose that specific affordances of video club (watching videos repeatedly, pausing for discussion), when paired with anti-deficit framing (Louie et al., 2021), could help TCs see students' contributions as resources integral to science learning and notice resources that may have been overlooked as they were teaching. In addition, these reflective discussions could enable TCs to collectively imagine how they could cultivate students' strengths in the context of the lesson they are watching or in their future teaching.

Method

This study was conducted in two methods courses at a large university in the midwestern US that took place virtually using Zoom in Autumn 2021. One course focused on middle childhood science (grades 4-8) and included 15 TCs; the other focused on secondary science (grades 7-12) and included 7 TCs. We use pseudonyms that were

chosen by TCs to represent themselves. We focus our analysis on video clubs, which took place 3 times during each course. We use interaction analysis (Jordan & Henderson, 1995) and inductive coding (Charmaz, 2006) to explore how this design supported teachers to see strengths in students' contributions, focusing on how they reframed students' contributions as substantive rather than "silly."

During video clubs, TCs selected, watched, and discussed short video clips of their teaching (3-4 minutes) in small groups with four of their peers and a facilitator from the research team. TCs shared clips from their field placement as well as from their "microteaching" assignments (a mini-lesson planned and taught by TCs to their peers). To build toward an anti-deficit frame, before beginning video clubs, TCs read a case excerpt from Warren et al. (2020) about Jonathan, an African American boy who argued that the sun is living – an idea that aligns with contemporary systems-based perspectives in science, but that was initially dismissed by Jonathan's teacher. TCs discussed the case from the perspective of the teacher and the student, then reflected on connections to their own experiences as teachers and learners. Video club was introduced as a way to help TCs practice seeing students' strengths that might similarly be overlooked during teaching. Video club discussion was guided by three prompts: (1) How *does* the teacher or activity make space for students' ideas, (2) How *could* the teacher or activity make space for students' ideas, (3) What strengths do you notice in students' contributions?

Findings and discussion

Our analytic focus on "silly" questions and ideas emerged from a tension initially raised in the secondary science class. In her video club, Fairygirl explained that only "genuine" questions or ideas (rather than "silly" questions or ideas) were welcome in her classroom: "I think that that's really important to talk about in your classroom to make it a safe and respected environment for everybody to bring their own opinions. Not silly opinions or silly facts, but genuine questions, genuine ideas should always be welcomed." Here, Fairygirl distinguished between "genuine" and "silly." Yet, in reality, there are no objective criteria that can help teachers distinguish between these categories. Moreover, resources like children's play that might be constructed as silly (Keifert & Stevens, 2019) or otherwise inappropriate (Flores & Rosa, 2015) can be generative for classroom inquiry and science learning (Keifert et al., 2021; Pierson & Brady, 2020). Based on this interaction, when video clubs were introduced in the middle childhood science class, we attended specifically to how TCs constructed students' contributions as "silly" (or inappropriate) versus "genuine" (substantive or generative). Below, we present examples from the middle childhood class, focusing on two sessions: (1) the "practice" video club, where the whole class participated in a video club using a video of the instructor, Pierson, teaching in a 6th grade classroom, and (2) the first video club in which TCs shared videos of their own instruction. We show how video club helped TCs surface and challenge tensions related to "silly" questions in science classrooms, reframing students' contributions as substantive rather than "silly." We propose that slowing down and collaboratively seeking out students' strengths in their video clubs supported TCs' shifts from constraining to expansive perspectives of students' contributions.

Reframing "silly" in instructor's examples

Before the "practice" video club, Pierson asked TCs if they had experienced tensions like those experienced by the student and the teacher described in the "Jonathan and the Sun" reading. Margaret shared that her Spanish teacher "yelled at a student for asking what color a pumpkin was and he was colorblind," adding that it is important that teachers "not make assumptions that students are trying to cause problems." In response, in the Zoom chat, Shoobop wrote "that's not funny, but also a really funny question." This led into a conversation about what Shoobop described as students' "bravery" and "courage" to share risky questions and ideas, including ideas that might seem "funny" or "wrong" to the teacher and other students.

Building on this idea, Pierson intentionally highlighted in her teaching clip (students participating in an embodied model of an ecosystem with algae and guppies, see Pierson & Brady, 2020) student contributions that could be perceived as "silly." Early in the video, Shoobop picked up on one student comment that he saw as funny: a student's suggestion that "maybe if the guppies would communicate" they would survive longer in the ecosystem. Pierson asked him to "talk a little bit more about this quote." In the exchange that followed, the student's idea was reframed; rather than being "funny" it was seen as generative and appropriate for science learning:

> **Shoobop**: I honestly thought it was a funny sounding idea. I like that you [Pierson], like, kind of went with it though. Like it's kind of like a silly idea that like, I mean I don't know if [guppies] communicate with each other… but the idea of them, like, talking to each other just kind of made me smile.

> **Pierson:** That's interesting, because I, I think you're pulling out like, "okay, so a student is saying something, but if you take it seriously, where does it go?" Is that kind of what you're getting at?
> **Shoobop**: Yeah, like, I guess, well, I like the way you were like taking what they said and, like, rolling with it and, like, yeah, "let's imagine what might be different if the guppies were communicating."
> **Pierson**: Why would it be helpful, to talk about how different organisms communicate?
> **Margaret**: Yeah, so like, obviously, we talk a lot. Talking is how we communicate. But, like bees communicate though, like, shaking their butts. I think that's how they do it… there are certain things that like communicate through smells.

In this interaction, the TCs and Pierson worked together to reframe the student's contribution as a generative resource for exploring ideas critical to the biological and ecological phenomena the students were studying (whether and how organisms communicate), valuing and legitimizing a contribution initially described as "funny." At the end of the video, when students were dancing, Pierson referenced the interaction above again. After describing how dancing became a resource in this classroom, Pierson said, "so even things again like Shoobop was saying that seem kind of silly in the moment can be really great resources." Slowing down to imagine possible trajectories for students' ideas in this example laid the groundwork for TCs to later reframe and value students' "silly" contributions in their own video clubs.

Noticing and responding to students' contributions

The framing above helped TCs consider how they could invite and cultivate students' contributions in their own teaching, even if their students were afraid of being "wrong" or "silly." When sharing his own teaching video, Shoobop paused to highlight a moment when he says "There's no wrong answers in this classroom." Margaret commented on this statement, saying "it's important to open up the floor to the idea that nothing is off the table." With this comment, Margaret affirmed that all students' contributions could be valuable for learning. To encourage Shoobop to share his perspective, the facilitator asked: "so what were you thinking?" He explained:

> One of my favorite things to do in the classroom is just kind of like, if it feels like one angle isn't working, where, like, as before I was trying to go, like, there head on, like, let's talk about the content, I was, like, "well if we try to think outside any context, like, what we think is right or wrong answer, like let's discuss, like, what could be." I don't know. I don't think I'd go so far as to say like, "what would this look like in a parallel universe," but, like, "why don't we talk about that?" and then whatever we end up talking about we can then draw back to more, like, the actual meat and potatoes of the lesson.

This response echoes themes from the "practice" video club: that it is important to hear students' ideas because they can connect to the "actual meat and potatoes of the lesson." Yet, it also positions students' contributions as supportive of the curricular pathway, rather than an opportunity to open new lines of inquiry. In this sense, Shoobop's explanation indicates openness to students' ideas, but does not offer students epistemic authority (Haverly et al., 2020; Miller et al., 2018). Other students expressed similar stances. Ren said, "He was ready to go with it. He just kept the train rolling and encouraging that line of thought. I think that gave a great opportunity for students to share their thoughts." Billy added "He doesn't necessarily tell them if their ideas are right or wrong, but he does tell them, 'yeah, that's a great idea' and he still uses the ideas to just continue on that conversation." Once again, TCs positioned students' ideas as either "correct" or "incorrect" (even if the teacher withholds this information), which could lead to deficit perspectives of students' ideas. Still, these statements illustrate a shift in the TCs' stance away from narrowly focusing on ideas represented in their standards and curricula and toward inviting and valuing students' ideas. Later in the discussion, TCs discussed challenges with this approach. They said it can be difficult to respond to students' ideas in the moment. Shoobop shared a strategy that he used to slow down during instruction: repeating students' contributions (to allow himself time to process). He explained: "I think that's something that generally makes me uncomfortable in the classroom is like I very much so want to be the expert, which I think every teacher should be, and from time to time, when I'm like 'OK well I actually like need to think about what that person just said,' because I'm also a literal human being and need to think about things." Slowing down in this way allowed Shoobop to create space for himself to notice and respond, which in turn contributes to a classroom community where students' ideas are valued.

Conclusions and implications

Our findings have implications for the design of science methods courses that aim to support equitable teaching. Our data demonstrate how video club can help TCs see strengths in students' contributions. Here, we focus on the contrast between framing students' contributions as silly versus substantive, but we propose that this lens could be applied to other student contributions seen as "inappropriate" for science learning. Video clubs allow TCs time to pause and reflect on students' contributions and imagine generative possibilities in their responses. Over time, this could lead to shifts toward anti-deficit approaches that value and take seriously students' contributions. We conjecture that as these TCs continue with video club, they could shift toward seeing students' contributions as valuable in their own right (rather than only as means to the "meat and potatoes" of the lesson).

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International Society of the Learning Sciences

Study on Evaluation Indicator System of Interdisciplinary Problem-solving Ability for Pre-service STEM Teachers

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Abstract: With the advent of the era of artificial intelligence, the problems that students need to solve are more diversified and integrated. Therefore, it is very necessary to cultivate interdisciplinary problem-solving (IPS) ability for students. Pre-service STEM teachers play a very important role in interdisciplinary education, the analysis and evaluation of IPS ability of pre-service STEM teachers is helpful to understand the current ability level. Based on the literature review and the Delphi method, an evaluation indicator system for pre-service STEM teachers' IPS ability is constructed. Expert consultation and Analytic Hierarchy Process (AHP) method are used to determine the weight of indicators. 98 surveys from 10 colleges are collected, results indicated that the evaluation indicator system has high validity, pre-service STEM teachers' IPS ability is generally average. Finally, directions are also provided for evaluating and improving the IPS ability of pre-service STEM teachers.

Introduction

With the constant development of innovative technology, the problems that students need to solve are more diversified and integrated, the social demand for student is becoming more comprehensive. Cultivating learners' interdisciplinary problem-solving (IPS) ability have gradually become one of the key training objectives in the educational reform of most countries. In order to improve IPS ability of pre-service STEM teachers, the Australian and UK governments have issued corresponding policies towards providing high-quality special training and learning support. The Chinese government has also taken measures to construct specialist teacher groups with outstanding IPS ability through multi-school collaborative interdisciplinary teaching and research activities (Ministry of Education, 2019). IPS ability is important to students, however, pre-service STEM teachers as the ones who develop this ability in students, must also possess IPS ability (Ming & Sha, 2019). Researchers have evaluated middle school students' IPS ability (Feng, 2019). However, there are little research on teachers' IPS ability. Existing research mainly focus on the orientation of STEM instruction (Günbatar & Bakırcı, 2019), improving pre-service teachers' STEM knowledge and problem-solving skills ((Berisha & Vula, 2021; Özçakır Sümen & Çalışıcı, 2021). It has been an urgent need to cultivate IPS ability of pre-service STEM teachers. Previously, the concept of pre-service STEM teachers' IPS ability is needed to be clarified. Secondly, a corresponding indicator framework is necessary to estimate the ability. Therefore, in order to understand the current situation of IPS ability of pre-service teachers, it is necessary to establish the corresponding indicator framework that can diagnose pre-service teachers' IPS ability level.

Theoretical framework

IPS ability of pre-service STEM teachers is mainly discussed in this article. STEM teacher refers to teachers of subjects related to STEM such as mathematics, science and information technology. Pre-service teachers majoring in Educational Technology are good at STEM education and science education (Ming & Sha, 2019). IPS ability means that when pre-service STEM teachers encounter interdisciplinary problems in teaching, based on the attitude of facing the problem, combine the methods and strategies of multidisciplinary knowledge when dealing with problems, as well as the quality of interdisciplinary problem solving in exploring and integrating different disciplines.

Construction of evaluation indicator system

The cultivation of IPS ability is the trend of the times and one of the goals of current education. In this study, we refer to the outline of STEM teacher ability indicator system issued by China Institute of Education Sciences. The dimensions of problem-solving are referred to relevant literature as well (Huang Maozai & Chen Wendian, 2004). Then, an evaluation indicator system is constructed initially to evaluate the IPS ability of pre-service STEM teacher combining with the characteristics of pre-service teachers. Expert consultation questionnaire is designed

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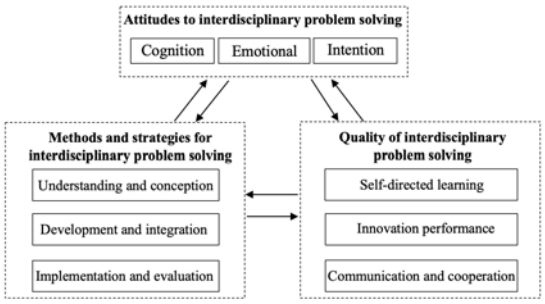
to further determine evaluation indicator system. Finally, pre-service STEM teacher' IPS ability evaluation indicator system includes 3 first-level indicators and 9 secondary indicators (see Figure 1).

Figure 1

Evaluation Indicator System of Pre-service STEM Teachers' IPS Ability



The attitude dimension of interdisciplinary problem solving can be divided into three aspects of cognition, emotion and intention. “Attitude" refers to individual's stable psychological tendency and response to others or things, including cognition, emotion, and intention, which are usually manifested in beliefs, feelings, and behavioral tendencies (Shi, 2012). "Cognition" refers to the understanding and problem-solving beliefs of pre-service STEM teachers. "Emotion" is an emotional experience from the inside. "Intention" is the behavior of the pre-service STEM teacher’s sense of responsibility and mission to solve interdisciplinary problems, which is manifested by cognitive and emotional factors.

Interdisciplinary problem-solving methods and strategies dimension refers to the use of interdisciplinary thoughts and knowledge to solve problems. In this study, methods and strategies are divided into three parts (Su, 2017). The understanding and conception part indicates pre-service STEM teachers' understanding of knowledge involved in interdisciplinary problems and their conception of knowledge performance. The development and integration part indicates pre-service STEM teachers’ competence to obtain materials through multiple channels when developing teaching resources, integrate resources from the perspective of cultivating students' abilities in various aspects. The implementation and evaluation part refers to the methods and strategies used by pre-service STEM teachers to solve interdisciplinary problems in teaching organization and teaching implementation, it also can evaluate and optimize the process of solving interdisciplinary problems.

The quality dimension of interdisciplinary problem solving refers to the active learning, innovative performance and communication and collaboration abilities of pre-service STEM teachers in the process of solving interdisciplinary problems (Huang Maozai & Chen Wendian, 2004). Firstly, pre-service STEM teachers can recognize interdisciplinary problems, use appropriate methods to solve problems, improve the solutions and promote professional development. Secondly, pre-service STEM teachers need to show a unique way of thinking at all times, discover problems creatively. Finally, the development of pre-service STEM teachers emphasizes teamwork spirit, which stand for a harmonious atmosphere to share resources, communicate with each other, and jointly complete solutions to problems in cooperation.

Research questions

Based on the above construction of the evaluation indicator system, the current study mainly focuses on two questions:

(a) How to verify the effectiveness of the pre-service STEM teacher’s IPS ability evaluation indicator system?
(b)What level do the study objects perform in each dimension of IPS ability?

Research Design

Determine indicator weight

In the study, the expert consultation questionnaire of the indicator weight is designed after the construction of the evaluation indicator system. Then, the average (Likert five-point scale) is used to express the degree of the importance of each evaluation indicator, and the concentration of expert opinions is expressed by median and majority. Experts' opinions on each indicator are collected to delete indicators with low support. After two rounds of consultation by 12 experts, the evaluation indicator system is also determined.

The Analytic Hierarchy Process (AHP) is a decision-making method and proposed by the American operations researcher Saatty T.L. Firstly, an analysis structure model of the pre-service STEM teacher's IPS ability

evaluation indicator system is established in the yaahp software. Secondly, the 1-9 ratio scale method is introduced to compare and analyze the factors of each layer in pairs, distinguishing which element is more important. Finally, the judgment matrix is constructed. The weight of the pre-service STEM teacher's IPS ability rating indicator system is established through calculation and analysis of the experts' scoring of the importance of each indicator in the judgment matrix at the last (see Table 1).

Table 1
Pre-service STEM teacher's IPS ability evaluation indicator weight

First-level indicators	Weight	Secondary indicators	Weight
1. Attitudes to Interdisciplinary problem solving	0.28	1.1 Cognition	0.22
		1.2 Emotion	0.30
		1.3 Intention	0.48
2. Methods and strategies for interdisciplinary problem solving	0.33	2.1 Understanding and conception	0.29
		2.2 Development and integration	0.33
		2.3 Implementation and evaluation	0.38
3. Quality of interdisciplinary problem solving	0.39	3.1 Self-directed learning	0.25
		3.2 Innovation performance	0.35
		3.3 Communication and collaboration	0.40

Questionnaire design

The questionnaire is developed by using the pre-service STEM teacher's IPS ability evaluation indicator system constructed in this research. The questionnaire is a Likert five-point scale. The first part is the basic information of the survey objects, including gender, grade, major, and college level, etc. The second part is the current situation of survey objects' IPS ability, including 3 first-level indicators and 9 secondary indicators.

Participants

The survey objects cover senior undergraduate in educational technology and postgraduate in modern education technology from 10 normal colleges in China. The participants have mastered professional knowledge and teaching skills, and have participated in educational internships for 3-6 months in primary and secondary schools. However, they haven't entered the teaching field formally, lacking educational practical experience.

Procedure

A total of 104 questionnaires are collected in this survey and 98 are valid questionnaires, with an effective rate of 94.23%. Through SPSS analysis of the overall validity of the questionnaire, it is concluded that the overall KMO coefficient of the questionnaire survey is 0.885, the overall Alpha reliability coefficient is 0.954 and the Alpha reliability coefficient of each dimension type is greater than 0.7, which proves that the reliability of the questionnaire is relatively high.

Results

RQ1: How to verify the effectiveness of the pre-service STEM teacher's IPS ability evaluation indicator system?

Firstly, the pre-service STEM teacher's IPS ability evaluation indicator system is based on literature analysis and the Delphi method, more importantly, it is determined after two rounds of expert consultation. Secondly, the indicators weights at all levels are determined according to the analytic hierarchy process (AHP). Thirdly, the questionnaire is developed by using the pre-service STEM teacher's IPS ability evaluation indicator system. Finally, the result shows that the IPS ability levels of the research objects are normally distributed, the overall IPS ability is average level. In addition, some research objects claimed that the allocation of the evaluation indicator system is relatively reasonable, reflecting the requirements for specific abilities such as subject knowledge and operational skills at each stage of IPS. Therefore, the IPS ability evaluation indicator system designed in this research has high scientific and use-value.

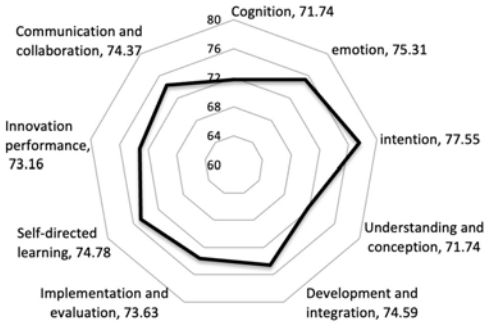
RQ2: What level do the research objects perform in each dimension of IPS ability?

The total score of pre-service STEM teachers' IPS ability is 74.27. According to the classic grade classification standard (Juan, 2016), the result indicates that the pre-service STEM teachers' IPS ability is generally average. The score of attitudes to IPS is 75.60. The methods and strategies of interdisciplinary problem solving and the quality of interdisciplinary solving are a little lower than average score, 73.40 and 74.05 respectively.

From the perspective of secondary indicators, the performance of the pre-services STEM teacher's intention and emotion, development and integration, self-directed learning, communication, and collaboration are better than that of other secondary indicators. While the level of cognition, understanding and conception, implementation and evaluation, innovation performance are relatively low. Especially the cognition, understanding and conception lag behind the level of development of other indicators (see Figure 2).

Figure 2

Pre-service STEM teachers' IPS ability secondary indicator score



Conclusion

The evaluation of pre-service STEM teachers' IPS ability is the prerequisite for STEM education. The localized design and development of the evaluation indicator system is a necessary way to evaluate the training effect of pre-service STEM teachers. In this study, the Delphi method is used to construct an evaluation indicator system for pre-service STEM teachers' IPS ability, the analytic hierarchy process (AHP) is also used to calculate the weights of indicators at all levels. The practical result shows that the evaluation indicator system can diagnose the pre-service STEM teachers' IPS ability levels and existing shortcomings to some extent. However, it's a complex system engineering to construct a scientific and reliable localized evaluation indicator system, which needs to be continuously revised and improved based on the evaluation object and the educational environment. In the future, the evaluation indicator system should be expanded in such aspects as the survey scope of regions and grades.

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Emotional engagement assessment: self-reports versus facial expressions

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Abstract: Current research utilizes self-reports and facial expression recognition analysis to provide a more continuous and objective insight into how students' emotional engagement unfolds and impacts learning. Analysis of nursing students learning with virtual reality simulation revealed that only the facial expression data channel, compared to self-reports, was sensitive to fluctuations in engagement which varied throughout the different learning session phases. In addition, findings show that learning achievements were negatively associated with facial expressions of anger and positively associated with positive self-reported emotions. Hence, this study demonstrates that the methodology of using multimodal data channels which encompass different types of measures, can provide insights into a more holistic understanding of engagement in learning and learning achievement.

Introduction

Engagement is a multidimensional construct that refers to an individual's active involvement in a learning activity (Christenson et al., 2012). This study explores only the emotional aspect of engagement. The *emotional engagement* focuses on states that are related to students' emotional involvement during learning activities (Christenson et al., 2012). Positive emotions include enthusiasm, interest and enjoyment while learning (Renninger & Bachrach, 2015). Whereas, negative emotional components include boredom, sadness, and frustration in the classroom (Skinner et al., 2008). Theories of motivation, including the self-determination theory, and the control-value theory (CVT) of academic emotions (Deci & Ryan, 1985; Pekrun & Linnenbrink-Garcia, 2012), emphasize the role that both positive and negative emotions have on students' involvement in learning activities, and underscore how affective dynamics sustain or disrupt learners' engagement to impact learning performance. The CVT predicts that positive activating emotions (e.g., curiosity and enjoyment) positively influence learning outcomes, whereas the inverse is true for negative-deactivating emotions (e.g., boredom) (Pekrun & Perry, 2014). Given the importance of emotional engagement, it is therefore crucial to capture how emotional engagement unfolds and what initiates and diminishes emotional experiences with the long-term goal of helping leaners to re-engage. So far, the most predominate measures of emotional engagement were self-reports and observations (D'Mello et al., 2017). This study suggests evaluate the additive value of the multimodal approach, using both, subjective self-reports and objective facial expression recognition analysis.

Facial expression recognition is a fully automated measure which it is based on artificial neural networks that can match varying sets of action unit activities to different discrete emotions (Ekman & Rosenberg, 1997). Facial expression analysis allows identification of changes in facial movements at very short time intervals, and can therefore provide an unobtrusive detailed view of students' emotions transitioning throughout a learning session (Dindar et al., 2020). Importantly, it has been suggested that self-report measures mainly reveal emotions a person has become consciously aware of, whereas an automatic facial expression analysis captures fast changing emotions in the implicit dimension of the subconscious (van Bommel et al., 2020). As such, incorporating the traditional measures of engagement, such as self-reports, with fully automated measures of engagement, can capture the grain size of engagement dynamics and provide both objective microlevel and subjective macrolevel perspectives (D'Mello et al., 2017).

Research questions

(1) How do students' emotional engagement unfold while they learn, as revealed by their self-reports and by facial expression analysis; and (2) What is the synergistic effect of this emotional engagement, as measured by the multimodal data streams of self-reports and facial expressions, on the students' learning achievements?

Methods

Participants

In total, 65 freshmen nursing students at an Israeli university volunteered to participate in the study. Due to technological issues of data collection (e.g., calibration errors), data of four participants was excluded, resulting in a final sample size of 61. Most participants were female (n=44), and the mean age was 23±5.1 years.

The study was conducted following the approval of the university's ethics committee (#0001776-2).

Research design and procedure

This study is part of a more extensive study (Dubovi, 2022). This was a prospective study with a pre-test – post-test design. The students' demographics and prior content knowledge were assessed via a pre-test paper-and-pencil survey. Each participant was then asked to sit in front of a computer and a calibration of their facial expression tracking was performed. Following this, participants were offered to learn with a desktop virtual reality simulation. The VR simulation incorporated the architecture of a 3D hospital (Dubovi et al., 2017). Playing the role of a nurse-avatar, participants were asked medication administration procedures. Emotional engagement characteristics were captured during the entire learning experience using facial expressions recognition algorithm. In addition, students were asked on three occasions by the VR simulation to complete the Positive and Negative Affect Scale (PANAS) questionnaire (Watson et al., 1988): Time 1, before the intro phase; Time 2, after the intro phase; and Time 3, after the last phase of the summing-up video. After the learning session, participants completed a paper-and-pencil content knowledge post-test. The iMotions 9.0 Biometric Research Platform (https://imotions.com) was used to setup the experimental design and to collect the data.

Data Collection Instruments

Facial expression recognition

The Affectiva Affdex algorithm provided by iMotions 9.0 (https://imotions.com) was used to obtain in real-time the 7 basic emotion likelihoods for joy, anger, surprise, contempt, fear, sadness, and disgust at a 30 Hz frequency. The algorithm uses the Facial Action Coding System to identify and categorize facial expressions based on specific facial 'action units' and was shown to be reliable (Ekman & Rosenberg, 1997; Kulke et al., 2020). The metrics can be thought of in terms of probability; as the emotion or facial expression occurs and intensifies, the score rises from 0 (no expression) to 100 (expression fully present). Then a thresholding for time and for absolute amplitude probability was carried out based on the iMotions guidelines (https://imotions.com/blog/facial-expression-analysis/) to extract emotion percentage metrics. Facial expressions were collected for the overall learning experience.

Positive and Negative Affect Scale (PANAS) questionnaire

The PANAS is a list of 20 adjectives used to describe 10 positive emotions and 10 negative emotions (Watson et al., 1988). The positive affect captures the feelings of being attentive, active, alert, excited, enthusiastic, determined, inspired, proud, interested, and strong. Negative affect includes the feelings of being hostile, irritable, ashamed, guilty, distressed, upset, scared, afraid, jittery, and nervous. The order of questions in the questionnaire was mixed between positive and negative affect scores. Respondents are required to indicate the extent to which they feel these emotions "at this moment" on a 5-point scale. Cronbach alpha yielded a good internal consistency score of .86 for the global positive affect and 0.82 for the global negative affect.

Content knowledge test

The Medication Administration Test (MAT) assessed the nursing students' understanding and practical applications of the medication administration guidelines. The test was validated in a previous study (Dubovi et al., 2017). The test consists of 13 multiple-choice items. Analysis of the MAT using Cronbach alpha yielded a good internal consistency score of .74.

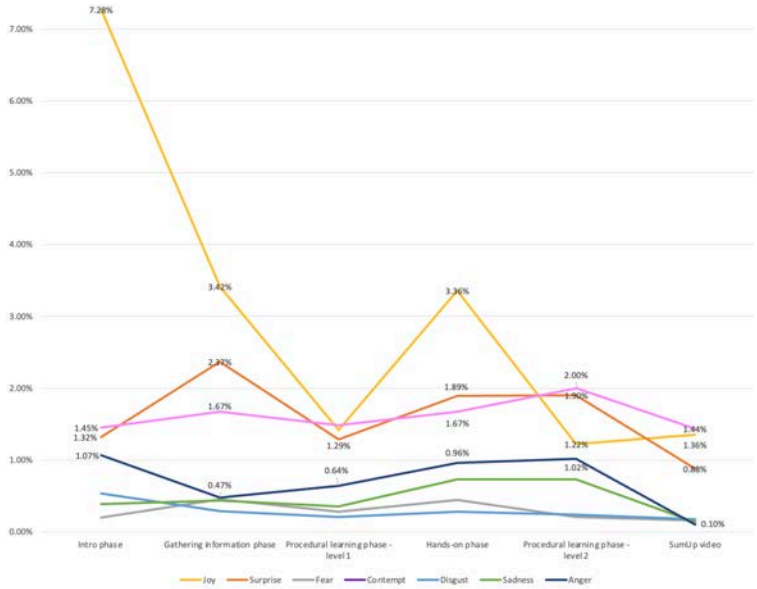
Results

Emotional engagement throughout the overall learning experience was captured via facial expressions extraction and PANAS self-reports. The Kruskal-Wallis H test of facial expressions revealed that participants experienced significantly more joy 4.0±3.6% than other emotions, such as surprise 1.7±2.6%, fear 0.3±0.9%, contempt 1.5±2.5%, disgust 0.3±0.6%, sadness 0.4±1.2%, and anger 0.8±1.6%; ($\chi 2(6) = 314.710$, $p < .001$). Furthermore, a linear mixed effects model (LMM) for repeated measures showed a significant interaction between the type of expressed emotions and the VR simulation phase ($F(30, 420.699) = 7.545$, $p<0.001$). Post-hoc analysis showed significantly more joyful expressions for the intro phase ($p < 0.001$) and for hands-on phase ($p < 0.001$; Figure 1). In addition, facial expressions of anger and surprise were expressed significantly less during the final sum-up video phase ($p < 0.005$).

While facial expression analysis captured the fluctuation of the students' implicit and fast changing emotions, the PANAS self-report detected the students' explicit emotions at three different time-points. Similarly to the facial expression analysis, the PANAS analysis revealed that students experienced significantly higher levels of positive emotions than negative emotions ($F(1, 3658)=6882.5$, $p<0.001$; 3.8±1.1 vs. 1.3±0.7, Table 1). The most predominant emotions while interacting with VR were interest (4.5±0.4), attentiveness (4.5±0.5) and alertness (4.3±0.5). A non-significant change in emotions was demonstrated by an LMM for repeated measures throughout the three times that the PANAS was administered ($F(38, 2239.068) = 0.964$, $p=0.533$).

Figure 1

Changes in students' emotions according to the VR simulation sequence phase.



The MAT content knowledge post-test scores were significantly higher than the pre-test scores (paired $t=-6.422$, $p<0.001$; 90±9 vs.78±16). To further understand the impact of emotional engagement on the students' knowledge gain, a bivariate intercorrelation analysis was performed (Table 1). The analysis revealed a significant negative correlation among anger facial expressions and post-tests scores ($r=-0.323$, $p < 0.1$; Table 1); as well as positive correlation of PANAS positive self-report emotions to post-tests scores ($r=0.294$, $p < 0.1$; Table 1).

Table 1

*Bivariate intercorrelations between MAT content knowledge post-test with emotional engagement (*N*=61)*

Variable	1	2	3	4	5	6	7	8	9	10
1. Content post-test knowledge	--									
Facial expressions										
2. Joy	-.116	--								
3. Surprise	-.048	.008	--							
4. Fear	.135	-.031	**.294***	--						
5. Contempt	.017	**.265***	.090	-.048	--					
6. Disgust	.088	.090	.080	-.027	**.545****	--				
7. Sadness	-.122	-.025	.084	-.075	-.057	.048	--			
8. Anger	**-.323***	-.119	-.095	-.033	-.018	.119	.114	--		
PANAS self-report (Positive/Negative)										
9. Positive	**.294***	-.003	-.106	.106	0.190	**-.267***	-.06	-.104	--	
10. Negative	-.111	.106	-.055	-.054	.026	-.111	.081	-.085	-.044	--

*$p < .05$; **$p < .01$

Discussion

The main goal of this study was to identify the synergistic impact of the multimodal metrics on the students' learning achievements. The facial expression continuum revealed that joy (i.e., enjoyment) was the most predominant emotion that was expressed by students. It became evident that the frequency of the joy expression changed across the different VR learning phases. Although facial expressions of joy were the most frequent emotions expressed by students, there was no significant impact of joy on post-test learning achievements. In contrast, although facial expressions of anger were expressed at a relatively low frequency with no significant changes across the different phases of the learning session, they did show a significant association with post-test learning achievements. Interestingly, the subjective perception of their emotional experience, a PANAS self-report, demonstrated the significant impact of self-reported positive emotions on learning achievements. This study demonstrates that it is crucial to integrate both automated objective channels with subjective methodologies to provide a more holistic and comprehensive perspective on complex learning processes and learning outcomes.

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Mundane Practices on the Edges of Intentional Design in a Maker Project

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Abstract: Maker-centered learning engages students in the creation of tangible artifacts. We focus on the edges of this intentional design process, where mundane materially entangled practices that are not driven merely by human intention happen. We build on theoretical perspectives that consider practices as assemblages and matter as active, relational, and dynamic. Together with teachers, we conducted an invention project in Finland. Students aged 14 to 15 designed and built smart products in small teams. To understand the continuity of details, we analyzed video recordings of three teams' design sessions on three levels: the macro, intermediate, and micro. The analysis framed the learning process as a balancing act. In addition to performing the learning task, students simultaneously created functional artifacts and adapted their creative flow to the institutional rhythm of the school classroom. Materiality created messiness and unpredictability but also provided tangible boundaries that allowed for action amidst this uncertainty.

Introduction

A key aspect of maker-centered learning is idea materialization, the transformation of abstract ideas into tangible forms. Working with tangible artifacts has been found to support learning that is multimodal and transactive across settings (Peppler et al., 2021). With our background in craft, design, and technology education, we perceive the idea materialization process as an entanglement of designer and matter, where the human maker learns from matter and thinks with it (Heimer, 2016). However, much activity takes place at the edges of this intentional design process, such as spontaneous play, matter that is entangled with sociopolitical questions (Vossoughi et al., 2016) or knowing beyond traditional academic skills (Kuby et al., 2015). We focus on these edges and mundane materially entangled practices that are not driven merely by human intention, but also affected by, for example, materials and technologies (Bodén et al., 2019).

Sensitizing ourselves to details and more-than-human relations does not offer universal facts. Instead, such a perspective helps us to recognize issues that call for response (Haraway, 2016). A focus on the wider connections between details can make actors hiding in mundanity, such as commercial corporations, visible (Decuypere, 2019). Appreciating moments of uncertainty and nonlinearity can help us to notice opportunities to support learning that places learners as part of the world, not outside observers, which is crucial in future education (Common Worlds Research Collective, 2020). To better understand the multiple fluid practices (Mol, 2002) that take place in a maker-centered learning project, we ask: How is the idea materialization process enacted in classroom practices?

Theoretical approaches

We understand idea materialization as an iterative and nonlinear process that includes constructing, evaluating, and revising various material models, such as sketches, mock-ups, prototypes, and final artifacts (Kangas et al., 2013). Our longstanding research in craft, design, and technology education helps us to avoid blindly adopting branded definitions of making, which, as Vossoughi et al. (2016) argue, can limit maker-centered learning to technological innovation aimed at contributing to economic growth. Our understanding of making emphasizes aspects such as embodied knowledge (Heimer, 2016) and wide-reaching material connections (Latour, 2005).

Widening the scope of our inquiry to the edges of intentional design allows us to explore the unverbalized practices that emerge during idea materialization. This approach helps us to understand the multiple realities that take shape in the classroom (Bodén et al., 2019). Placing special emphasis on acknowledging material agency as part of sociomaterial entanglements, we build on theoretical perspectives that consider practices as assemblages and matter as active, relational, and dynamic (Bodén et al., 2019; Haraway, 2016; Mol, 2002).

We begin by acknowledging that matter matters; it can transform situations (Latour, 2005). However, this material agency is not a static attribute but is instead enacted in relations (Mol, 2002). Therefore, instead of single actors, our focus is on the heterogeneous entanglements of human- and nonhuman actors and sociomaterial encounters in which humans and nonhumans transform each other (Latour, 2005). These transformations and

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effects of encounters are not predetermined; thus, we do not seek to establish fixed or stable roles of matter. Instead, we consider the practice of materialization to be fluid assemblage, which is constantly changing (Mol, 2002). We purposefully do not predetermine who or what participates in enacting the materialization. The more-than-human relations that constitute materialization cannot be clearly formulated in a neat network, as reality is not always logical (Mol, 2002). Thus, we do not seek universal epistemic claims but theoretically grounded situated knowledge (Haraway, 2016; Decuypere, 2019).

Methodology

For several years now, we, together with teachers, have conducted co-invention projects in elementary and secondary schools as part of regular curricular activities. This study focuses on a project that took place in spring 2019 in a Finnish upper secondary school. Students aged 14 to 15 designed and built smart products in small teams. The project lasted for 8 weeks and involved 17 sessions, lasting 75 minutes each. The orientation phase (three sessions) included a coding workshop, a lecture from a professional designer, and a visit to a design museum. During the initiative ideation phase (three sessions), students oriented themselves toward problems in their everyday lives and the artifacts involved in those problems. Teachers formed teams of three to four students, and these teams chose one initial idea to be developed and materialized, first as a mock-up and then as a functioning prototype (10 sessions). Finally, teachers organized an in-class invention fair, where students presented their inventions and gave and received constructive feedback (one session).

The first two authors were present at the school throughout the process. After orientation, we video recorded the 14 design sessions of three student teams. The inventions of these teams were named (by the students themselves) the Magic Bunny (a smart piggy bank that counts the money inserted), the Light-Up-Shirt (a garment with decorative LED lights that adjust to the environment), and the Pussi Cat (a smartphone bag that heats up if the temperature drops). To understand the context of the making process and the continuity of details, we analyzed video recordings (approximately 44 hours) on three levels: the macro, the intermediate, and the micro.

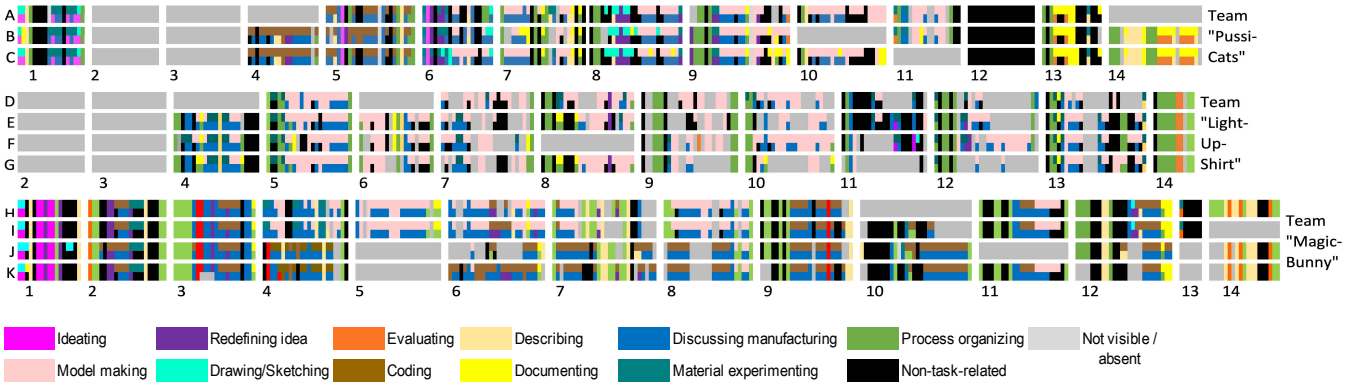
On the *macro level*, we engaged with the data by weaving a "Making-Process-Rug" (Riikonen et al., 2020). We went through the video recordings systematically and coded the main verbal and embodied design activities in 3-minute segments. This allowed us to create a visualization of the intentional design process (Figure 1). The Making-Process-Rug acted as a basis for the next level of analysis as well as provided a background for reflecting the relations among multiple aspects of idea materialization.

On *the intermediate level,* we unraveled dichotomies between classification and wonder (MacLure, 2013) by allowing the productively slow (Ulmer, 2017) coding process to guide our attention toward the edges of the intentional design process. We sought events that did not quite fit in the coding scheme but appeared still to be related to the idea materialization. On *the micro level*, we focused on details. We paid attention not only to the words, talk, and gestures of the students but also to the material aspects of the process by considering sounds, space, rhythm, and movement.

Finally, we considered these three levels along with complementary data. We reflected on how the micro-level details were present in student interviews, portfolios, and our field notes. This wider perspective enabled us to analyze how the materialization was enacted in nonlinear trajectories across the entire process. This thinking process was guided by theoretical concepts of material agency (Bodén et al., 2019; Latour, 2005) and fluid assemblage (Mol, 2002).

Figure 1

Making-Process-Rugs. Each color represents a different verbal or embodied action. Numbers 1 to 14 refer to the design sessions, and letters A to K refer to the students.



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Findings

In this paper, we focus on three aspects of the idea materialization process. For all student teams, the process was simultaneously a learning performance, the emergence of a functional artifact, and an adaptation to an institutional rhythm.

The material constraints of the process affected and refined the nature of the *learning performance*. All details of abstract flowy ideas had to be concretized while coding. For example, blinking lights and the sounds of the microcontroller gave feedback on coding actions (Figure 2, Magic Bunny), demanding precise and detailed actions. The functionalities of commercial coding software (Microsoft MakeCode for Adafruit Circuit Playground) constrained the ideas that could be materialized and how they were materialized. When combined with the constraints of time, knowledge, and material resources, the materiality of coding required students and teachers to simplify the idea to make it an appropriate learning performance that was challenging enough but not unachievably difficult.

Technology actively shaped the process (Latour, 2005), and students had to think together with matter (Heimer, 2016). This allowed knowledge to emerge without verbalization (Kuby et al., 2015). However, the effect of technology was unpredictable and occurred regardless of preplanned process structures (Bodén et al., 2019); it was not merely a consequence of intentional design experiments. The central role of software and educational technology obscured the dichotomy between local mundane practices and global commercial actors (Decuypere, 2019). When the idea was adjusted to match the material resources, the multiplicity of the process was momentarily coordinated into a whole (Mol, 2002), resulting in a balancing act between ambitions and skills.

In addition to a learning performance, the process was also the emergence of a *functional artifact*. For example, the Light-Up-Shirt team mostly focused on making shirts that would complement their existing wardrobes or duplicate existing favorites (Figure 2, Light-Up-Shirt). These tangible objects were connected to the students' everyday lives beyond school. The open-ended design task allowed students to create artifacts that were meaningful for them, not merely to complete prefixed tasks. Sewing the smart LED lights onto a detachable piece of fabric allowed the students to fulfill the requirement to use digital technology with minimal effort. This balancing act between learning performance and personal interests illustrated how different aspects of the process were able to co-exist and interact (Mol, 2002).

The idea to be materialized was not abstract nor merely human to begin with but was instead informed by qualities of existing artifacts. The presence of artifacts embedded the process within wider society and cultural phenomena, such as fashion and consumer culture. Although these issues were not deliberately or verbally addressed, they were present in the artifacts (Latour, 2005).

The process was an adaptation to an *institutional rhythm*. The materialization process had to be adjusted in accordance with predefined school schedules, resources, and practices. Neither teachers nor students could have known beforehand how much time making the artifact would take; materials provided surprises. Even though the Pussi Cat team often engaged in non-task-related chat during design sessions, their making process flowed faster than anticipated. To make use of the allocated time, the team added decorative elements to their invention (Figure 2, Pussi Cat). The fragmented nature of the process, determined by the school schedule, demanded practices to facilitate transitions, such as routines for organizing the required materials in specific places after use and tracking the process with portfolios. In addition, the tempo of movement within the classrooms thickened toward the ends of the sessions, when students worked to finish their ongoing tasks.

Learning with matter (Heimer, 2016) extended from making design choices to balancing creative flow with institutional resources through material actions. Formal and informal aspects were allowed to co-exist by distributing them to different modalities (Mol, 2002), for example when progressing the learning performance by embodied means while verbally discussing informal issues.

Figure 2

Ongoing idea materialization: Magic Bunny (a), Light-Up-Shirt (b), Pussi Cats (c)

(a) (b) (c)

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Conclusions and implications

The coexistence of multiple aspects of idea materialization made the learning process a balancing act. The aim was not only to materialize design aspirations but also to cope with local resources, such as school schedules, the societal connections of objects, and the functionalities of the technologies of making. This materiality turned students' general inventions into situated artefacts, embedding abstract issues within tangible details at hand.

Furthermore, the open-ended design task and unscripted making sessions gave students space to act on their own terms. Much of this action took place on the edges of the intentional design. The material details of the designed artefacts were able to serve multiple, even contradictory purposes simultaneously. Non–task-related activities were neither opposed nor alternatives to task-related activities. Instead, the mundane activities provided opportunities for learning to cope with local requirements.

Methodologically, becoming sensitive to such multiple realities in the classroom requires that researchers acknowledge the agency of materiality and eagerly follow even surprising trains of thought prompted by data. In our case, going systematically through the video data gave us space to wonder at the ordinary and zoom in on what did not quite fit into predetermined categories. Instead of being deterministic explanations, theories acted as sensitizing devices, guiding the gaze toward fluid assemblages.

We have suggested an approach that examines classroom practices happening at the obscure boundaries of on-task and off-task activity. The aim is to evolve the understanding of the purpose of learning from mastering the world to cultivating responsible, situated action. In practice, such a perspective could be implemented by exploring how craft practices, which provide enabling constraints, could be utilized in various educational settings beyond maker-centered learning.

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Using hierarchical logistic regression analysis to investigate equity in classroom discourse

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Abstract: This paper presents a novel methodology for examining equity in classroom discourse. Coding discourse data at the level of the exchange (rather than the utterance) affords investigation of the relationships between teachers' expectations, teaching patterns, students' social backgrounds and participation patterns. Using a hierarchical logistic regression model, we found that the likelihood of students' answers being developed by the teacher in this particular classroom was greater for Jewish students, for boys, for students from higher socio-economic backgrounds, for answers given following teacher nomination, and for relevant responses. In contrast to previous studies, the teacher's perception of the student's learning ability and the type of question posed had no statistically significant effect on the likelihood of the teacher developing the student's answer. The study contributes to our understanding of the mechanisms of educational injustice, to the development of methods for investigating equity in classroom discourse, and – thereby – to its rectification.

Theoretical framework: Participation and equity in classroom discourse

Studies of classroom interaction drawing on sociocultural theory (Vygotsky, 1978) stress students' active participation as a necessary component for fostering learning opportunities and outcomes (e.g. Snell & Lefstein, 2018; Black, 2004; Howe, Hennessy, Mercer, Vrikki, & Wheatley, 2019; O'Connor, Michaels, & Chapin, 2015). Applying this lens, other studies showed there are differences in students' participation in terms of frequency and quality, based on socio-economic background (Black, 2004), ethnicity (Kelly, 2008), and gender (Myhill, 2002). Differences in student participation could be the result of personal qualities, such as cognitive abilities, intrinsic motivation, attitudes towards school, etc. (Jurik, Gröschner, & Seidel, 2014).

A complementary perspective sees variations in participation levels as caused by the teachers' differential behavior towards students from different backgrounds (Sedova & Salamounova, 2016). Thus, teachers' expectations from their students likely affect the ways in which they interact with their students and influence how and what they teach, which may in turn shape students' learning processes and outcomes (Wang, Rubie-Davies & Meissel, 2018). Such differentiated teaching likely has negative consequences, especially when based upon students' social background, perceived ability and/or prior achievement (Black, 2004; Kelly, 2008). Teachers' implicit biases have been shown to influence their expectations of their students (Adair, Colegrove & McManus, 2017), leading to differential treatment and differential learning opportunities (Black, 2004; Snell & Lefstein, 2018). The above-quoted studies focused on teacher actions. However, Calarco (2018) argued that children are not the passive victims or beneficiaries of teachers' biases. Studies of teachers' expectations cannot, in most cases, explain whether teachers' responses are shaped by students' behaviors or by their demographics, because they rarely discuss how students' behaviors may shape differentiated teaching (Calarco, 2018). A few qualitative studies have combined teachers' expectations and behavior with student behaviors, but focused on case studies of individual students, which are telling but unsystematic (Black 2004; Orner & Netz, 2021; Snell & Lefstein, 2018; Sedova & Salamounova, 2016). Similarly, Wang, Rubie-Davis and Meissel's (2018) recent systematic review of quantitative studies on teacher expectations suggests that studies of students' classroom behaviors as both an outcome and a mediating factor of the effects of teachers' expectations have received limited scholarly attention. Only four quantitative studies of this question were identified during the past decades, with inconsistent findings. Based on their review they argue that it is necessary to examine quantitative variables (e.g., how often and for how long students speak) alongside qualitative variables (e.g., utterances' content, immediate context, and identity work).

One problem limiting current efforts to bridge the gap described is the lack of a suitable methodology. Addressing this methodological gap, the present study proposes a new methodology for examining equity in classroom discourse. This methodology involves expanding the unit of analysis from the utterance to the exchange, which enables examination of the inter-relationships between multiple identity categories (e.g., gender, nationality, socio-economic status, the teacher's perception of the student's abilities) and discourse forms (means of attaining the floor, type of question addressed, relevance of the response). Such expansion of the unit of analysis allows us to use hierarchical logistic regression analysis to address complex issues such as: Does the teacher

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develop (through elaboration moves) more answers from boys because they are viewed as more capable or because they tend to answer open questions and their answers are viewed as more relevant?

To understand such gender differences, a model that controls the various variables is required. Understanding the fine-grained workings of this and similar mechanisms is a crucial step towards their rectification. To illustrate the methodology, we address the following research question: How do background characteristics, perceived learning ability and patterns of students' participation affect the likelihood of the teacher developing students' answers? Teacher development of student answers is critical to learning processes because it takes students' ideas seriously, either by challenging them or building on them. Examples of teacher development include probing the student to elaborate their (usually, his) response, or posing an uptake question: that is, a new initiation that incorporates the student's answer. Previous studies have found these questions to be "optimal patterns" that increase participation and thus increase learning opportunities (e.g., Howe et al., 2019).

According to the research hypothesis, the likelihood of developing an answer will be higher among boys, Jews, students from high socio-economic status, with high perceived abilities who answer open-ended questions, receive permission to speak with the teacher's approval, and provide relevant answers. We hypothesize that patterns of students' participation (means of attaining the floor, relevance of the response) and perceived learning ability will shape the likelihood of teachers' developing student responses. Moreover, we hypothesize that these variables will not be sufficient to explain the correlation between student background variables (gender, nationality, socio-economic status) and the likelihood of teachers' developing student responses. Rather, we expect that demographic variables will have an impact above and beyond student behavior.

Research setting

This illustrative case study is part of a design-based research project conducted in 21 Israeli Hebrew-speaking secular state schools and designed to promote academically productive talk. One of the issues we investigated, in a focused study in a sub-set of two schools, is how students' social backgrounds shape their educational experiences and learning. The current study was conducted in one of the schools participating in these two projects. The class was composed of 24 fifth graders, aged 10-11: 15 boys and 9 girls, from middle to low socioeconomic backgrounds, and their language arts teacher. Four of the students were Arab, which was out of the ordinary in the relatively segregated Israeli education system, in which students from each sector (secular Jewish, religious Jewish, ultra-orthodox Jewish, Arab and Druze) study separate curricula in separate schools. We chose to focus on this classroom due to the diverse backgrounds of the students who study in it. The data were collected during the 2019-2020 school year. All participants and their parents or guardians gave informed consent.

Data collection and analysis

Data analysis is based on a subsample of eight lessons that were observed, videotaped and transcribed in full. The transcripts were arranged in a database (Figure 1), with each line representing an event, which we defined as a sequence that opens with the teacher's initiation, proceeds to a student response and concludes with teacher feedback (adapted from IRE – Initiation, Response, Evaluation (Mehan, 1979)). The arrangement of events requires the exercise of judgement that may affect the findings – for example, when the teacher's request leads to several overlapping responses and one feedback that is difficult to characterize for whom it is intended. In this case, one researcher segmented all the events. After segmenting the data set, we coded each event (N=1142) according to categories developed and adapted from previous studies of class discourse (Table 1). Although we coded other variables, we only report here the variables included in the regression. We used Cohen's *kappa* test to calculate inter-rater reliability of the coding. We estimated a hierarchical logistic regression model to predict the likelihood that the teacher would develop the student's response given background characteristics, perceived learning ability, question type, the form of the student's bid for participation and the relevance of the response.

Findings

Variables shaping the likelihood of a student's answer being developed by the teacher

Our macro unit is the students, within which are nested interactional events (micro-level). Because we are interested in the differences between students as well as the differences within each student from interaction to interaction we chose the random slope model where each student has his/her own slope. Table 2 summarizes the coefficients and standard errors of the hierarchical logistic regression model predicting the likelihood of the student's answer being developed by the teacher.

Table 2
Hierarchical logistic regression model predicting the likelihood of a student's answer being developed by the teacher (N=1142)

	Exp (B)	SE
ISEI	1.043***	0.012
Gender (ref: Boys)	0.223***	0.076
Nationality (ref: Arab)	4.664**	2.356
Perceived learning ability	1.044	0.104
Teacher's question (ref: Closed)		
Open question	0.992	0.182
No question	0.527*	0.153
Speaking with permission (ref: without the teacher's approval)	3.226***	0.539
Relevance of the answer (ref: Irrelevant)		
Non an answer to a question	0.729	0.272
Relevant	2.062*	0.606
N^2	1142	

*$p<.05$ **$p<.01$ ***$p<.001$

The findings of this study present a complex picture in relation to the effect of background characteristics, perceived learning ability, and students' participation on the likelihood of this teacher developing their answers. On the basis of previous studies we expected to find statistically significant effects for gender, nationality and socio-economic status on the likelihood of the teacher developing students' answers. Indeed, the likelihood of developing a girl's answer was 78% lower on average compared to boys while controlling the other variables; each increase of a unit in socio-economic status increases the likelihood of the answer being developed by 1.04 points on average while controlling the other variables; and the likelihood of Jewish students' answers being developed is 4.6 times greater on average compared to Arab students while controlling the other variables. However, in contrast to previous studies, we were surprised to find that the regression model of the learning ability perceived by the teacher has no statistically significant effect on the likelihood of the answer being developed by the teacher. This can probably be explained by the relationship of the ability variable with the additional background variables – a relationship that requires further examination in a broader sample. Regarding the question characteristics, the findings also contradicted the research hypothesis that the likelihood of developing answers to open-ended questions would be higher. In fact, the effect of the type of question (open/closed) was not statistically significant. This surprising finding requires qualitative examination beyond the scope of this work. Moreover, the likelihood of a student contribution that was offered not in response to a question being developed is 47% lower on average compared to an answer to a closed question while controlling the other variables. In accordance with our hypothesis, the probability of answers given with the teacher's approval to be developed is 3.2 times higher on average compared to answers given without explicit permission while controlling the other variables. In addition, the likelihood of a relevant answer to be developed is 2.06 points greater on average compared to irrelevant answers while controlling the other variables. Finally, the variance of the random slope, i.e. the variance between each student's mean value of responses being developed is almost zero (4.19e-33). Also, the fact that there is not necessarily a need for a random slope, that is, that the dependence between the observations for each student is not high, contradicted our hypotheses.

Limitations

Although the model findings are not the focus we will note that there are limitations to the sample which limit the validity of the findings. First, the analysis is based on observations of eight lessons in only one classroom that deviates from the normal distribution. In order for the chosen model to be valid it is necessary to expand the sample so that it meets the normality assumption. Second, the homoscedasticity assumption, according to which the variance in each of the random components is the same throughout different values of the explanatory variables, does not appear to hold for the following variables: gender, nationality, socio-economic status, perceived academic ability. However, the assumption does hold, i.e. the variance is fixed, for the different modes of the teacher's question, the manner of obtaining permission to speak and the relevance of the answer. Another limitation is that this study of one teacher in one classroom is in no way representative of other teachers and other classrooms. We build here on Shaffer and Serlin's (2004) use of intra-sample statistical analysis as a technique for using quantitative tools to support qualitative inquiry. As such, our findings "don't 'generalize' in the

traditional quantitative sense, but they do justify drawing statistically based conclusions about observations in a qualitative context" (p.3).

Regarding the methodology, the arrangement of events according to the IRE structure imposes upon the discourse a teacher-led structure that may not always be appropriate and obscures, for example, interaction between students that is not mediated by the teacher (though this was not a problem vis-à-vis the current data set). In addition, the model does not take into account the cases of silent students, who did not participate at all. Similarly, we included in the analysis only events in which students actually spoke. A more complete picture would include students who bid for turn but who were not nominated and did not speak without permission. We intend to address these limitations in future research.

Significance of the study

Expanding the unit of analysis from the utterance to the exchange in the methodology we developed helps bridge the gap in the literature in relation to the mediation process between teachers' expectations and perceptions of learning ability, teaching patterns and students' participation patterns. In this case we presented a model that predicts teacher elaboration moves on the basis of student background variables and participation, but many other predictive models can be constructed, for example, for predicting students' participation patterns based on background characteristics and teaching patterns. Exposing these patterns and power relations enhances our understanding of existing mechanisms in classroom discourse that promote or hinder learning opportunities, advancing us towards their rectification, and its conclusions may be used in designing a teaching strategy that promotes equitable participation among learners. As noted above, the contribution of this paper is methodological; realizing the potential of this methodology requires using it in examination of a broader, ideally representative sample.

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Intertwined Development of Interest Pursuits

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Abstract: Whereas interest research has long focused on one specific interest within one context (e.g. mathematics interest in class), students pursue multiple interests in parallel. As such, development of interest pursuits can become intertwined. The current study explores such intertwined developments by using a qualitative ESM smartphone application and interviews with 30 students (aged 14-25 years) in different educational programs. Analysis of the interviews shows three main intertwined developments: 1) *object genesis*, where one interest develops out of another, 2) *parallel engagement*, i.e. two interests co-occur or their engagement is mediated by similar skills or knowledge, and 3) *related meaning-making*, i.e. two interests have a similar meaning or gain meaning in relation to each other. Whereas interest theory typically speaks of interest development as a process of deepening of a single interest, the results of the current study reveal how interest development can also reflect broadening and connecting of multiple interests.

Introduction

Whereas interest research has long focused on one specific interest within one context (e.g. mathematics interest in class), in recent years there is increasing attention for multiplicity of interest (Akkerman & Bakker, 2019; Hofer, 2010; Krapp, 2002). Small-scale studies such as Akkerman and Bakker (2019) have demonstrated how adolescents pursue multiple interests in parallel, which concern a high variety of domains (academic and nonacademic) and encompass topic-, activity- and event-based objects of interest. Given this multiplicity, as a student moves through daily life, they take with them all their previous (interest) experiences into the current moment (Dewey, 1938; Roth & Jornet, 2014). As such, connections between interests are likely to arise, whether unintentionally or prompted by others, and these interest pursuits may (temporarily) become intertwined and develop in parallel.

Not much is known about the way interests develop in relation to each other, although case-studies have provided some initial conjectures. For instance, Azevedo (2011) investigates amateur model rocketeers and observes links with other objects of interest. Amateur rocketeer Bill, in this study, is also a movie fanatic and often specifically seeks out movies about rockets. His friend George has a computer engineering background and consequently experiments with incorporating electric machinery in his rockets. Similar examples can be found in work of Ito and colleagues (2019), e.g. a girl makes crochet designs associated with her interest in Harry Potter. Next to such intertwined interest pursuits, Slot and colleagues (2020) report on alternation of interest based on their investigation of how school is reflected in students' interest experiences. They find that students sometimes deliberately alternate school-related interests with leisure interests (e.g., gaming or watching series) in order to process their school work or rejuvenate after a long day. These articles together show some initial examples of intertwined developments, and demonstrate the need for a more systematic investigation of intertwined development of interest pursuits over time. As such, the present study aims to extend understanding of interest development as not just the deepening of a single interest, but also the broadening and connecting of multiple interests. By explicating the ways in which adolescents relate their interest pursuits in daily life, we hope to aid educators in recognizing and amplifying existing connections between objects of (potential) interest for adolescents within classroom settings and beyond.

In the current study we describe interest development from a comprehensive person-objects-contexts perspective such as proposed in earlier work by the last author (i.e., P-O-Cs perspective, Akkerman & Bakker, 2019), a perspective that assumes persons to continuously pursue and shape multiple idiosyncratic interests across multiple social contexts throughout their everyday lives. We explore the development of interest pursuits in daily life by answering the following research question: *What intertwined interest development do adolescents report?* A better understanding of the developmental processes of multiple interest pursuits can extend interest theories beyond a single interest and support theorizing multiplicity. This in turn can add to the practical understanding of interest developments which may seem unexpected when just looking at a single interest. In addition, explicating the intertwined development of adolescents' interests can aid approaches that aim to connect education to adolescents' daily life experiences (e.g., Ito et al., 2019), by demonstrating how these connections naturally take shape and develop in daily life.

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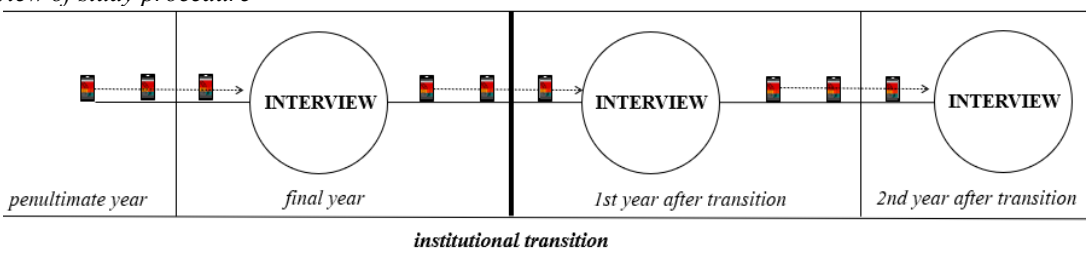
Methods

In order to explore the multidirectional developments in parallel interests, we employed a qualitative longitudinal approach using interviews informed by qualitative ESM (Experience Sampling Method) data collected using a smartphone application called *inTin*. The timeline of this study is outlined in Figure 1. The participating students were interviewed three times, with one year in between each interview. Preceding the interviews, students reported on their interests in inTin during three intermittent weeks (three to four months in between each week). Data was collected between March 2018 and December 2020, the last two inTin weeks and the last interview took place during the COVID-19 pandemic.

Figure 1

Overview of study procedure



Participants

Thirty students participated in the interviews and ESM study. Participants were enrolled in diverse educational tracks in the Netherlands, including (pre-)vocational education, general (professional) and (pre-) university education (in Dutch: *mavo, havo, vwo, mbo, hbo, wo;* five participants per track) and were aged 14-25 years at the start of the study, with 63% female. This diverse sample was chosen to capture a large variety of complex interest experiences across different educational settings and life-wide situations. The first interview took place in the final year of the students' study program. Respondents volunteered to participate and were offered financial compensation for taking part in the study. All participants signed an informed consent form and for participants who were younger than 16, a parent or caregiver signed an additional permission form. Ethical approval for this study was given by the Ethics Committee of the Faculty of Social Sciences.

Materials

The methods employed in this study concern interviews informed by qualitative ESM data. An ESM application was used to capture (changes in) daily-life interests of the participating students. Students used this application to log their existing and novel (incidental) interests that they experienced within a week. Following from our person-centered perspective, participants were free to give any name to their objects of interest instead of choosing from pre-existing categories, doing justice to the idiosyncratic nature of interest (Akkerman & Bakker, 2019).

Each participant was interviewed three times, with one year in between each interview. The interview scheme contained semi-structured questions that were adapted to the interests that the participants reported in the ESM application during the three weeks of using the application preceding the interview. In the first interview, participants were asked about the history, value and forms of engagement for several of their interests, aiming at a variety of different interests (e.g., asking them to talk about an interest they had pursued for a long time and an interest that was rather new). These questions were aimed at one interest at a time, but participants often mentioned other interests that they considered related. In addition, participants were asked to think about next year, and to predict which of their objects of interest they would still be interested in and why, which probed them to consider any foreseen trade-offs between interests. In the second and third interview, the students were asked about any changes in their objects of interests that occurred since the preceding interview. Each experienced change was discussed in more detail using semi-structured questions, asking about the experienced origin of the change, and about the current value and form(s) of engaging. In answering these, participants regularly related these changes to (changes in) their other interests.

Analysis

The second interview is the main focus of analysis. In this interview we detected relations between interests by marking passages where the student, when talking about one interest, mentions one of their other objects of interest. For example, when asked about their interest in hiking, a participant describes how they also listen to music while hiking, which is one of the other objects identified as interest. For each interest-relation that is identified in this way, passages about the associated interests are selected in all three interviews. When reading these interview

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excerpts, we selected for further analysis only those relations where a) the relation between the interests is object-based and b) the interests are involved in each other's development. This means we did not include relations where the described connection was generic (e.g., when reading a book is mentioned in relation to soccer because they both take up leisure time), nor relations without indication of intertwined development.

For each selected interest relation, we made short descriptions of all involved interests and their relation at each interview timepoint. These descriptions were further synthesized in one summary per relation that reflected the core of the intertwined development. We then contrasted and grouped together all interest relations that showed comparable intertwined development, until exhaustive and meaningful categories were reached. Half of the sample is used for initial explorative analysis, and after the categories were determined we examined whether these were supported by data of the remaining fifteen adolescents**.**

Results

Results demonstrate notable inter- and intraindividual varieties in development of associated interests. Whereas some adolescents experience many connections between their parallel interests, others seem to experience or talk about their interests in more isolated ways and mention only few notable relations between their various interest pursuits. Below we describe the three intertwined developments that we observed in the data.

Object genesis

Firstly, adolescents described how novel objects of interests arose from engagement with their longstanding objects of interests. For example, Ronald has been interested in "playing videogames" with friends for a long time. In the interview, when asked how his interest in "programming" started, he mentions: "My brother bought an Xbox when I was six, or eight, the very first one and then we started gaming together. So that's how the interest in those devices started actually. It was quite a logical step for me, it's just fun." In this case it seems that the content of playing videogames and programming are close enough together that simply playing games sparked Ronald's interest in programming. Ronald pursued a study program and career in IT, which shows that this interest that initially arose from a leisure interest becomes a long-lasting theme in his educational and professional life.

Further examples show the mediating role that other people can play in this process. This is evident for Steve, who was interested in "badminton" for a long time, training multiple times a week and being very competitive. In the first interview he says he definitely wants to continue playing badminton, but preceding the second interview two of his teammates quit the sport. His remaining teammate then said he was going to play tennis instead, and Steve tells us: "So then I said: 'great, I'll do that too'." Despite his initial plans to continue playing badminton, he switches to tennis rather impulsively. During the third interview he still became increasingly more skilled at and enthusiastic about his new interest in "tennis". Other people within a certain interest-related practice can thus suggest ideas that become identified as new objects of interest, which can subsequently last for a long time.

Parallel engagement

A second intertwined development regards parallel engagement of interests. The most predominant way in which we observed this to happen is *co-occurrence*, wherein an adolescent recognizes and appreciates multiple objects of interest within the same moment. For example, Piper is interested in "music", and enjoys listening to all kinds ranging from classical music to heavy metal. She describes how she sometimes recognizes and appreciates music when watching movies, which for her is another interest: "If I hear something in a movie, … if I hear something somewhere that really grabs my attention, then I immediately turn on Shazam and then I link it right to Spotify and I have it right there and then, yeah, I can study it a little bit, listen to it a little bit more often." She also describes how, when watching certain movies, she can really feel the music inside and it makes her feel strong emotions. In Piper's case, these objects of interest co-occur because they are combined in societal structures (i.e., films generally contain music), which she then both recognizes within one situation. In some cases the objects of interest even seem to be nested, meaning they cannot be separated but co-occur by default of the social activity (e.g., "science" and "Medicine", "judo" and "giving judo training"). This is contrasted with cases where co-occurrence is not imposed by (societal) structures but emerges from daily life or from personal initiatives.

Notably, we also found instances where participants described parallel engagement without the interests co-occurring in a situation. These engagements were connected through skills, knowledge or resources by which engagement of both interests developed in a similar way, which we term *mediated engagement*. This can be illustrated by Nicky, who is interested in the "news", which she reads daily and discusses with her parents. She feels it is important to know what is going on in the world and it makes her realize how good her own life is. After completing secondary school she starts studying "Medicine" and there learns to read scientific articles critically. She observes that this has changed the way she reads the daily news as well, looking at news articles more

critically (especially when this concerns scientific findings). In this way, the adolescent describes how the development of these interests is intertwined by skills that are used in both practices, or transported from one practice to another.

Related meaning-making

A third intertwined development concerns adolescents relating the meaning they ascribe to their interest, to another interest. A first exhibit of this concerns interests pursuits whose meaning is similar to each other, i.e. *comparable meaning*. Nicky talks about this in the context of her interest in "childcare", her side job, which decreased when she started studying Medicine: "I have always liked taking care of people, I can't explain it, but I used to get that satisfaction from childcare. But now I'm pursuing a study where actually caring for people is central, so that's where I kind of get that satisfaction now". Although she still likes to work at the daycare, it has become less important to her and she talks about looking for another job closer to her university. In this way, the comparable meaning of both interests has consequences for the continuity of her interest in childcare: it seems less necessary than before. It should be remarked that comparable meanings were often observed for multiple sport-related interests, which often had a similar meaning in an adolescents life (e.g., maintaining a healthy lifestyle) and thus were seen as interchangeable.

Whereas the above describes a stable relation between the interests, we also observed many instances where an interest gains a different meaning in relation to another interest pursuit, which we call *transformed meaning*. For example, Hilbert becomes increasingly interested in what he calls "personal development": learning new things in general and setting goals for his future. In light of this interest and his desire to do useful things with his time, he reconsiders the value of other interests, such as "Netflix" and "gaming": "If you look at what gaming brings me, then it is not as much as three hours invested in watching YouTube videos on how I can achieve my goal or … whether I want to become smarter in a way or whatever. So that's why certain traits have been toned down or left out altogether, like gaming and Netflix." In other words, Hilbert looks at his interests in "gaming" and "Netflix" through the lens of his interest in "personal development", and increasingly regards playing games and watching series on Netflix as a waste of time compared to activities that allow him to develop as a person. Hence, Hilbert compares and contrasts his interests, which leads to one of them decreasing in value and possibly disappearing altogether.

Discussion

The aim of the present research was to explore intertwined development of interest pursuits. By studying what connections adolescents themselves make between their interests, we have demonstrated how intertwined development can be described in terms of object genesis, parallel engagement and related meaning-making. Whereas interest theory typically speaks of interest development as a process of deepening of a single interest (e.g., Hidi & Renninger, 2006; Renninger & Hidi, 2015), the results of the current study demonstrate how interest development can also reflect broadening and connecting of multiple interests through these three developments.

Processes of object genesis, parallel engagement and related meaning-making were observed for objects of interest that can be considered close in terms of domain (e.g., food/health and cycling), but also for objects that are societally further apart (e.g., food and music). Hence, even when connections seem unlikely given societal distance, in daily life different objects of interests can connect. This goes not only go for leisure interests, but also for school related interests. Hence, educators that want to connect their learning materials to students' daily life, may start by being open to the connections that students themselves already naturally see.

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Exploring Focused Responsiveness as an Approach to Facilitation in Professional Learning

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Abstract: Meaningful professional learning (PL) for teachers needs to center their assets, aims, and needs while also bringing them into conversation with research-based instructional approaches that support student learning. In service of facilitating meaningful PL, this study introduces and aims to develop characterizations of focused responsiveness in PL. I draw on multiple literature bases and interviews with science teacher leaders who facilitated professional learning communities to build understandings of what focused responsiveness to teachers may entail and look like in PL, and associated tensions. Deeper understanding of this approach has the potential to contribute to the design and enactment of PL environments that value teachers as highly knowledgeable professionals and experienced co-generators of their own learning.

Introduction

Formal K-12 educational settings in the United States are heterogeneous and ever-evolving landscapes of initiatives, priorities, and local constituencies. In science education, the field is amid ongoing reforms with the *Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS); calls to address "deep and enduring disparities in K-16 science education" (NASEM, 2021, p. 8); and liberatory efforts to center richly diverse student and educator repertoires (e.g., Warren et al., 2020). To meaningfully engage teachers within such landscapes, PL needs to focus on research-based instructional approaches shown to support student learning, while also centering teachers' assets, aims, and needs.

This study aims to develop characterizations of an approach to PL facilitation aligned with the vision above—focused responsiveness. Broadly speaking, focused responsiveness refers to facilitation that provides opportunities for teachers' voices to be valued in and shape PL (being *responsive*), echoing recent calls in PL literature for increased responsiveness and opportunities for teacher agency (e.g., Buxton et al., 2015; Cavendish et al., 2020), while also building toward broader goals for teacher learning (shaping *focus*). Responsive and goal-oriented facilitation can be mutually supportive but may also give rise to tensions common to PL that brings local actors and broader initiatives into conversation (e.g., Allen & Heredia, 2020).

Here, I draw on multiple literature bases and interviews with teacher leaders (TLs), who facilitated PL with science teachers, to stitch together initial contours of focused responsiveness as an approach to PL facilitation. Generating deeper understandings of focused responsiveness has the potential to contribute to the design and enactment of PL environments that support more localized, meaningful teacher learning opportunities and value teachers as the professionals and people they are.

Theoretical underpinnings of focused responsiveness in PL facilitation

Facilitation matters for effective PL but is often an understudied component (Borko et al., 2014). Some studies exploring the nature of PL facilitation have identified generative sets of facilitation moves and practices linked to specific goals, such as promoting collaborative learning among teachers (e.g., Gibbons et al., 2021; Zhang et al., 2011). However, few studies have focused on how facilitators navigate being responsive to teachers. The work of Koellner et al. (2011) and Remillard and Geist (2002) are notable exceptions here, and the present conceptualization of focused responsiveness builds on insights from these studies and broader literatures on 1) responsiveness to student thinking in K-12 settings, 2) adult and teacher learning, and 3) features of effective PL. Together, these literature bases point toward several key facets of focused responsiveness.

First, focused responsiveness as an approach to PL facilitation foregrounds taking an asset- or resource-based view of teachers and their contributions—presuming that what teachers bring to bear is valuable and generative. This stance is evident in work on responsiveness to students' contributions in K-12 settings (e.g., Campbell et al., 2016; Hammer et al., 2012) and work on teacher learning that treats teachers' knowledge and experience as assets (e.g., Horn & Kane, 2015; Remillard & Geist, 2002). For instance, Remillard and Geist explored how facilitators navigated "openings" in an elementary mathematics PL curriculum when teachers raised challenges or questions, and they ultimately framed such contributions as opportunities for learning. Second, focused responsiveness involves inviting and pursuing teachers' contributions and participation in direction-setting. This facet is evident across the identified literature bases, including perspectives on adult learning that emphasize the importance of adults determining the direction of their own learning experiences (e.g., Knowles, 1973). Pursuing teachers' contributions may occur in the moment within interactions, and/or over time when

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shaping lines of inquiry and associated structures (e.g., Hammer et al., 2012; Koellner et al., 2011). Third, focused responsiveness seeks to bring teachers' contributions into conversation with goals that matter for supporting student learning and experiences within classrooms. In other words, like responsiveness in K-12 settings that maintains connection with disciplinary ideas and practices (e.g., Hammer et al., 2012) and consistent with research on effective PL (e.g., Darling-Hammond et al., 2017), focused responsiveness in PL maintains connection with identified goals for teacher learning. The remainder of this paper explores these facets in the rich perspectives of teacher leaders (TLs) who facilitated science professional learning communities (PLCs) described below.

Study context and methods

This study took place in the context of a partnership to support science teacher learning with a large urban district. Since adopting the NGSS, the district science office has emphasized two main instructional goals—enhancing 1) rigor and 2) educational equity in science instruction. Briefly in this context, rigor refers to learning opportunities that integrate the three dimensions outlined by the NGSS within cognitively demanding tasks and responsive and collaborative talk (e.g., Tekkumru-Kisa et al., 2019). Educational equity refers to learning opportunities that connect to and leverage diverse assets and ways of knowing (e.g., Warren et al., 2020) and work towards justice. The district is cultivating PLCs with foci connected to these goals, such as supporting student discourse or connecting to students' cultures. In 2020-21, sixteen high school science teachers were selected and supported in serving as TLs. PLCs led by these TLs met virtually six to eight times and engaged in inquiry cycles connected to teachers' aims within the PLCs' focus areas. Thus, PLCs and TLs have latitude to be flexible and responsive to teachers, *and* they are expected to advance rigor and equity in students' opportunities for science learning—making this a rich context for exploring focused responsiveness.

At the end of the 2020-21 school year, I conducted semi-structured interviews with six TLs who facilitated PLCs. Interviews invited TLs to share motivations for and experiences of leading PLCs, facilitation practices, and examples in which they felt they were able to be responsive to teachers or found it challenging to do so. I foregrounded responsiveness rather than focused responsiveness in my questioning as something more recognizable to TLs. All interviews lasted between 25 and 45 minutes and were audio recorded and transcribed.

I engaged in grounded, qualitative analysis (Charmaz, 2008) to explore characterizations of responsiveness from TLs' perspectives. I began by identifying examples and non-examples of responsiveness that TLs described. Examples involved a TL foregrounding or responding to teachers' contributions in the PLC, either in real-time or across sessions. Non-examples involved a TL explicitly depicting not being, feeling able, or feeling successful in being responsive. There were 19 examples and five non-examples of responsiveness across the interview corpus. For each, I drew on TLs' wording to characterize the nature of the responsiveness (or desired responsiveness, for non-examples), what the TL was responding to, whether the TL drew connections to PLC foci, and evident tensions. Finally, I looked across examples and non-examples to identify patterns in the data.

Major findings: TLs' characterizations of responsiveness in PL facilitation

Each TL reported enacting multiple ways of being responsive to teachers in the PLCs. Table 1 summarizes several characterizations of responsiveness that crosscut examples and TLs. (All TLs' names are pseudonyms.)

Table 1

Teacher Leaders' Characterizations of Responsiveness in PL Facilitation

Characterization: Responsiveness as…	Prevalence	Tied to PLC focus?	Indicative quote
Providing resources to meet teachers' aims or needs	5 examples 1 non	Often	*Liza:* "Like responding to people's [PLC focus] needs, in terms of ideas for what to do in certain scenarios… we tried to be responsive… to provide ideas for them, new things to try, and we tried to bring in based on where they were at… what they said they needed..."
Changing structures to meet teachers' aims or needs	4 examples 2 non	Not often	*Veronica:* "… we decided to shift to more of a focus each session… whoever the focus person was was really bringing their problem of practice that they want to work on and everyone could collaborate with them. So, that was one way we were trying to be responsive…"

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Participating and co-constructing with PLC colleagues	4 examples	Often	*Jake:* "I wanted to position myself as sort of another participant in a way, and I mean honestly a lot of that comes from identified need. Like I really think I could do a better job of… meeting the goals of the PLC in my instruction… all the teachers… have really interesting ideas and insights that I certainly don't… we're all just kind of professionals- a community of professionals trying to tackle these things."
Addressing challenges in teachers' contributions	6 examples 2 non	Mixed	*Clara:* "I had a teacher who expressed that they were in the PLC so that they would understand… but that they really didn't need to do or get the work done because they had a co-teacher… I was trying to do that experience for [them]… to internalize that it's not I'm just here to see what you guys do..."

Depictions of responsiveness as *providing resources to meet teachers' aims or needs* shared several similarities. As in the example described by Liza, TLs depicted providing resources, ideas, or feedback typically specific to the PLC focus in response to what teachers brought up or requested. TLs pursued teachers' requests and direction-setting in this characterization, though TLs often took responsibility for providing resources themselves (rather than, for instance, drawing out resources from the group). Tensions arose for several TLs with respect to understanding and balancing teachers' requests and being responsive when they felt they did not have the requisite content or instructional knowledge; these were exacerbated by COVID and remote learning.

Another characterization of responsiveness described by TLs was *changing structures to meet teachers' aims or needs*. Structural forms of responsiveness included being flexible with protocols and timing or shifting activity structures (as described by Veronica). In another example, Clara intentionally integrated different kinds of structures in response to teachers' reported learning preferences. This characterization tended to be less connected to the PLC focus and more about process, and tensions arose when TLs felt unsure of teachers' aims or desires. One TL also reported a "self-imposed" tension of wanting to "get through the program."

TLs also depicted a responsive practice and framing of *participating and co-constructing with teachers in the PLC*. Here, TLs explicitly noted rich assets from teachers with respect to the PLC's inquiry, and they positioned themselves as co-learners in pursuing those together. Few tensions were noted here.

A final characterization was responsiveness as *addressing challenges in teachers' contributions*. As depicted in the name of this characterization, TLs did not focus on assets but rather what they perceived as challenges or issues to resolve. They tended to do so through providing targeted guidance or, as Clara described above, designing specific learning experiences for teachers. Responses were sometimes at odds with the PLC focus, depending on the nature of the challenge. TLs expressed tensions in how to address issues collegially, and again how to do so when they felt they did not have the knowledge or tools required.

Conclusions and significance

This study articulates the initial contours of focused responsiveness as an approach to PL facilitation, contributing to needed understandings of how PL can be more responsive to teachers (Buxton et al., 2015; Cavendish et al., 2020). In conceptualizing focused responsiveness, multiple literature bases highlighted the importance of taking an asset- or resource-based view of teachers' contributions and attending to their participation in direction-setting, while seeking to bring teachers' contributions into conversation with goals that matter for supporting student learning and thriving. TLs' interviews added to and complicated this general conceptualization by illuminating numerous characterizations of responsiveness, in which TLs took certain kinds of actions (e.g., providing resources, changing structures) to respond to different aspects of teachers' contributions (e.g., teachers' aims, perceived challenges). The range of characterizations identified in this study add to the landscape of what focused responsiveness might look like in PL practice.

TLs' varied characterizations also demonstrated different facets of the literature-based conceptualization of focused responsiveness. For instance, in many cases, TLs demonstrated attention to and pursuit of resources like teachers' ideas and aims, but *addressing challenges in teachers' contributions* was less aligned with the asset-based facet of focused responsiveness. Additionally, characterizations ranged in the degree of focus on matters of science teaching and learning. Characterizations that centered the instruction-oriented substance of teachers' contributions often connected to the focus of the PLC, but examples of responsiveness that were more structural or process-oriented did not tend to emphasize the PLC focus directly. While such examples may ultimately be in

service of supporting the PLC's focused work, as some TLs noted, there were sometimes tensions in when and how to respond if not directly aligned with the PLC's focus.

Moving forward, future work could explore instances of focused responsiveness *in situ* in PL facilitation contexts and impacts on teachers' experiences in PL and on their learning and practice. Building on findings from this study, research could also examine ways of reinforcing asset-based perspectives with facilitators and the role(s) of facilitators' knowledge in focused responsiveness—including when "not knowing" may be an affordance, as potentially in the characterization of *participating and co-constructing with teachers*. Focused responsiveness in facilitation has the potential to contribute to the design and enactment of meaningful PL environments that center teachers as highly knowledgeable and experienced co-generators of their own learning.

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Historians' criteria for appraising historiography: An interview study

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Abstract: Developing and applying epistemic ideals or criteria is a core component of epistemic practices. In history education, epistemic criteria have been included in approaches to teaching history as well as in theoretical frameworks for investigating the learning and understanding of the domain. One justification for these frameworks is in the epistemic practices of expert historians; however, empirical evidence about historians' epistemic criteria is scarce. Thus, we set out to explore epistemic criteria historians use to determine quality in their own and others' work through an analysis of interviews with 26 Finnish historians. We identified over 80 criteria that we placed in categories such as internal characteristics of works; connections to past and present knowledge and practices; connections to future knowledge and practices; proxies; connections to non-epistemic use; and emotions. These findings open up possibilities for better developing criteria in history education and considering their connections to those of experts.

Introduction

Epistemic criteria are a central component of epistemic practices: They are ideals or standards for determining when and why inquiries have reached their goals, or when and why some epistemic products might be preferred over others (Chinn & Rinehart, 2016). The use and need for epistemic criteria is well recognized within philosophy and practice of historiography (Jordanova, 2019; Kainulainen et al., 2019; Kuukkanen, 2015). In history education too, epistemic criteria are relevant for many approaches to learning and teaching history. These include, for instance, modeling and supporting historical reading skills, employing historical evidence, classroom argumentation, and broadly methods that involve students in evaluating and interpreting products of historiography (Fogo, 2014; Herrenkohl & Cornelius, 2013). Epistemic criteria also play a crucial role in the study of learners' understanding of the nature of history or their epistemological beliefs (VanSledright & Maggioni, 2016). In recent decades much of history education has indeed centered on simulating the practices of historiography and has emphasized the educational aim of "the development of an understanding of how historical knowledge is constructed and evaluated" (Voet & De Wever, 2017, p. 312).

We propose that the part of history education that involves appraising products of historiography should build more strongly upon an evidence-based understanding of the ideals or criteria that domain experts themselves use in such tasks; however, research on this topic is still scarce. As one exception, Gottlieb and Wineburg (2012) studied religious historians' use of epistemic criteria in evaluating historical claims presented in curated sets of short document extracts, and they identified criteria applied by the historians such as trustworthiness of evidence and intertextual references. They also found that historians applied different epistemic criteria depending on whether the documents related to their religious commitments or not.

We explored this topic by conducting interviews in which historians at length presented and discussed their own research as well as some research by others. We used the AIR model of epistemic cognition (Chinn & Rinehart, 2016) as one framework guiding our methods and analysis. According to this model, epistemic cognition refers to people's ways of knowing. The model analyzes epistemic cognition into three components—epistemic Aims and value, epistemic Ideals, and Reliable epistemic processes. Epistemic aims refer to the goals people set for knowing and understanding. We have documented a range of epistemic aims relevant for expert historians; these include critiquing existing ideas, gaining understanding, popularizing research, and developing their own epistemic competences (Kainulainen, et al., 2022). Epistemic ideals are the criteria or standards that people use to appraise whether they have achieved their aims and to evaluate epistemic products. In science, epistemic ideals for good explanations can include fit with evidence, fruitfulness, and simplicity. Chinn and Sandoval (2018) proposed possible differences between scientists and historians in the ideals that are commonly used; in this paper, we explore what historians' epistemic ideals are. Finally, reliable epistemic processes are the individual or community strategies, activities, or methods that people use to achieve their aims. (1)

Research Question

In this paper, we analyze the ideals that historians describe as important to their epistemic practice. We ask: What ideals (criteria or standards) do historians use for appraising quality in historiography?

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Methods

Participants

The participants were 26 volunteer Finnish historians, who were recruited by contacting various history departments and writing an invitation to a national online forum for humanities scholars. The historians represented a variety of different faculties and traditions of historical research. All had earned a PhD degree, but their career lengths varied from post-doc researchers to emeriti professors. All of the participants were somehow affiliated with at least one Finnish university. In order to secure the confidentiality of the participants, we only refer to the participants as "Historian [nr]" and exclude their universities, degrees, and details of research topics in all of the excerpts below.

Procedure

The first author conducted semi-structured interviews with the historians in Finnish language. The length of interviews varied from less than one hour to almost three hours, averaging 90 minutes. The full interview scheme included questions related to all components of the AIR model as well as other topics, and the historians discussed their research in detail and at length. In terms of identifying historians' epistemic ideals, key questions in the interview included: "What is your best work, and why?"; "What about someone else's best work, and why?"; "When reviewing papers, books, or presentations, which criteria do you usually use to evaluate such work?"; and "What are your common critiques regarding methods in such review situations?" The full interview scheme is available from the authors.

Data Analysis

The transcribed interviews were analyzed by means of a qualitative content analysis (Schreier, 2012) that proceeded through various iterative and collaborative stages. In the beginning, codes were developed extensively. Later on, when it became apparent that some of these codes did not prove useful in characterizing the data, they were either removed or merged with another similar enough code. Hence, in a way, the coding scheme from the earlier stage of research can be considered a self-made analytic tool, which we then used, tested, and further developed during the analysis. The final coding scheme is available from the authors.

Results

Our analysis of historians' epistemic criteria identified over 80 different criteria (or codes), divided into to eight categories. Below, due to the short length of this paper, we limit our discussion to six of the categories (2), focusing on those criteria that (a) were mentioned by several historians, and (b) we consider especially relevant for history education and its practices.

We begin with the category titled "internal characteristics of historiography"—i.e. criteria that refer mainly to features of the products (e.g., articles, books, conference presentations) themselves. All historians mentioned ideals assigned to this category, including 26 different ideals. The most frequently mentioned ones can be roughly grouped into ideals for evaluating the output's literary or rhetorical quality and ideals for evaluating its methodological quality. These groups have clear implications for history education: Both should be accounted for. Regarding the first group, historians spoke of *internal coherence* (whether the work fits together); *quality of argumentation*; *readability*; *communicativeness*; and, as in this excerpt, *style of text and presentation*:

> [A] fluent writing style that moves one's own argumentation forward is important. So even though the topic might be interesting as such, if it is written in a dull and bland way, it is not a good article. (Historian 9)

The methodological quality of the products of historiography could be assessed based on the *perspectival* aspects of the work (whether there is a perspective; whether it is brought forth; and whether it is interesting or important); *scope and quality of sources*; *amount of theory, analysis and narration*; and *transparency of processes* (whether and how the frameworks and methods of the study are presented). As an example of the last, one historian (13) criticized some work for not "explicating their methods" and considered the experience of reading such work irritating and "an unfair game, because you are not telling what you do, and why."

The second category—also one that all historians referred to—was "connections to past and present knowledge and practices." This category reflects Kuhn's (1977) famous notion of the 'essential tension' between tradition and invention in scholarship. In this category, some of the mentioned ideals—namely *contextualization*; *timeliness*; and *positioning the work in relation to ongoing discussions*—are already incorporated in some history

education practices; however, they might not be explicitly discussed as ideals of the domain. Other ideals, however, require considerable domain expertise. These include *originality, exceptionality and innovativeness*; or *methodological originality*, the last being exemplified below:

> It combined the kind of things that had not been done before; read sources in a whole new way. And by studying a small detail he was able to say something about a very wide thing, by generalizing something that nobody had noticed before. (Historian 16)

Third, historians also highlighted "connections to future knowledge and practices." This implies that historiography should not just build on or challenge existing understandings, but also be fruitful in opening up vistas for new work. This appears something that the tasks and practices typical to history education do not always allow. The specific codes in this category include ideals such as *connections to future theory and knowledge*; *connections to future methods and practice*; *ability to promote future research;* or *interdisciplinary value*. Exemplifying the last, one historian (15) considered their work valuable to the research field because "it not only contributes to historical research, but it could also have use for researchers in other fields." In educational applications, it is possible that students could come to appreciate the value of ideas that open up new questions for inquiry.

Fourth, when assessing historiography, the interviewed historians also referred to "proxies" in determining quality in their own and others work. This category refers to externalizing or outsourcing (part of) the criteria to others. The category can be further divided into expert and lay proxies. Thus, in educational applications, students could also learn the value of expert and lay audience evaluations as central to how historical work is appraised. Expert proxies include ideals such as the very act and process of *experts publishing* the work; more generally, *reliance on expert commentary and evaluation;* and *experts' acceptance or engagement* in or with the work. The last is exemplified below (in a statement that also resonates with the previous category):

> Well, the criteria comes through that discussion that is presumably formed after the publication of this book, and it has already formed in many workshops and conferences. Through that, I can then see how well it works. (Historian 22)

Some historians also referred to *lay visibility* (the extent and nature of public visibility); or, as exemplified below in a statement related to engaging local communities with one's studies, *lay excitement and interest*:

> I don't use any criteria [to determine whether aims have been reached]. I don't, like, sit and think with some criteria how they [the aims] are fulfilled. […] It is not rational to think of criteria, even though perhaps I should. But one sees it through the echo given by teaching, whether students are excited. Once or twice a week I go to talk to different [groups and organizations], so in a way that is the criteria: the interest the research raises in others than colleagues. (Historian 6)

Fifth, historians also referred historiography's "connections to non-epistemic uses," in terms of whether the work had *societal impact*. What differentiates this from lay or expert proxies is influence on societal changes and political debates (and not only interest in or acceptance of the work). For example, one historian (20) wrote a history of a profession, and mentioned as an important feedback from contemporary practitioners of the same profession how they "considered it as an empowering book […] that meant a lot to their professional self-perception." It is possible to envision historical inquiries among students in which students consider community applicability of ideas as one of the criteria for evaluating them (see, Goldenberg, 2019).

Finally, historians referred to their "emotions and affects" that works of historiography raise. These include *happiness, fun, and satisfaction*; and many historians mentioned *excitement and interest* related to historiographic output. While many referred to their own interest upon engaging with others' work, some also referred to the excitement of other historians producing and presenting the work:

> Also, if it seems that a person is somehow themself not at all excited about it; If someone comes to a conference and does a terribly mechanical paper, then you cannot pick up the important things from there, even though there may be some. (Historian 12)

Incorporating such ideals into historical inquiries in educational settings could enrich these inquiries with the epistemic emotions that help animate professional historical work.

Discussion

In sum, the interviewed group of Finnish historians working in the contemporary academia mentioned tens of different epistemic ideals they use as criteria for evaluating historiography. These ideals range from the characteristics of the (literary) output to its significance both scientifically and societally, and to historians' own affective responses to the work in question. Our observations have at least two general implications for the development of history education. First, we should explicate not just learning goals or teaching practices, but also the epistemic ideals of the domain related to them, since they apparently play a role in how experts in the field conduct their work. Second, the sheer number of epistemic ideals identified in this study makes one hesitate to claim that we are even now grasping any full scope of them. It is, then, no wonder that teachers are not all that familiar with the range of epistemic criteria in history (e.g., Koutsianou & Emvalotis, 2021). However, it still seems apparent that experts apply a wide range of ideals; therefore, why should educators expect students to operate with only a few? And even if only a few, which few? To be sure, not all epistemic ideals we identified are as useful in designing learning and teaching as others, but, at the minimum, awareness of the scope of expert epistemic ideals in history seems necessary, if educators aim to bring history learning closer to what the practice of historiography entails.

Endnotes

(1) In an ongoing investigation, we are also exploring historians' epistemic processes.
(2) In addition to the ones discussed here, there were also the categories of *negative ideals* and *other ideals*

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International Society of the Learning Sciences

Biology teachers' re-designed eLearning units: The relationships between knowledge types and scientific practices

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Abstract: Lately, eLearning has substituted traditional forms of teaching and learning. However, little is known about the possible link between eLearning, addressing epistemic knowledge and scientific practices. We aimed to analyze teachers' re-designed eLearning units and examine the extent to which high school biology teachers address epistemic knowledge and scientific practices in the Personalized Teaching and Learning, PeTeL platform. We qualitatively mapped the re-designed ecology and evolution eLearning units according to knowledge types and scientific practices. We found that a few teachers addressed epistemic knowledge in their re-designed eLearning units, and that questions that include only content knowledge, mostly lacked scientific practices. Thus, it seems that most of the teachers find epistemic knowledge difficult to address.

Introduction

In the past 25 years, eLearning has substituted traditional forms of teaching and learning in schools, higher education and companies (Herden, 2011). During the COVID-19 pandemic, when educational institutions were closed all over the world, eLearning has become necessary, facing the challenges of preserving the process of learning while ensuring that it is still valuable (Mailizar et al., 2020). Designing eLearning units and incorporating them into the students' curriculum might increase student motivation and the use of these techniques will probably be needed in the future as well (Mystakidis et al., 2021).

Teachers report an increase in ownership, agency and professional development when they re-design eLearning units (Penuel et al., 2007). In this study, as part of a 30 hours professional development (PD) course of in-service teachers, teachers re-designed eLearning units in an eLearning platform, called PeTeL (*PeTeL*, 2022). The main aim of this study was to analyze teachers' re-designed eLearning units and trace the epistemic knowledge and scientific practices that the teachers had implemented into their units.

Theoretical background

Scientific literacy and types of knowledge

A central goal of science education is preparing students for their roles as future scientifically literate people, as reflected in many policy documents worldwide (National Research Council., 2012). In this paper, we follow the definition suggested by the OECD PISA Framework (*PISA 2018 Science Framework*, 2019), which defines three components of scientific literacy: (a) content knowledge - knowledge of the theoretical concepts and ideas of the discipline; (b) procedural knowledge - knowledge of the standard procedures that underlie the methods and practices used to establish scientific knowledge; and (c) epistemic knowledge - understanding the rationale of scientific inquiry, how scientific knowledge has been derived; and the degree to which such knowledge is justified by evidence or theoretical explanations. We shall concentrate specifically on this type of knowledge and the way it is reflected in the eLearning units that teachers had re-designed since it has been found that students' interest in science learning was positively correlated to their understanding of the epistemic knowledge of science (Ho & Liang, 2015). Additionally, when students actively engage in the practices of science, it means that teachers believe that their students are capable of thinking in an epistemic manner (Stroupe, 2014). Students who view that scientific knowledge changes and that experiments are needed to prove it, are more likely to hold constructive conceptions of learning science (Ho & Liang, 2015).

Scientific practices

The National Research Council (2012) defined eight science and engineering practices which follow behaviors that scientists engage in as they investigate and build models and theories about the natural world (Next Generation Science Standards, 2013): a) Asking questions; b) Developing and using models; c) Planning and carrying out investigations; d) Analyzing and interpreting data; e) Using mathematics and computational thinking;

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f) Constructing explanations; g) Engaging in argument from evidence; and h) Obtaining, evaluating, and communicating information.

The PeTeL platform and teachers as re-designers

The PeTeL platform, developed by the Weizmann Institute Department of Science Teaching, is an interactive online Learning Management System (LMS) that allows educators to manage their classroom materials and individual curricula in a single platform. The vision of PeTeL is to enable science, technology, engineering, and mathematics (STEM) teachers in Israel to teach science accompanied by a single, collaborative, digital platform, rich in interactive units that enable diagnostic and evaluation processes integrated into the LMS.

When designers design learning units, the content is usually developed from scratch. Yet, in many cases, it is possible to use existing course materials such as written books, exercise sheets, instructions for laboratory lessons and so on, as a basis for developing eLearning units (Herden, 2011). In these cases the teachers are called re-designers and we shall use this term when relating to the teachers who participated in the PD course.

Research goal and research question

The link between usage of epistemic knowledge, scientific practices and re-designing of eLearning units in the context of high school biology in general and in ecology and evolution in particular, has not been previously investigated. In this study, we attempt to analyze biology teachers' re-design of eLearning units during a PD course and trace the epistemic knowledge and scientific practices that the teachers had implemented into these units. Accordingly, we aim to answer the following research question: To what extent do high school biology teachers address epistemic knowledge and scientific practices in the eLearning unit they re-designed?

Methods

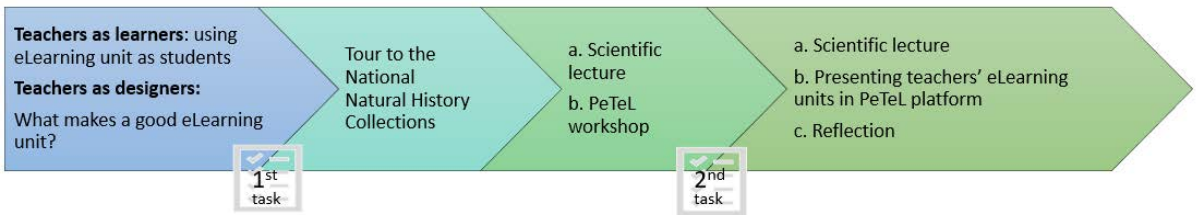
Research design

During summer 2021, a 30 hours PD course "Ecology, evolution and datasets - from the researcher's desk to classroom teaching" was offered to high school biology teachers in Israel. The participants of this study were 20 experienced high school biology teachers. The teachers voluntarily chose to participate in the PD course and in the accompanying research.

PD course description

The course was designed to help high-school biology teachers incorporate eLearning to their instruction in the context of ecology and evolution. The PD course was carried out as a hybrid course due to the COVID-19 outbreak restrictions. The 30 teaching hours, included online sessions, a guided tour and asynchronous meetings dedicated to two tasks (Figure 1). The first day of the course was dedicated to introducing an ecology eLearning unit in the PeTeL platform from a student's point of view, a review of techno-pedagogy in science education and collaboratively establishing criteria for good eLearning instruction units. Following this session, a task was assigned to the participants, in which they were asked to re-design an instruction unit based on either a textbook, a simulation or a dataset (Figure 1, 1st task). Later, they received personal feedback from the authors based on the pre-established criteria. The second day of the course was dedicated to a tour at the National Natural History Collections with an emphasis on the fish, reptiles and the paleontological collections. The third day included a scientific lecture on evolution, and a further look into the interactive PeTeL platform. On the last day, following a lecture on ecology, the teachers presented their eLearning units (Figure 1, 2nd task), received feedback from their peers and reflected on the process of re-designing their unit.

Figure 1
Professional development time line



Data collection and analysis

During the PD course, each teacher or small group of teachers re-designed an eLearning unit. The data sources of this study were 14 eLearning units in the PeTeL platform. Each question of each unit was coded according to the knowledge components of scientific literacy (*PISA 2018 Science Framework*, 2019) and NGSS science practices (Next Generation Science Standards, 2013) using ATLAS.ti Scientific Software. Each question received multiple codes. This paper refers to the analysis of a total of 176 questions included in the 14 eLearning units.

The data sources were coded by the two first authors. First, two units were coded together. Then, each author coded half of the units herself and the units were swapped. The degree of consent was 95%. The differences were discussed until a 100% agreement on all encodings was reached.

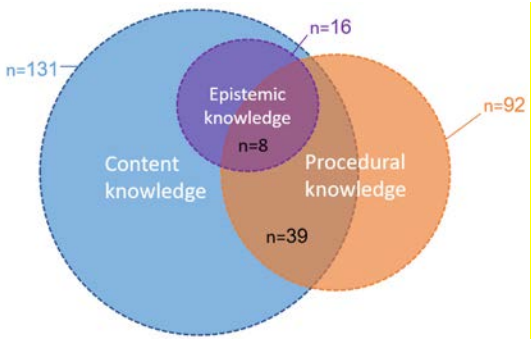
Results

Distribution of knowledge types in the teachers' eLearning units

The distribution of the scientific knowledge needed to answer the questions that were included in the eLearning units that the teachers re-designed is shown in Figure 2. Out of 176 questions, 131 questions required the use of content knowledge (blue), 92 procedural knowledge (orange) and 16 epistemic knowledge (purple). Thirty-nine questions required both content and procedural knowledge. All 16 epistemic knowledge questions included content knowledge, and eight of them included all three knowledge types (Figure 2). While all 14 units included content and procedural questions, only four units included epistemic knowledge questions.

Figure 2

Distribution of knowledge types in eLearning units' questions (n=176)



Do teachers link types of knowledge and scientific practices in their questions?

When teachers use questions that include only content knowledge, a large proportion of the questions do not include any scientific practice (n=50/76). On the other hand, when re-designing questions which require the use of epistemic and/or procedural knowledge, they always use scientific practices. An example of a question which includes all knowledge types and uses the 'planning and carrying out investigations' practice is as follows: "*Design a controlled experiment with which you will try to prove which of the theories, Darwin's or Lamarck's, is correct. For the experiment you are given mice that are genetically identical. Describe the course of the experiment*." (Teacher NK)

Discussion

In this study we present an analysis of biology teachers' re-design of eLearning units through which we investigated the teachers' use of knowledge types in these units, dealing with ecology and evolution. Our main findings are that teachers use mainly content knowledge in eLearning units they re-design, then procedural and the least epistemic knowledge. This finding is in line with PISA's target distribution of score points by knowledge type, which states that the proportions of content, procedural and epistemic knowledge would be 55-66%, 19-31% and 11-22% respectively (*PISA 2018 Science Framework*, 2019 table 4.9). However, our results meet this distribution only in the overall analysis, since we found that only a third of the teachers contributed to the epistemic components and most of the teachers did not relate to epistemic knowledge at all.

Although it is known that epistemic knowledge is important for students to become future educated citizens that can judge misinformation, understand scientific claims and make informed decisions (Hofer, 2020), usually students engage in a rather small amount of epistemic knowledge during their science lessons (Erduran &

Garcia-Mila, 2015). Despite the importance of this issue, some teachers do not refer to it during their teaching, maybe since some teachers do not have enough confidence with epistemic knowledge, and find it difficult to deal with NOS in class (Leach et al., 2003). This might explain our finding that only a relatively small percentage of teachers dealt with epistemic knowledge in their units.

It was recently shown that there is a hierarchy between knowledge types, when high-school students are using a molecular viewer for answering questions about protein structure and function. It was shown that the use of epistemic knowledge is not possible without the use of content knowledge and procedural knowledge (Levkovich & Yarden, 2021). The analysis of the units described here has also shown this pattern. Thus, epistemic knowledge is difficult for teachers to include in their units not only because they might not fully understand it, but also because prior content and procedural knowledge, are needed as a basis for students to engage in epistemic knowledge.

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International Society of the Learning Sciences

Every Glass Ceiling Has a Floor (of Interaction): Studying Body Position During Floor-based Activities in Kindergarten Classrooms

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Abstract: Classroom environments have been hot spots for studies of conversational "floor maintenance," or the ways in which people establish interactional rights and obligations through turn-taking or topical cohesion. We know less about how the physical floor of interaction is negotiated when activities literally take place on the floor, as in Kindergarten classrooms. In floor-based learning activities, body movements, body positions, and proximity are key modalities for establishing rights and obligations for participating in tasks. This paper analyzes video of Kindergarteners engaged in a floor-based learning activity, where children moved around and positioned themselves (and others) to participate. We found that while children often leaned in to the task-space, there were occasions where they sat back, but were nonetheless productive. Referring to these latter forms of participation as "zones of productive exclusion," we analyze how body positioning indexed children's rights and obligations in-task. We discuss implications for analyses of the powered relations between differently-positioned bodies.

Introduction

Classroom environments have been hot spots for studies of conversational "floor maintenance," or the ways in which people establish interactional rights and obligations through turn-taking or topical cohesion (e.g., Erickson, 2005; Macbeth, 1992; Philips, 1983; Shultz et al.,1982). Rights and obligations to initiate a topic, respond, change topic, or extend topics are involved in negotiating conversational floors (Shultz et al., 1982). Collaborative sense-making requires maintaining the conversational floor, or as Erickson (1982) put it, "topics require floors to be in" (p. 47). Local discursive ordering entails both talk's floor and the physical, "custodial" floor of the classroom (Macbeth, 1992, p. 126); however, typically, studies of conversational floor maintenance focus on *talk* that takes place while children and teachers are "carpentered to the desk" (McDermott, 1976, p. 43, as cited in Davies & Hunt, 1994). This paper explores how topics are also physically instantiated and examines body position as a means of floor maintenance in the context of floor-based Kindergarten learning activities.

Like conversations, floor-based learning activities have their own collaborative norms, rules that govern how, when, whether, and to what ends people are supposed to move around, interact with materials, or position themselves with respect to others. Just as it is usually improper to "turn-shark" during classroom conversations (Erickson, 2005, p. 54), in floor-based group learning activities that are the subject of this analysis, it was not customary to take other people's materials out of their hands, nor to crisscross your body over someone else's to assert an idea or course of action. However, breakdowns in conversational and collaborative task norms *do* routinely occur, presenting a question: *How do children's body positions establish rights and obligations to maintain the floor of interaction when tasks literally take place on the floor?* We addressed this question in the context of a Kindergarten classroom activity, analyzing how talk-in-interaction and arrangement of materials shaped how people positioned themselves and each other to have particular rights or access. Tracing dynamic body movements of people within collaborative tasks showed how they managed the floor of interaction, even when they were excluded from the task-space. We focus on exclusion as a form of body positioning that accomplished floor management and argue that *body* position can index *social* position in floor-based activities.

Perspectives on body position in maintaining floors of interaction

We draw on perspectives within traditions of interaction analysis (IA), focusing on embodied ways of establishing "patterns in the allocation of interactional rights and obligations among all the members who are enacting a social occasion together" (Shultz et al., 1982, p. 94). In verbal exchanges, people adopt metaphorical floor-management strategies (i.e., "taking the floor," "holding the floor," "yielding the floor," etc.) according to standard practices. Managing conversational floors in interactions means establishing "who's got the floor" (Edelsky, 1981), which entails conventional rights and obligations vis-à-vis topical change, cohesion, and extension. Learning environments have been ground zero for studies of interactional floors (Macbeth, 1992; Philips, 1983; Shultz et

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al., 1983), and negotiation of rights and obligations in the physical space of a classroom's "custodial floor" (Macbeth, 1992, p. 126) has received some attention (e.g., Erickson, 2005). However, prominent examples of research on positional dynamics focus on physical arrangements of people seated around tables (e.g., tables, desks, Shultz et al., 1982) or standing (e.g., cocktail parties, Kendon, 1990). And while research on untethered learning designs explores how the body is an important resource for sense-making and establishing a social order (e.g., Danish et al., 2020; Lee, 2015; Marin et al., 2020), often these designs involve groups of people standing or moving around on foot. We know less about how the floor of interaction is negotiated when activity literally take place *seated* on the floor, as is customary in early childhood classrooms. Negotiating rights entails relations of power, and this analysis also builds with studies that theorize learning, bodies, and power together, and as always in relation (Goodwin, 2006; Ma & Munter, 2014; Marin et al., 2020; Stevens, 2012; Vossoughi et al., 2020).

Methods of data collection and analysis

The teaching and learning described in this paper was part of a design-based study set in the Mountain West region of the US and designed to investigate young children's STEM learning. Data analyzed were collected over one month in a rural elementary school classroom that was part of a grant-funded program providing full-day Kindergarten to support English Language Learners, students who had an Individualized Education Plan (IEP), and students identified by their entrance assessment. Fifteen students participated at this site in 4 groups of 3-4 children. We analyzed three groups with equal numbers of boys (n=2) and girls (n=2) per group, because we were also exploring social categories like gender as potentially relevant for participation. Lessons were video recorded and taught by research team members who had formal experience teaching young children. In the STEM tasks we designed, a tangible programming robot typically needed to go on some adventure, travel to a series of locations, or avoid obstacles placed in its path. Materials included a large floor grid; a collection of directional arrow cards that serve as codes or commands; one template per group for organizing codes that we call a "program organizer;" and a mechanical robot with buttons for each of four directional commands (Figure 1). This paper does not analyze children's programming per se; however, materials used in-task help contextualize interactions.

Nine hours of video-recorded lessons were first reviewed and content logged (Jordan & Henderson, 1995). We then conducted iterative rounds of open coding and a series of group video viewing sessions. We coded interactions according to how children were positioning themselves to use or access materials, and we thematically grouped types of positional configurations around the floor in broad categories that describe diametrically opposed positionings: *comporting/contorting* and *leaning in/sitting back*. In the latter categories, sitting back was much less common than leaning in. We decided to focus on the smaller subset of instances of children sitting back to understand how they were participating when they assumed these positions. We focus the following analysis on a specific form of sitting back we call "zones of productive exclusion" in which children were positioned away from the "mainline" activity but nonetheless stayed engaged in the task from the sideline.

Establishing a zone of productive exclusion

While it was entirely possible to participate in tasks from a distance (and many children did so), leaning in and extending the body into the toy's grid-space (see grid in Figure 1, Frame 4) was a pervasive form of interaction across tasks and groups. Therefore, it was quite noticeable when someone sat back or was denied access to the floor grid and materials. Most tasks were designed for children to have a mainline focus with a front-row vantage point towards the grid; however, because of the size and configuration of the physical environment and materials, there was often someone left out, displaced to a marginal position off to the side or on a corner of the mat. Sometimes, the person in the excluded position started off the task sitting back or offset from the rest. Other times, despite starting off with mainline access, they were progressively or systematically elbowed out by eager programmers.

Figure 1 *Bowen leans on Hazel (1) and reaches across her to select his codes and place them on the program organizer (2). Hazel finds space for her counter-idea in the air (3) and off to the side (4).*

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When Hazel and her partner Bowen began a task for programming their robot's route, Hazel was in an optimal, mainline position to access the critical materials and had an ideal vantage point for visualizing the robot's path. However, as they started programming, Bowen immediately leaned on Hazel's body (Figure 1, Frame 1), stretching over her to reach the materials (Frame 2). Hazel first looked for alternative spaces to place her codes, because Bowen was quickly filling up the program organizer without consulting her. After making a bid to modify the program, Hazel tried to find space to express her idea. First, she tried to place the code cards on the floor grid.

Then she tried to hold a sequence of codes aloft in her hand (Frame 3). When she could no longer hold any more cards, she turned at a ninety-degree angle to the grid and programmed off to the side, sitting back from the mainline and periodically looking over her shoulder at the codes and the robot in order to determine its next move (Frame 4). When their teacher brought the pairs of children together to test their programs, Hazel claimed that the program Bowen had made was "not her program." She explained quietly that she "did not have enough room." Hazel's sidelined programming, conducted in a zone of exclusion, established a floor space for programming, still on topic, but not within the same floor of interaction where her partner performed his activity. We now turn to a discussion of interactional floor maintenance, and discuss this instance in terms of patterns of exclusion we observed and implications for the organization of floor-based activities.

Processes of exclusion for establishing floors of interaction

Whereas cohesion in conversation requires speakers to extend or change topics, collaboration in floor-based learning activities involved children using their bodies to maintain the floor of the activity. We found that for some children, maintaining the floor of interaction in coding tasks involved processes of exclusion, whereby sitting back from or being forced out of the mainline activity established an alternative space for engaging in the task. For Hazel, establishing a "zone of productive exclusion" was important so that she could build the program she had in mind. When Bowen dominated their programming, Hazel took the task in her own direction on the physical floor. When the interactional floor fell out from under her, and her partner obstructed her participation in the mainline programming, Hazel's sidelined orientation created her own zone of exclusion, a space where she could think through the program without needing to justify her thoughts or jockey for position.

We noted earlier how leaning-in was a frequent form of embodied participation; this was true for boys and girls. It is also worth noting that in the more infrequent instances in which children sat back, it was typically girls who were positioned away from the group or the grid. Girls in these marginal positions often engaged in peripheral activities like exploring or organizing unused coding materials, producing utterances to themselves about coding, or programming their own path; such tasks, while not mainline, were nonetheless productive for their sense-making. To be clear, we are not advocating a model of separating certain children from the group. Nor do we believe "sitting back" should be valued over "leaning in." These practices represent ways of disciplining difference and perpetuating classroom regimes in which quiet children do well, and active children are deemed out-of-line or off-task. Leaning in and sitting back are not proxies for disruption and docility. Rather, *we see children's own positionings of themselves and each other as agentive forms of producing spaces for sense-making*.

These marginal positionings represent potentially beneficial learning arrangements, in that they produced the sort of spaces that support children's diverse forms of participation, particularly for those who are systematically excluded in STEM, such as children who identify as girls or children from minoritized backgrounds. Analyzing physical dynamics of floor-based activities prompts us to think more critically about the social dynamics operating in classroom spaces. How are body position and social position co-constituted through intersectional identities where gender, language, race, age, or ability are "omnirelevant" to interactional rights and obligations (Stokoe & Smithson, 2001, p. 251)? Exploring this question will involve interrogating *exclusions entailed by our methods of interaction and conversation analysis*. We conclude with a few methodological implications we anticipate for future interactional studies of body positioning, learning, and relations of power.

Implications for future analysis of body positioning

CA and IA have not tended to treat gender and other social categories as relevant to interactions unless participants index them through talk or orient to them in-task (Stokoe & Smithson, 2001; cf. Schegloff, 1997). Yet, as analysts of interactions which are always powered, we observe that positioning in relation to member categories is not always explicit in interaction, and "what we call categories of gender, race, ethnicity, etc., are shorthand for a set of structures that position persons" (Young, 2005, p. 19). Seeing social positionings through body positioning means recognizing ways that power is instantiated in bodies, and how "conversely, these spatial configurations of bodies and actions index membership categories relevant to the activity in progress" (Takanashi & Den, 2019, p. 270). We urge learning scientists to continue to strengthen impoverished treatments of both gender divorced from other salient categories of difference like race (e.g., Patel, 2021), and gender defined as binary, sex-based

difference (e.g., Dennis et al., 2019). Finally, we encourage analysts to consider how theories not only describe what is possible for some bodies and not others, but what is actually experienced *as differently-positioned bodies* in physical environments. In that spirit, we conclude with Ahmed (2017), whose queer theorizing concerns not only theoretical spaces of possibility, but real, physical spaces constructed by whiteness and sexism in academic settings. She writes, "walls are how some bodies are not encountered in the first place. Walls are how other bodies are stopped by an encounter" (p. 145). Classrooms are made up of walls as well as doors that are more open to some bodies than others. Classrooms also have floors, and for every glass ceiling, there is a floor (of interaction).

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Emphasizing the role of coordination class theory on the study of student learning with representations

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Abstract: Visual representations are a core feature of teaching and learning in STEM disciplines. In all STEM fields, visual representations are used to describe phenomena, support problem solving, and aid communication. A significant body of research has documented that STEM students face challenges interpreting, generating, and translating representations across STEM curricula resultant from deficits in students' "representational competence" skills. In this paper we examine the theoretical underpinnings of representational competence (RC) and argue that the constraints of RC can be remedied by instead applying coordination class theory. Considering two examples of students' problem-solving with representations, we illustrate how developing coordination classes better explain the observed challenges students face with external representations in STEM disciplines.

Introduction

The teaching and learning of visual representations are key parts of education, particularly in STEM fields. How students understand representations is inextricably linked to their development of content knowledge since a common way of communicating conceptual information is through external modes of visualization (e.g., images, videos, simulations). Typically, the analysis of students' learning with representations is related to their conceptual understanding through the correct use of disciplinary representations (Nitz et al., 2014; Stieff, 2011). The theoretical construct that often frames such research is known as representational competence (RC) and is a presumed barrier for learning in STEM (Kohnle et al., 2020; Kozma & Russell, 2005; Nitz et al., 2014). RC assumes that as students develop their ability to utilize disciplinary representations their learning of associated conceptual knowledge is facilitated. However, such an assumption neglects the myriad ways that novice learners interpret and understand the features of external representations. We propose that reconceptualizing representational competence as developing coordination classes will effectively address the shortcomings of RC. Coordination class theory (diSessa & Sherin, 1998) offers a perspective on student learning with representations that considers internal cognitive processes beyond demonstrated skills that better characterize the ways students employ their prior knowledge to make meaning out of representational features. While we do not present an empirical study that directly tests our claims, we do utilize some exemplar cases from prior research conducted by the authors that demonstrate the application of coordination class theory as opposed to representational competence. By doing so we provide researchers with an alternative approach to studying external representations that may provide more productive outcomes for research and instruction.

Theoretical framework

The representational competence construct was developed from work by Kozma and Russell who studied the ways novices and experts interpret, generate, and transform chemistry representations (Kozma & Russell, 1997). Invoking the Knowledge-in-Pieces framework (KiP; (diSessa, 1993), Kozma and Russell argued that chemistry learners develop a fragmented understanding of chemistry concepts because they lack prior knowledge based on observable phenomena in their everyday lives (Kozma & Russell, 1997). While intuitive knowledge elements originate from direct experiences in domains such as physics (e.g., p-prims), chemistry instruction relies more heavily on visual representations to describe the sub-microscopic nature of phenomena. Therefore, Kozma and Russell argued that conceptual change in chemistry is inhibited by students' difficulty interpreting representations and inability to apply representations in problem-solving contexts. Their observations led them to develop a set of representational skills they believed necessary for the advancement of novices to expert-level conceptual understanding in chemistry.

While the RC construct leverages several aspects of KiP, Kozma and Russell are unclear on how these elements function through the RC skills to promote conceptual change. Additionally, much of the scholarship that invokes RC as a theoretical construct and dimension of analysis only consider whether students demonstrate RC skills. This leads to binary classifications of whether students "have" or "do not have" RC, which narrows the scope of interpretations and useful insights from such research. Without considering *how* and *why* students engage

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with visual representations in particular ways there is little value in instructional methods that simply promote the correct use of representations. Coordination class theory (diSessa & Sherin, 1998) provides a perspective that can answer these *how* and *why* questions while also characterizing the connections students make between features of external representations and their prior knowledge.

While diSessa and Sherin explored the implications of KiP in physics, they recognized that there was a common issue of how concepts are discussed and studied in education research that fails to account for how learners establish an understanding of a concept across representations or phenomena. They argued that conceptual change for some core concepts in STEM is better conceived as the development of coordination classes that include two structural components. First, readout strategies describe how students interpret information from the external world; second, causal nets describe how students create meaning based on their interpretations and develop connections to their prior knowledge. The readout strategies students use to extract information from the world and their assumptions involving underlying knowledge elements that comprise causal nets are integral to understanding how students progress from novices to experts. Additionally, students can coordinate information through their readout strategies in two ways: integration and invariance. The former describes how one must attend to different pieces of information within a situation to formulate a comprehensive understanding. The latter refers to how an idea can be presented in different ways across multiple situations. With respect to representations, a student must come to recognize how one representation communicates information about underlying phenomena through various features (integration), as well as how different representations may describe the same information but in different ways (invariance).

When comparing representational competence to coordination classes, the former lends itself to representational skills being distinct yet related to content knowledge. It is ambiguous whether Kozma and Russell truly contest that RC is separate from content knowledge, yet later research that invokes the construct has come to treat RC and conceptual change as independent outcomes (e.g., Nitz et al., 2014; Stieff, 2011; Stieff & DeSutter, 2021). By considering the inherent connections made between representations and the concepts they communicate, coordination class theory allows us to better understand how students develop content knowledge through the use of disciplinary representations. Since the connections novice students make between knowledge elements and representational features are less likely to be as straightforward and canonical as the connections we see experts create, it requires deeper consideration of the ways in which students reason. As such, coordination class theory provides a more fine-grained approach by considering what the student interprets from a visual representation together with how they apply their prior knowledge.

Reframing representational competence as coordination class theory

In proposing this alternative to understanding how students engage with visual representations, we present a set of exemplars that demonstrate how researchers might apply coordination class theory. We describe how students interpret pre-existing disciplinary representations as well as how they generate their own representations through sketching. These examples are from prior research conducted by the authors to gain a better understanding of how students engage with chemistry representations, however, coordination classes were not a framing theory or approach to analysis. Importantly, the discussion of these examples is not intended to be a developed methodological approach for the application of coordination class theory. Rather we seek to broadly describe how coordination class theory could be invoked in research on external representations and the resultant implications.

The first example is from the first author's dissertation research that included semi-structured interviews with thirty first-semester general chemistry students. These interviews were conducted to understand how students use different chemistry representations when introduced to a novel topic area. Students were provided with instructional materials that included a short reading passage introducing the topic of molecular geometry along with a chart of all fifteen molecular geometries with example molecules in one of three different representations (ball-and-stick, dash-wedge, or Lewis dot). The second example stems from a larger project involving high school students' engagement with a design-based chemistry curriculum that employs workbook activities in conjunction with sub-microscopic simulations (Stieff et al., 2012). This specific activity prompted students to draw what they thought water would look like on macroscopic, microscopic, and sub-microscopic scales and modalities.

Example 1: Inferences about dash-wedge diagrams

When considering coordination class theory, we see that students apply several different readout strategies in congruence with connections in their causal net to understand a novel concept (molecular geometry) using unfamiliar representations like dash-wedge perspective formulas (see Figure 1).

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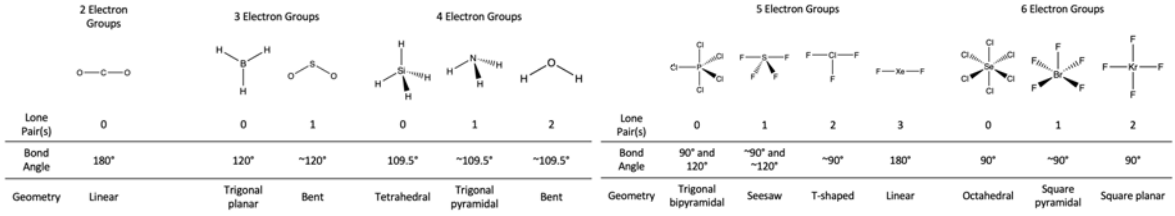
Figure 1

Dash-wedge perspective formulas provided to students as part of instructional materials.



When presented with this form of representation, students would first focus on familiar features they learned from chemistry instruction. For instance, students would utilize readout strategies to recognize that the letters in the representation communicated information regarding the elements involved. From here, they would take advantage of connections in their causal net between the element symbols and information from the periodic table. When prompted, students would try to explain additional formalisms of the representation such as the dashed and wedged lines. Students applied additional readout strategies to collect further information about the representational features (e.g., that the dashed and wedged lines form triangles; the wedged line is bolder/darker; the dashed line is more dispersed). Unlike the element symbols, many students did not have developed connections in their causal net between the dashed and wedged lines and spatial orientation, therefore they invoked other knowledge elements to form connections. In this case, they often related the dashed and wedged lines to relative bond strength or different types of bonds (e.g., covalent, ionic, single or double bonds).

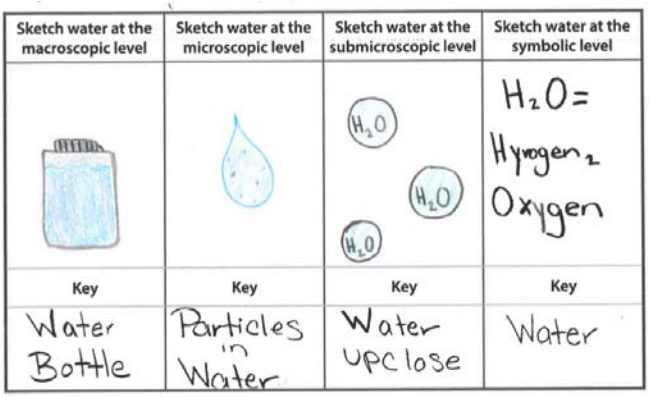
Analyzing these student responses from the lens of representational competence, we would only be interested in whether the students could correctly identify the conventional meanings of the dashed and wedged lines. When considering the responses from the perspective of coordination class theory, we can see how the familiarity of representational features and the related causal nets influence students' attention and their interpretation of the representation.

Example 2: Understanding different scales

The second example involving high school students' sketching gives us insight into how students make connections between knowledge elements, which in turn leads them to generate sketches with a focus on particular features. Figure 2 is a student artifact from a workbook activity in which students were asked to draw water at three different scales. We can see that the student has a rich causal net based on frequent engagement with water at a macroscopic scale, yet they are less familiar with the microscopic and sub-microscopic, so they attempt to apply similar representational features based on readout strategies from the macroscopic. Across panels in the figure, the student still draws water at a macroscopic scale as a droplet, and they conflate symbolic features in their sketch of water at a sub-microscopic scale.

Figure 2

Student-generated sketches of water at the macroscopic, microscopic, and sub-microscopic scales as well as in the symbolic form.



While prior studies around representational competence might simply deem these two sketches as incorrect due to their non-canonical forms, coordination class theory provides us with a more detailed

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understanding of the possible reasoning behind these sketches. We can see that the student has continued to use the color blue in both their microscopic and sub-microscopic sketches, which may indicate that they are trying to demonstrate invariance in their drawings based on the causal net they have developed for water at a macroscopic scale. The student is also likely unfamiliar with the conventions utilized in disciplinary chemistry representations at these two scales, so they invoke prior knowledge to integrate how they understand water in other situations (e.g., using the chemical formula for water in the sub-microscopic sketch).

Conclusion

This paper demonstrates the theoretical power of applying coordination class theory to the study of students' engagement with disciplinary representations. Rather than taking the narrow focus of whether students can correctly use and interpret representations, coordination class theory emphasizes the ways in which students understand external representations and link them to underlying phenomena. Moreover, coordination class theory provides a more detailed understanding of how students engage prior knowledge that other frameworks, such as diagram comprehension (Zhang, 1997), do not investigate closely.

Researchers may use this information to develop interventions and targeted instructional practices that redirect the focus in learning with representations to the connections formed between representational features and the concepts they communicate, rather than the procedural use of disciplinary representations in specific contexts. Additionally, it would be of interest to investigate how different forms of instruction influence the development of readout strategies and causal nets around the use of representations. Specifically, how instruction that emphasizes and describes the connections between representational features and underlying phenomena would help engage students in useful readout strategies that will allow them to make further connections and inferences in their causal nets. In doing so, students may be better equipped to identify aspects of invariance and integration in disciplinary representations as well as generating representations in novel contexts.

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Title: Math on cortex – Underlying delta synchrony during naturalistic math demonstrations in math experts and novices

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Abstract: Neuroimaging studies show that expertise in math shapes brain functions. To understand the brain processes behind complex math tasks and manipulation of large abstract concepts, we need to study the brain with naturalistic stimuli. Such stimuli are, for example, long math demonstrations that evoke simultaneous and overlapping cognitive and metacognitive processes. In our EEG study, we compared math experts and novices while they actively processed long math demonstrations in sitting and standing. Experts had an enhanced delta (0.5-4 Hz) phase synchrony over the centro-parieto-occipital electrodes compared to novices. Internal concentration and engagement may play a role in such enhanced delta synchrony.

Introduction

Behavioral studies have shed light on cognitive mechanisms and concepts arising during mathematics and cognition. Brain research aims to understand, on a neuronal level, these mental transformations related to math processing. Thus far, neuroscientific studies in children, adults, and math experts have focused on relatively simple mathematical processing in the brain.

Until now, brain research of mathematical cognition is accomplished with very quick mathematical tasks such as single- or double-digit arithmetic, or a short sentence describing a mathematical concept (e.g. Amalric & Dehaene, 2019; De Smedt et al., 2009). All of these studies are made with a strictly still body posture, due to noise sensitivity of the imaging methods and artifacts caused by body movement. Problems may emerge when simplified models, based on such short and artificial tasks in isolated and static settings, are applied to complex psychological phenomena, like mathematical cognition. Complex cognitive phenomena are exceedingly difficult, perhaps impossible, to describe through the data of their building blocks alone, since these phenomena are greater than the sum of their parts (Zaki & Ochsner, 2012). Our study aims to contribute to the naturalistic leap in brain research of math, the path of which is already being developed by interesting studies, such as Dikker and collaborators (2017) on STEM learning in a classroom measured by EEG.

In our study, we focus on the brain processes of math experts and novices over three oscillation frequencies: delta, theta, and alpha. We study the cortical synchrony with EEG when the participants actively processed longer math demonstrations with a duration from 13 to 68 seconds. By active processing, we refer to the mental activity we do when we read notes, proofs, and worked examples. Therefore, active processing is not restricted to solving problems. The math demonstrations are presented in symbolics and geometric manner when the participants are sitting and standing. We expect the math experts to show stronger activation over the parietal electrodes than novices when processing math demonstrations (Grabner & De Smedt, 2012), possibly due to the expected activation of the domain-specific number network (Amalric & Dehaene 2019).

Methods

Participants

In the math expert (bachelor and master students in math or math-related disciplines) and novice (no university-level math studies) groups, there were 23 participants (6 female and 17 male; 6 female and 17 male, respectively).

The age of the participants ranged from 19 to 24 years (mean 21.0 years, standard deviation 1.82) among math experts and from 19 to 35 years (mean 23.6 y, std 3.89) among novices. All participants in both groups were right-handed. No participants reported hearing loss or history of neurological illnesses. The experiment protocol was conducted in accordance with the Declaration of Helsinki and approved by the local Ethics Commission.

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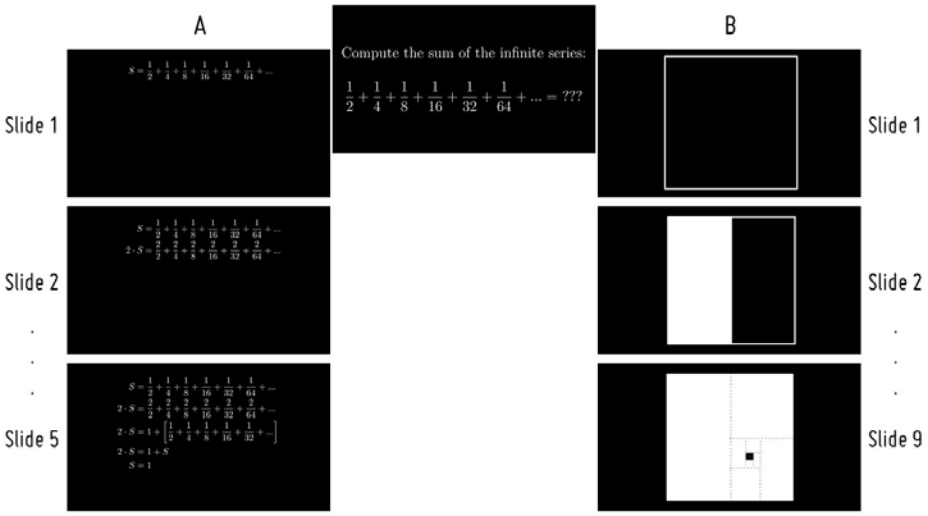
Stimulus

Participants watched 16 math demonstrations in a pseudorandomized order knowing that after watching them, they are asked to explain them to the experimenter. After each demonstration they were asked three self-evaluation reflections to which they answered by pressing a button in a 4-button response box. Each set of trials contained 4 excerpts of the same presentation style (symbolic or geometric) in two conditions (sitting or standing). One out of 8 math demonstrations is shown in Figure 1, both in a symbolic (Figure 1A) and in a geometric form (Figure 1B). The self-evaluation reflections (SER), which were presented after each demonstration, were the following: *I had enough of time to follow the math demonstration* (SER1), *I was familiar with the math demonstration* (SER2), *I understood the math demonstration* (SER3), and *I found this math demonstration engaging* (SER4). The options for the answers given via the response box were the following: 1 = *Completely disagree*, 2 = *Somewhat disagree*, 3 = *Somewhat agree*, and 4 = *Completely agree*.

Each math demonstration consisted of several slides, varying from 4 to 12 slides (6.9 slides on average) depending on the complexity of the demonstration. The total duration of math demonstrations varied from 13 seconds to 68 seconds (33.1 seconds on average). The timing of each slide was fixed and was defined based on a previous online screening with math experts and novices who did not participate in the actual study.

Figure 1

One out of 8 math demonstrations shown in symbolic (A) and geometric (B) form. The first slide (image in the middle) was the same in both symbolic and geometric presentation and was not used in the data analysis.



Equipment and procedure

The stimuli were presented to the participants with the MATLAB version R2019b via PsychToolbox version 3. The total length of the experiment material was approximately 15 minutes. The data were recorded using Ant Neuro eego mylab electrode caps with active 128 EEG channels and 4 external electrodes for eye movements.

Data analysis

The average of all the EEG electrodes was set as a reference meaning taking the average of the signal at all EEG electrodes and subtracting it from the EEG signal at every electrode for every time point. The data were treated with independent component analysis (ICA) decomposition with the *runica* algorithm of EEGLAB to detect and remove artefacts related to eye movements and blinks. The data were split into the frequency bands of 0.5-4 Hz (delta), 4–8 Hz (theta), and 8–13 Hz (alpha) with high-pass and low-pass filtering.

We calculated the phase synchrony values (PSV; Tass et al., 1998) of the EEG data to the math demonstrations. The PSV value was calculated for 5-second segments with 50% overlapping for each math demonstration excluding the first two seconds and last second of the presentation. We conducted the synchrony analysis over the 12 electrodes of F3 (5), Fz (6), F4 (7), FCz (42), Cz (16), CP3 (48), CP4 (49), P1 (51), Pz (26),

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P2 (52), PPO1 (92) and PPO2 (93; the 128-channel Ant Neuro EEG cap gap). Many of these fronto-parieto-occipital electrodes are traditionally used in EEG studies of mathematical cognition and show modulations in oscillation over memory retrieval, procedural strategies, and math training (e.g. De Smedt et al., 2009; Grabner & De Smedt, 2012).

The statistical analyses were conducted with MATLAB. The statistical analysis, repeated-measures ANOVA with a between-subject factor Group (Experts and Novices) and within-subject factors Posture (Sitting and Standing for math demonstrations), and Stimulus (Symbolic and Geometric), was conducted separately for each electrode pair (66 electrode pairs), each frequency band (delta, theta, and alpha). pGG indicates the Greenhouse-Geisser adjusted p-values of the repeated-measures ANOVA. For false discovery rate (FDR) correction, we employed a q-value threshold of 0.05. In the results section, we report only the statistically significant results in which both the pGG and the pFDR are < 0.05.

Results

Behavioral results

Self-evaluation reflections are an important indicator of how well the participants understood the math demonstrations (SER3) and how deeply they felt engaged with each demonstration (SER4). We also screened familiarity (SER2), and whether the participants had sufficient time to follow the steps of the demonstrations (SER1). For SER1, SER3 and SER4 experts reported significantly higher scores than novices, pGG=8.2e-06, pGG=8.2e-06, and pGG=0.0042, respectively. For SER2, there was no group difference, pGG=0.63.

EEG results

EEG results related to the Group differences and their interactions are reported and discussed in this paper The only statistically significant Group differences and their interactions occurred over the delta band (Table 1).

Table 1

Repeated measures ANOVA was calculated individually for each frequency band with between factor Group (Experts, Novices) and within-factors Stimulus (Symbolic, Geometric) and Posture (Sitting, Standing). This table presents the significant group main effects and interactions and in all of them Experts have stronger synchrony than Novices (Experts > Novices).

Delta: 0.5 – 4 Hz	Electrode pair	pGG value	pFDR	Multiple comparison (Bonferroni)	Difference	Standard error
Group main effect	Cz – PPO1	0.015	0.0097		0.12	0.046
	Pz – P2	0.020	0.0067		0.14	0.056
	CP3 – P1	0.049	0.0080		0.10	0.051
Group*SitStand interaction	Cz – Pz	0.014	0.00035	Standing: (p= 0.035)	0.11	0.049
	Cz – P1	0.020	0.00035	(p= 0.034)	0.11	0.052
	CP4 – PPO1	0.049	0.00048	(p= 0.046)	0.11	0.052

Discussion

In our study, we compared math experts to novices when they were actively watching long and complex math demonstrations in an EEG laboratory in sitting and standing body posture. Our main finding is that the math experts have a stronger delta phase synchrony over the centro-parieto-occipital electrode pairs than novices when watching math demonstrations. Our results refer to enhanced internal concentration (Harmony, 2013), and/or activity related to the number network in experts in comparison to novices (Amalric & Dehaene, 2019).

Internal concentration

When processing long and complex math demonstrations, internal concentration is crucial bringing the focus to the task at hand. Simultaneously, brain processes related to other external stimuli or task-irrelevant internal thoughts need to be suppressed. Harmony and colleagues (Harmony, 2013) showed that left parietotemporal

cortices have an increased activation on the delta band (3,9 Hz) during an arithmetic calculation in comparison to control tasks. After other results from their laboratory, Harmony and colleagues (2013) reasoned this increase in the delta band to occur due to enhanced internal concentration required to solve the arithmetic problem. Also in our study, the enhanced delta phase synchrony in experts over the centro-parieto-occipital electrodes may reflect their deeper internal concertation in comparison to novices. The self-evaluation reflections would also support this interpretation since experts reported stronger engagement and a better understanding of the math demonstrations than novices.

Sitting and standing body posture

Most of the group differences in delta synchrony in experts and novices occurred during both body postures, sitting and standing. However, some synchrony differences, expanding to the right hemisphere, emerged only during the standing position. To our knowledge, our study is the first one that investigates complex math in a standing body posture. Visuospatial working memory seems to function faster and more precisely when standing than when sitting down (Dodwell et al., 2019). However, sustained upright posture seems to require constant attentional engagement (Woollacott and Shumway-Cook, 2002). In our study, potential attentional interference between standing and math tasks appears to challenge math novices more than experts, who might have more automatic mathematical processing and thus require less attentional effort (Jeon et al., 2019).

Conclusions

Our novel study setting with long and complex math stimuli revealed enhanced delta synchrony in math experts in comparison to novices over the centro-parieto-occipital electrodes. Over some electrode pairs, the group differences were shown only when standing but not while sitting. Taken together, these results indicate a deeper internal concentration in experts and/or potentially a stronger activation of the number network in comparison to novices when actively processing math demonstrations. Our results encourage future study of the brain with naturalistic stimuli, such as long and complex math tasks, in naturalistic setting including different body postures to understand how the brain functions in the real world in which continuous and overlapping stimuli are encountered and interacted with, evoking several simultaneous sensory, cognitive and emotional brain processes.

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Personalized Instruction to Teach Secondary Students to Deeply Comprehend and Build Knowledge from Science Texts.

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Abstract: eBRAVO is a unique, theory driven, web-based teaching tool that simultaneously provides advanced reading comprehension assessment and skill development, knowledge building skills, combined with a standards-based science curriculum in ecology. The instruction is individually paced, has whole classroom activities to aid classroom pacing, teacher and student dashboards demonstrating progress, and is open source. We describe the approach to theory-driven development, co-design and evaluation in the project and the implications for supporting reading comprehension in STEM.

Introduction

In order to be successful in school, students need to be able to read content-area texts well enough to learn and remember new content, and they must be able to apply what they know in future reading and learning situations, as well as apply the knowledge in novel contexts. Comprehension instruction is intended to give students specific tools that expert readers use, to be applied in situations where comprehension breaks down (e.g., Biancarosa & Snow, 2006; Goldman, 2012; Kim, Vaughn, Wanzek, & Wei, 2004; Pilonieta, 2010; Pressley, 2000). However, in the middle school years this instruction typically consists of isolated strategy or skill development taught in remedial reading and English/language arts classes and often ignores the goal of cumulatively building knowledge from texts (e.g., Duke, Pearson, Strachan, & Billman, 2011).

The eBRAVO project targeted this well-documented weakness in reading comprehension (particularly for expository texts) that typically persist and significantly impact students' further academic progress (e.g., Anonymous, 2017; Chen & Ho, 2012; Norris and Phillips, 2003). It addresses the problem with current practices in comprehension instruction by embedding explicit comprehension instruction in a content-area context that improves reading comprehension skills in middle school readers. The approach is designed to provide scaffolded support to help students understand difficult content-rich, informational text, teaching them how to overcome misconceptions, understand the text meaning, and build knowledge.

Developing eBRAVO

For the project, researchers developed and pilot tested the eBRAVO intervention aimed at helping middle school students develop deep comprehension skills necessary to read, comprehend, and build knowledge from informational texts. This project used a novel approach to translating theory to practice by simultaneously addressing parallel learning processes in actual learning settings: skillfully reading challenging texts to achieve deep understanding while also building knowledge about a complex content area from the content in the reading. At the same time, this project worked iteratively with stakeholders—teachers and students—to design a tool that works practically in both classroom and individual learning settings (e.g., Penuel, Fishma, Cheng & Sabelli, 2011).

The eBRAVO development used a theory-driven adaptation and enhancement of a previously-developed paper-based intervention (BRAVO; Fostering Comprehension and Knowledge-Building in Middle-School Struggling Readers), shown in prior work to have promise for improving students' reading comprehension outcomes (Foltz, Littrell-Baez, & Kintsch, E, 2018). eBRAVO, like BRAVO, is aimed at improving the reading comprehension skills of middle school students who have adequate reading fluency but still have trouble learning from informational text as they read. The intervention, embedded in a STEM curriculum, teaches students how to implement reading comprehension strategies and how to actively build knowledge.

Moving from a paper-based to an online curriculum afforded multiple changes in design to permit individualized comprehension strategy instruction within a curriculum with contextualized texts at different levels of reading difficulty. eBRAVO was developed as a web-based reading application that contained a complete ecology curriculum. A design-based implementation research (DBIR) approach was used to carry out the project (Penuel, Fishman, Cheng, & Sabelli, 2011). This approach consisted of co-design meetings which allowed researchers and instructors to interact as full partners in developing and evaluating materials and instruction.

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The eBRAVO curriculum is an adaptive reading experience with embedded formative assessments on web-enabled devices in which students work through a twelve chapter ecology curriculum. It is designed to allow students to proceed through the lessons at a self-paced rate, rather than as a class. To accommodate this personalized learning experience in an intelligent tutoring approach, we adapted the five class-level lessons from BRAVO into videos and a practice problem personalized for each chapter, creating 119 lessons. As students work within eBRAVO, they first read a short chapter of 3 to 11 paragraphs of ecology reading content connected to what they have read so far in the curriculum. These readings incorporate in-text highlighting and clickable definitions for key vocabulary, along with embedded figures including images of important components or diagrams of certain systems. Once students have completed their readings, they proceed directly to open-ended writing asking them to record the big ideas found in the text. eBRAVO then probes their deep comprehension with multiple choice questions that target both issues brought up directly in the text as well as inferences and connections to greater ideas from previous texts. The open-ended writing is assessed using NLP-based approaches to measure content and inferences that were learned (Foltz et.al.2020; Foltz, 2017). The system assess multiple literacy skills and if the system determines a student should see subsequent reading lessons based on their comprehension scores, it then gauges which type of reading support (linking ideas, gist, summary, graphic organizer, or inference) with which the student needs help and sends them to the appropriate lesson for that chapter and content, The lessons further incorporate two to five minute videos that outline the key comprehension strategy that is targeted and demonstrate how to apply this comprehension strategy to parts of the chapter that the student has just completed.

Taken together these features provide students with just-in-time instruction on needed skills to better understand and learn from the text *as they are reading it* (Foltz et.al. 2020; Foltz, 2017). The process of development of eBRAVO for one STEM domain further resulted in a more general curriculum framework that may be applied to new content areas and that will allow more individualized scaffolding to better meet the needs of a variety of classrooms, students, and instructors in both Language Arts and content area classrooms.

Evaluation

The first two years of this project involved iterative development of the eBRAVO interactive, web-based tool, in collaboration with teachers and students. Researchers began by identifying and adapting previously developed and studied BRAVO curriculum components into a format that could be delivered online through eBRAVO. Participants in this study included approximately 288 students in 6th through 9th grades in suburban school districts in the Denver, Colorado area.. Data were collected from teachers and students via surveys, interviews, and focus groups to examine usability and feasibility as well as data from embedded formative assessments. The eBRAVO system also collected user data (e.g. click streams), and the researchers collected student performance data pre- and post-intervention. During this project, revisions were made to eBRAVO from iterative design with teachers and students as collaborators, followed by field testing of the upgraded system based on user feedback, use and performance. We implemented additional important features including an online concept map activity used to consolidate knowledge, and to more deeply understand the "Big Ideas. Additionally, scenarios were developed to bring students together in teacher-led classroom activities and to "catch up" students who engaged individually at a slower pace. Our small classroom efficacy study was impacted, however, by the pandemic, so due to school shutdowns this team pivoted and made design changes to make the intervention available nationwide over the internet, while preserving IRB protocols.

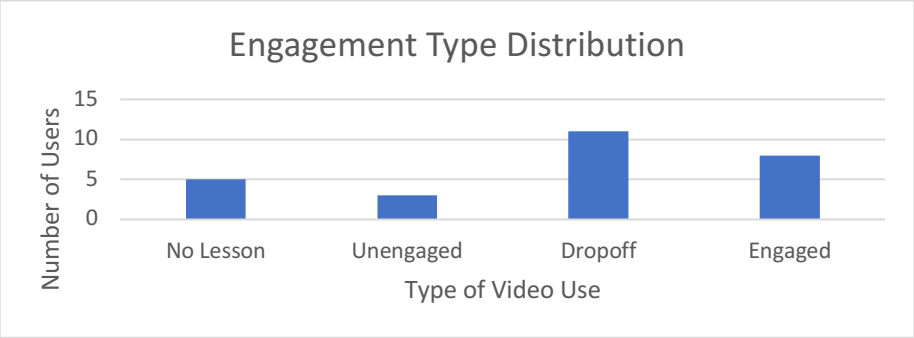
Proximal outcomes of the eBRAVO intervention included assessments embedded within the eBRAVO system, such as quick quizzes and writing prompts targeting deep comprehension of the ecology curriculum (Behrens, DiCerbo & Foltz, 2019). Researchers assessed student education outcomes a pre/post text recall task designed to assess their ability to extract/learn information from any novel informational text on a subject that was unfamiliar. In addition, click streams and other student behaviors using the eBRAVO intervention were collected to aid in usage and usability analyses. (e.g., Quigley, Caccamise, Weatherley, & Foltz, 2020).

Sample results

As an example of the results from the evaluation of eBRAVO, click stream data was used to sort out students demonstrating different levels of effort. In a pairwise t-test analysis of students' comprehension scores within eBRAVO, a significant difference was found when comparing Engaged & Dropoff with "No Lesson" and

Unengaged groups (p = 0.0405). This indicated that some exposure to the lessons had some positive effect (see Figure 1.)

Figure 1.



This project resulted in eBRAVO v1, a fully functional, interactive intervention that is open source and ready for use by educators, parents, and researchers. Key features of the intervention include the following: eBRAVO is an online reader that jointly provides standards-based middle school Ecology content AND a reading comprehension assessment, tutor, and knowledge-building assistant on a personalized instructional basis. Internal skilled reading components addresses local cohesion, global cohesion, inference, and knowledge integration. Each just-in-time lesson includes brief videos with comprehension and metacognitive strategies modeled for students. Content chapters combine to build a body of knowledge about ecology similar to any science text, but in eBRAVO there are activities for students to practice comprehension strategies on an individualized, as-needed basis, using this adaptive technology.

Outcomes and lessons learned

The main features of the intervention and findings of the project's pilot study are as follows:

- We developed a unique approach to comprehension instruction with an open access online instruction aid assisting students while they build knowledge from text using a personalized, interactive approach.
- We discovered and addressed a need to incorporate periodic whole-classroom activities to allow teachers to more fully assess what knowledge building had occurred and to adjust the curriculum to catch up the slower learners.
- We created an online concept mapping activity designed to help students process the information in the eBRAVO texts to promote deeper learning and knowledge building.
- We developed and evaluated NLP and Machine Learning based methods that allowed automatic scoring of the concept maps to measure the student knowledge representations and methods for assessing student summaries to measure the amount of information gained from the reading activities.
- We developed and evaluated machine learning algorithms to assess individual comprehension skills on the fly as students needed to use them to build knowledge. If they demonstrated a lack of needed skills in a given instance, they were directed to a short interactive tutorial about the deficient skill.
- eBRAVO was presented in the Ed Games Expo, 2021, a national showcase hosted by the Department of Education to demonstrate the latest in educational games, tutors, and electronic teaching tools whose development IES has supported.
- **Additional online resources and information:** Youtube video for Ed Games Expo, 2021. https://www.youtube.com/xxxxxxxxxxxxxxX (skip the ad that occurs before the video)
    - BRAVO website (xxxxxxxxxxx)

Conclusion

The research team adapted eBRAVO from the existing paper-and-pencil **B**oulder **R**e**A**ding inter**V**enti**O**n (BRAVO). By adapting BRAVO for electronic delivery, the researchers worked to make the curriculum framework and content more flexible while making delivery more accessible and workable for classroom teachers and their students. eBRAVO offers an automated, online curriculum that includes baseline assessments of students' comprehension skills, as well as formative and summative assessments throughout the curriculum. eBRAVO simultaneously combines comprehension instruction with content instruction in an as-needed basis to enhance learning and knowledge building as a student reads a challenging text for that purpose. We developed a

robust, commercial grade version and included features that enables automated scoring of concept maps and open-ended writing activities. Automating scoring of such learning activities allows teachers to incorporate these critical concept formation components that are normally not scalable in secondary classrooms. With broader exposure, this tool that teaches critical knowledge building skills used by skilled readers can be made available to anyone via the internet, dramatically increasing inclusion and potential equity for students nationwide who don't receive this sort of instruction through their school districts.

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What time and what place? Technologies' diverging role in online schooling across socioeconomical contexts during covid-19

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Abstract: The COVID-19 pandemic destabilized the prevailing grammar of schooling and forced schools to rely on digital technologies to create new routines and practices. This offers a unique opportunity to examine the interplay between digital technologies and the temporospatial features of schooling, and how these relations were mediated via contextual features. Based on semi-structured interviews with principals and teachers in Muslim-Palestinian and secular-Jewish schools in Jerusalem, this paper qualitatively analyzes the main technological tools used by educators: instant messaging (WhatsApp), video-conferencing (Zoom) and school-wide platforms (Google Classroom). Our findings stress how technological affordances varied according to socioeconomic status and diverging perceptions of schooling. Specifically, we found that lower-SES Palestinian schools, who faced more acute challenges, utilized digital technologies to restabilize the grammar of schooling in order to monitor and support students' basic needs, whereas average-SES Jewish schools focused on facilitating informal interactions that catered to students' emotional wellbeing.

Introduction

Digital technologies are often presented as nurturing "anytime-anyplace" learning – open, flexible, individualized and student-led learning – that would allow overcoming the staleness of conventional schooling (Selwyn, 2013). In practice, research shows that novel technologies have not had a substantial impact on the overall structure of schooling and have been mostly integrated within the prevailing "grammar of schooling": "the regular structures and rules that organize the work of instruction… standardized organizational practices in dividing time and space, classifying students and allocating them to classrooms, and splintering knowledge into 'subjects.'" (Tyack & Tobin, 1994; p. 454). However, during the COVID-19 pandemic, technology-mediated remote schooling (TMRS) had become compulsory and widespread almost overnight. Educators had to quickly negotiate how to rely on online learning tools to create a fully-fledged alternative to physical schooling. Therefore, digital technologies were now used to mediate the basic temporospatial facets of the grammar of schooling, thus potentially reshaping it. While it is still early to appreciate the long-term implications of the transition to TMRS, it is clear that it temporarily destabilized the prevailing grammar of schooling, requiring schools to prioritize and choose among competing goals and structures (Reich et al., 2020). The need to pursue such drastic changes therefore offers a rare opportunity to explore how digital technologies inform reconstructions of the "grammar of schooling".

Inquiries into the use of technologies in education often rely on the implicit assumption that technological devices have fixed affordances and will reproduce the same modes of conduct within and across educational settings, while ignoring the social and political features of technology-use (Davis, 2020). However, technological affordances are not inherent to tools nor are they static, but rather depend on users' needs, aims and associated meanings (Dishon, 2021). This is particularly pronounced during TMRS as it relies on having the necessary access to computers and the internet, a home environment conducive for learning, and caretakers who can support students (Williamson et al., 2020). Accordingly, this qualitative study examines the experiences, choices and perceptions of principals and teachers in socioeconomically diverse Muslim-Palestinian and secular-Jewish primary schools. We set out to examine the main technologies educators relied on during TMRS, how these different technologies shaped the temporospatial features of TMRS, and how they were mediated through socioeconomic and cultural characteristics. Our aim is not to offer a representative description of schools' use of digital technologies, but rather to offer theoretical contributions concerning how educational technologies reorganize key aspects of schooling, and how this function is mediated via contextual features.

Methods

The study was conducted in three Muslim-Palestinian and three Jewish-Secular primary schools in the Jerusalem school district. Studying Muslim-Palestinian and Secular-Jewish schools allows examining how the transition to TMRS was mediated by socioeconomic status and cultural and political characteristics, due to glaring disparities

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between the two populations in terms of access to physical infrastructure and education (Shtern & Rokem, 2021). All three Palestinian schools had students from very low SES status, whereas Jewish schools were characterized by an average SES population, with pockets of very lower SES students (e.g., refugees.). Schools were chosen based on a purposive sampling, which strived to offer socioeconomic and cultural variation within each of the populations.

Collecting and analyzing data

We conducted semi-structured in-depth interviews with school principals, head of ICT departments (if the school had one), and 2-3 teachers. The interviews were conducted October-December 2020 via the Zoom platform and were recorded and transcribed verbatim. Interviews focused on the transition to TMRS: the challenges and dilemmas schools faced, their responses, and participants' explanations for their choices. Thematic analysis was used to identify the main themes emerging from our data (Braun & Clarke, 2006). Each interview was read and analyzed by at least three team members, and discussed by the whole team, which allowed multiple perspectives to emerge (Cornish et al., 2014). While our analyses explored various aspects of schooling, in this paper we focus solely on those themes that had to with the temporospatial features of TMRS.

Findings

We identified three digital technologies that were central to TMRS: instant messaging (WhatsApp); video conferencing (predominantly Zoom); and schooling-platforms (Google Classroom). These technologies were not only the most prevalent, but they emerged as a common aspect of the organization of TMRS: teachers and principals attributed great significance to these technologies, explicating pros and cons for each tool, and further discussing their ramifications on the practices of schooling. While educators also mentioned the use of educational apps tailored for specific content knowledge and other generic tools used in classes (e.g., Padlet), these were mentioned far less frequently, and were mostly brought up in the more limited context of teaching and learning. Thus, beyond the more detailed uses of different technologies, it is vital to note the dominance of *commercial tools*. In what follows, we describe the key themes that emerged for each technology in terms of the temporospatial structures of schooling (table 2). In our discussion, we highlight key variations in technology use across schools.

Technology	Themes
Instant messaging	*Porous*: Rapid simultaneous interactions at different levels
	All-day schooling: unclear temporal limits to the school day
Video conferencing	*Familiar class routines*: approximating the temporal structure of schooling
	Breaking spatial barriers: blurring differences between the school and the home
Platforms	*Comprehensive school structure*: complex organization of children and classes

WhatsApp

WhatsApp is the most common messaging app in Israel, and a central tool for sharing information in schools pre-pandemic, mostly through class-wide chat groups with parents or students. As such, WhatsApp gained a primary role early in TMRS, serving as a means of communicating decisions regarding school operations during lockdown, and sharing educational material and tasks. Two key temporospatial themes emerged from participants' interviews: WhatsApp's *porous* nature, and its role in the establishment of *all-day schooling*.

The main temporospatial characteristic of WhatsApp was its *porous* nature. Due to its use to facilitate various formal and informal communicational contexts, it blurred and undermined demarcations within schools and between schooling and individuals' personal lives. Beyond personal use, WhatsApp was used to disseminate information to teachers, for teacher communication with parents, and as a tool for sharing and receiving educational materials, often for different classrooms. This blurring was not only temporal in nature. In more affluent populations, new personal connections were made between teachers and older students who had their own phones. While the class WhatsApp group was used mainly for sharing information, private chats were conducted in a new, amicable manner. This had rendered WhatsApp a liminal technological space, in which the division between personal and professional life was blurred. This also has to do with the blurring of the temporal structure of schooling. As teachers and students were often chatting during what is normally considered off-hours, the tone and content also geared towards informality.

The second theme centers on the blurring of the temporal distinction between school and home, described by interviewees as *all day schooling*. Each student could access materials on WhatsApp and react at various times throughout the day, which altered the temporal rhythm of schooling: instead of the uniform routine, students and families interacted with teachers at different paces and at different times. Moreover, as teachers often had to

function as "tech-support' for children and families, they felt they had to be "on-call" way past what was previously expected. Consequently, teachers reported very long work hours during TMRS, many of those spent on WhatsApp. As WhatsApp blurred the temporal boundaries on communication, teachers noted that its centrality led to a norm of *all-day schooling*, which was described as leading to a sense of burnout.

Zoom and video-conferencing apps

Shortly after school closings, video-conferencing applications (predominantly Zoom) were being introduced as core aspects of TMRS. While some schools integrated Zoom very quickly into their daily routine, others encountered difficulties stemming from scarcity of end-devices, unstable network connections, and poor staff and parents' technological literacy. In lower SES and Palestinian schools, families had to allocate their technological devices between children at specific times. In some cases, this led schools to organize different Zoom times for different age groups as to prevent overlaps within families. Two key temporospatial themes emerged with respect to the centrality of Zoom: *familiar class routines*, and *breaking spatial barriers*.

The strongest impact Zoom had on remote schooling was that it reintroduced *familiar class routines*: fixed timetables in which Zoom sessions were allocated according to disciplines. These familiar routines were also apparent in terms of the dynamics of each lesson: Zoom was perceived as a teacher-centered virtual space. Building on such capacities, it was often depicted as online frontal teaching, with slideshows serving the teacher as whiteboard. According to many teachers, the Zoom class schedule reinstated structure in students' lives and calmed their worried parents. At the same time, Zoom had brought back some familiar challenges of appropriate classroom conduct. In several schools, rules of participation and conduct were restated – cameras had to stay on, no eating was allowed during class, school uniform became mandatory and so on.

Though Zoom reintroduced familiar temporal routines, it concurrently *broke spatial barriers,* changing interaction patterns between teachers and students. First, due to the virtual presence in each other's home, Zoom was perceived as allowing a better understanding of students' experiences and emotional states, compared to a-synchronous tools. In higher-SES schools, Zoom was explicitly used for creating emotional affinity, ranging from shared breakfasts to more elaborate cases of joint cooking classes. Zoom created a new situation of blurred boundaries between private familial life, and professional educational life. In lower-SES schools catering for families living in dire situations, teachers reported that Zoom enabled supervision of familial life and the wellbeing of students, thus serving schools' pastoral role in the community. Second, the breaching of personal space was at times a challenge. In more religious Palestinian schools, participants noted issues of privacy due to the exposure of religious Muslim women in their home. In higher-SES Jewish schools, Zoom opened the classroom to the scrutinizing gaze of parents. Parents had interrupted teachers during lessons, asking questions, requesting attention to their children, and even correcting the teacher's grammar.

Schooling Platforms

School-wide platforms (e.g., Google Classroom) offer a panel of tools incorporated into tailored profiles both at class and student level. These platforms were described as requiring the greatest effort: creating dedicated email accounts, opening in-platform profiles for all students and staff, and teaching teachers and students how to operate them. Consequently, some schools did not attempt to integrate such platforms: one Palestinian school that did not have the required infrastructure, and two higher-SES Jewish schools, where principals explained that this would require a level of effort (from teachers and families) they thought was unrealistic during the pandemic.

School-wide platforms offered a hybrid of both task-centered and teacher-centered learning, organizing links to tasks, materials, and live video lessons. In this respect, they provide a digital representation of the *comprehensive school structure*: students can navigate in and out of lessons, teachers can coordinate Zoom teaching hours between classes, and management can consider which grades get which sessions at what time. Thus, the platform had served to create a coherent organizational structure. The personalized aspect of such platforms – connecting each student to a personal profile – allowed principals, teachers, and parents to keep track of students' progress. Hence, in terms of the temporospatial organization of schooling, platforms add another layer in that they enhance the summative and quantifiable tracking of students' and teachers' actions within the school, in ways more elaborate than were used before.

Discussion

The exodus to TMRS in light of the COVID-19 pandemic serves as a unique opportunity to examine the potential interplay between digital technologies and the grammar of schooling. Whereas above we focused on shared themes that emerged across schools, we now focus on how technology-use was mediated through contextual factors. Specifically, we examine how the temporospatial organization of schooling facilitated by the various technologies along two main issues: inequalities in access, and diverging perceptions of schooling.

Contrary to the adulation of the "anytime-anyplace" capacities of digital technologies, participants discussed to challenges characteristic of such modes of learning. First, schools serving minoritized populations were limited to relying on digital technologies "at very specific locations, in very specific times", i.e., when students have electricity, available end-devices and a stable network connection. Thus, in Palestinian schools, who faced both challenges in terms of access and organizational capacities (e.g., none had a designated ICT department), educators asserted that TMRS required closely monitoring and supporting students and families. This led lower-SES and Palestinian schools to adopt a more structured approach to schooling. This could explain the somewhat surprising finding that Palestinian schools were much faster to integrate school-wide platforms, although they were facing much more dire circumstances to begin with. Principals explained that without a structured organization of TMRS it would be too challenging for them to keep track of students' situation and offer the needed support. Second, across all schools, anyplace-anytime learning (mostly via WhatsApp) was perceived not as an opportunity, but rather as a burden. Teachers argued that all-day availability led to a sense of burnout, and highlighted the social nature of schooling, which required gathering teachers and students in a shared synchronous space. Accordingly, better-resourced schools opted for structured synchronous lessons via Zoom.

Besides issues of access, diverging definitions of the aims of remote schooling also shaped the functions of technological tools. Notably, the relatively higher-SES Jewish schools focused less on academics and social supervision, and more on how digital technologies allow establishing informal modes of interaction that cater to students' social-emotional needs (personal interactions, "extra-curricular" activities), which were deemed more urgent in light of the turbulences of the pandemic. These differences were reflected in diverging use of WhatsApp, but were most apparent in the perception of Zoom's role. Palestinian interviewees, that stressed the academic responsibilities of school to its struggling population, portrayed Zoom as the digital extrapolation of frontal teaching, intended to maintain academic progress. In contrast, Jewish interviewees highlighted how Zoom was used to facilitate emotional bonds. These differences might serve an explanation for why lower SES schools managed to introduce school-wide platforms in spite of the effort it required, while higher SES schools did not – such platforms were less relevant to their focus on the informal and intimate modes of teacher-student interaction.

Conclusion

In summary, our analysis revealed that schools mainly relied on free commercial technologies as the pillars of TMRS (Williamson et al., 2020): WhatsApp (instant messaging), Zoom (video conferencing), and Google Classroom (school-wide platforms). These played a different role in reshaping the temporospatial grammar of schooling: WhatsApp facilitated a flexible and porous school structure, where schooling was enmeshed with other aspects of teachers' lives. Zoom, in contrast, was mainly integrated into the familiar grammar of schooling (Selwyn, 2013). Yet, its blurring of the spatial separation of home and school (a separation often described as a key drawback of conventional schooling), was interpreted very differently according to context. Palestinian interviewees described this as an impediment to their responsibility towards families in dire need, while Jewish interviewees also depicted this as an opportunity to focus more on social-emotional aspects. Finally, schoolwide platforms, the only tools specifically tailored to education, created a virtual version of the grammar of schooling, which facilitated increased centralized control of learning and the collection and analysis of student data.

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Technocentrism in Visitors' Views of Computing and Computing Education in Informal Spaces

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Abstract: In this paper, we investigate how technocentric discourse shapes interactions between visitors, facilitators, and a computational science exhibit in a Canadian science museum. Technocentrism can lead both educators and learners to centre the production of technical artifacts (e.g., code, simulations) or the hardware and software of a learning environment in ways that ignore the social, cultural, and political aspects of learning. Drawing on video-recorded interactions of visitors with a computational science exhibit, we highlight the emergence of technocentric frames of both code/coding and computing education, and how they may impact visitor engagement (or non-engagement) with the exhibit and reify hegemonic notions of computing . Rather than letting computational learning environments "speak for themselves," explicit conversations about what computing is or should be are necessary to counteract technocentrism in computing education.

Introduction and purpose

Technocentrism was defined by Papert (1987) as the fallacy of referring answers to all questions about technology to the technology itself, rather than the social, cultural, and political supports that shape the use and meaningfulness of that technology. The pragmatic implications of technocentrism are of direct concern to us in the realm of computing education, given that technocentric discourses and pedagogies may hide the complexity of learning and teaching experiences that extend far beyond the computer (Sengupta et al., 2021) and may even further marginalize students who have been historically oppressed (Margolis et al., 2017; Vossoughi et al., 2016). Given this context, our work arises from the concern that the nature and role of technocentric discourse in computing education, especially in informal spaces, remains under-investigated. In this article, we draw from empirical data collected at a computational science exhibit in a Canadian science museum to highlight the ways in which technocentrism can impact visitor perceptions of computing education environments – even (or especially) those which purport to challenge technocentrism in their design.

Background: Technocentrism and informal computing education

Our work arises from a concern that despite attention to designing learner-centered environments and pedagogies, technocentric discourses and practices reduce complex educational challenges to a matter "of buying into the right technology and creating structures that standardize and routinize [its] use" (Burch & Miglani, 2018; p. 610). We view technocentrism as an ideological position (Philip & Gupta, 2020) that also shapes epistemological, axiological, and methodological approaches in computing education research. Ideologically, technocentrism positions computing education in a way that centers the production of technical artifacts (e.g., computer code, models, simulations, etc.) over the complexity of human experiences (Sengupta et al., 2021). Technocentric views have also been shown to be instrumental in shaping post-secondary students' perspectives of what should count as "real engineering" (Niles et al., 2020), potentially leading them to ignore the value of innovative learning experiences. Methodologically, this restricts research on the design of new technologies or environments to questions of efficacy of design, rather than attempting to understand the complexity of the experiences of learning and teaching (Sengupta et al., 2021). Axiologically, technocentric approaches can lead us to position historically marginalized learners using deficit lenses (Vossoughi et al., 2016; Kayumova & Sengupta, 2022). At the same time, given the difficulty of talking about a specific form of technology without referring to the technology itself (Sengupta et al., 2021), as well as a vast body of research in computing education and popular media representations of coding that promote the "charisma" of the computer over social interactions essential for computing (Ames, 2019) we believe that technocentric discourses may be shaping learning experiences of computing in both formal and informal spaces. This paper offers a preliminary exploration of this phenomenon in the context of informal computing education.

Research design

Setting and goal

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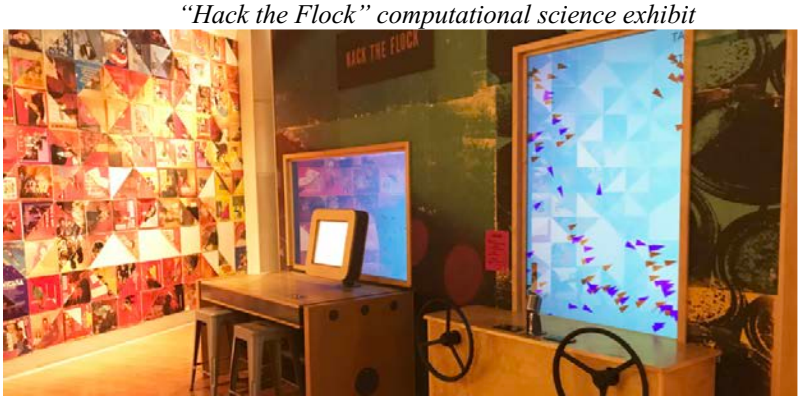
Hack the Flock, pictured in Figure 1, is a public computing environment (Sengupta & Shanahan, 2017) located in the Open Studio area of a science museum located in a Western Canadian city. Public computing environments are "open-ended, public learning environments, in which visitors can directly access, modify and create complex and authentic scientific work through interacting with open source computing platforms" (Sengupta & Shanahan, 2017, p. 1124). Our goal in this study is to explore technocentric discourses may be shaping visitors' interactions with Hack the Flock, especially given that the design of the exhibit explicitly seeks to decenter the technology (here understood as the programming language, the simulation code and the simulation display) in ways that may create tension with technocentric expectations (Sengupta et al., 2021) by supporting visitors through facilitation to center their own voices.

The simulation used in this exhibit is based on Reynolds' (1987) flocking algorithm in which Boids (bird-droids) flock around the screen according to three parameters: alignment, cohesion, and separation. Visitors can use the computer terminal to directly change those parameters in the code as well as, for example, change their colour, shape, speed, and size, and even add images of bees and monkeys onto the screen. The computer code is written in P5, a professional text-based programming language which is based on Javascript and Processing. The exhibit is intended to include facilitation, either live (a human facilitator at the exhibit) or in the form of comments or instructions embedded in the code itself.

Figure 1
"Hack the Flock" computational science exhibit



Data collection and analysis

We video and audio recorded visitor interactions at the exhibit, which captured discourse, physical movement, and changes made to the code. A total of 86 interactions were recorded, ranging in length from 50 seconds to 71 minutes (median length of 15:06). Each of these interactions included between 1-4 visitors of various ages (almost always including at least one child), one facilitator, and occasionally, a researcher (to answer questions as needed). We wish to be explicit that these videos of visitor/facilitator interactions were conducted in a naturalistic manner. Neither the facilitator nor the researcher explicitly asked the visitor(s) for their views on computing or the exhibit. However, during the interactions, some visitors made comments about computing education or the purpose of the exhibit, and a few specifically struck up conversations with the facilitator and/or the researcher on these topics. The first author watched all 86 interactions and flagged time periods in which visitors made comments about how the exhibit promoted, reified, or challenged their personal views of computing/computing education. This resulted in very few segments being flagged – 11 conversation segments across only 6 videos, possibly due to the young age of visitors (leading facilitators to focus on procedural aspects of working with the exhibit), and the fact that facilitators did not specifically ask visitors about their thoughts of computing/computing education. These segments were coded inductively using thematic analysis (Miles & Huberman, 1994) and constant comparison (Glaser, 1965). We compared the emergent codes against known perceptions and approaches in computing/computing education literature in terms of technocentrism (Papert, 1987; Sengupta et al., 2021). Our analysis focused on how visitors positioned code (i.e., assumptions about "real" code) coding (i.e., what coding in professional contexts looks like), and computing education (i.e., what computing education looks like).

Findings

Technocentric frames of code and coding: "Real" code must be complex

The use of a text-based programming language at Hack the Flock was a deliberate choice to break down growing divides between professional computing (which typically uses text-based languages) and computing education for children in the form of block-based challenges. While our exhibit uses the original flocking code from Reynolds (1987), it is split into different files, one of which includes easy-to-change variables and functions as well as extended commenting that can act as instructions. This design choice resulted in two men questioning whether the code with which they were interacting was "actual code":

> Visitor 1: What I'd really like to know is, [is] this the actual code behind something?
> Facilitator: Well [..] I mean, I guess this is the pretty version.
> Visitor 1: - simplified. Anyways. This is the pretty version.
> Facilitator: A version with instructions.
> Visitor 2: [sarcastically] What are you talking about, I am now officially a coder by coding this.
> Facilitator: Yes. To be honest, I am not a coding expert by any means. I know the extent of how to do this…
> [the facilitator and men spend several minutes working at the exhibit]
> Facilitator: Thanks for experimenting. You learned how to code. [laughs]
> Visitor 2: [sarcastically] We're basically coders now.

The visitor's sarcastic comment showed that since this code had been reorganized (simplified) and included instructions, it was not the same as real coding and therefore he implied that someone working with this code would not be a "real" coder. Despite the fact that the code was originally authored by computational scientists using a professionally used, text-based programming language, even something as minor as the code's organization and presentation diminished its authentic value. This is a technocentric view that emphasizes the technical work of *writing* code, ignoring the expertise that comes with *reading* and *commenting* code as well. In particular, commenting code is a socially valued practice in the discipline of computing, and has been shown to be an effective pedagogical practice for teaching and learning coding (Vieira et al., 2019), so the fact that the inclusion of comments or "instructions" is seen to diminish the authenticity of the computing education environment is in conflict with best practices from both computing education and the computing profession.

Technocentric frames of computing education: Erasure of human-human interaction

Western popular media has also promoted the idea of computing as an individual, anti-social endeavour (Lagesen, 2008). Along these lines, a woman remarked to the facilitator that while she thought the exhibit was a cool idea, there was no way that children under the age of 10 would spend more than three minutes at the exhibit (an assertion that our research has proved false). When the facilitator challenged that by pointing out that children spend more time when she is at the exhibit to help them understand it, the young woman argued:

> Young woman: But that's not the point of an exhibit right? Like, it's like human-exhibit interaction. I mean, human-human interaction is great. I honestly would've been like, "Oh cool," tried to change something, done nothing, walked away. So I like, appreciated this. But at the same time, I think that if it was a bit more clear...

While the visitor appreciated the help that she received from the facilitator and acknowledged that her interaction at the exhibit would have been much shorter without it, her words showcase a belief that human-exhibit interaction should be prioritized over human-human interaction at the exhibit. Her argument relies on a technocentric account of computing, in which the exhibit should "stand on its own" and the technology (the code, the hardware, etc.) is what determines whether or not a visitor can learn computing. The young woman in this section is advocating for a deliberate removal of "people" from the evaluation of an exhibit, that the need for a human facilitator is in fact a design flaw to be fixed. In fact, Hack the Flock is unable to "stand on its own" in the way that the young woman suggests. Even if visitors are simply able to sit down and start working at the exhibit, it is inherently tied to people through the values and visions of its designers, the history and perceptions of computing that are held on individual and societal levels, and of course, in the actions and words of the facilitators who enliven it. Without facilitators to challenge exclusionary perceptions of computing (i.e., it is only for "tech-savvy" white men) by explicitly inviting all learners to engage with the exhibit ("try changing a number!") visitors who would otherwise have novel, playful, and exploratory experiences with computing may walk by the exhibit without even trying it – perpetuating issues of equity in computing education.

Discussion and Conclusion

While several facets of technocentrism are evident in the visitors' interactions, perhaps most notable is the notion that facilitation is not the "point" of an exhibit, as noted by several visitors in our study. This stands in direct contrast with our observations as well as research on the role that facilitators play in promoting enjoyable learning experiences for visitors in science museums and other informal learning spaces (Dawson, 2019; Roque, 2016; Tran, 2007). For Hack the Flock specifically, we believe that the human-human interaction of facilitation is a key factor deepening visitor engagement (median of over 15 minutes), evidenced by the fact that without facilitation, visitors typically spent less than a couple of minutes at the exhibit, or even walked by it altogether.

Our wider concern is that technocentric notions of visitors may limit their participation in computational work. It is possible that visitor comments did not entirely stem from technocentric viewpoints and may have been influenced by other factors, such as uncertainty in the tone of a facilitator (in Finding 1), or their direct experiences working with particular segments of this exhibit's code and not others. But from an ideological perspective (Philip & Gupta, 2020), their implicit assumptions of what "real coding" looks like were also clearly shaping their experiences, which in turn has implications for the power relationships between visitors, facilitators and computing. Future work should involve more in-depth discussions and interviews with visitors around what computing has been, how it is currently viewed, and what it could or should be. These conversations should explicitly discuss design and pedagogical decisions including choice of programming language, the role of facilitators, and the expected types of interaction, in order to address hegemonic notions of computing as anti-social, necessarily difficult, and only appropriate for privileged learners.

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Iterative, Reflexive, and Generative Processes of Participatory Design of Arts: Interrogating Racial Ideologies in Design

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Abstract: Set in the context of our study that used digital illustrated stories to evoke the power of artistic renderings for public communication of research, we investigate underlying racial ideologies of the artist/researcher in the illustrations. We transformed our ethnographic findings around subjugated embodied disciplinary knowledge into artistic renderings to initiate discussion with teacher candidate participants on equity in school mathematics teaching. In the process of participatory design of arts, the artist/researcher engaged in multiple conversations with the teacher candidates through iterative redesigns centered on these discussions. Based on video data, interview data and the artist/researcher's reflexive accounts, we examined whether and how the collaboration between the artist/researcher and teacher candidate participants could open spaces for ideological expansion. Our findings demonstrate that iterative cycles of participatory redesign of arts, focusing on racial ideologies, can be generative toward ideological expansions toward equity.

Background

Design is never neutral. From benches in the park to illustrations in picture books, design can discriminate (Benjamin, 2019). Picture book illustrations that children encounter in the early years of their lives can carry problematic racial ideologies such as color blindness, white gaze, and objectifying racialized people through representation (Rogers & Christian, 2007). These ideologies are not static or rigid; rather they are "sense making that stabilizes, challenges, and/or transforms the distribution of material and symbolic resources in society" (Philip et al., 2018, p. 184). From this perspective, ideologies can dynamically change in the course of interactions.

Our study used digital illustrated stories to evoke the power of artistic renderings for public communication – in the context of this study, public communication of critical views on embodiment in mathematics education with teacher candidates. In the normative disciplinary spaces of mathematics, bodies marginalized due to gender, race, and other dimensions of histories of oppression can be subjugated (Takeuchi, 2018). The design of the digital illustrated story was carried out in iterative cycles, by attending to lived experiences shared by the teacher candidate participants, being mediated by the illustration. In this paper, we focus on the negotiation of ideologies enacted in the process of design. Our study was participatory design wherein we critically attended to the power, historicity, and relational dynamics, as provoked by Bang and Vossoughi (2016). Inspired by socially engaged arts (Dewhurst, 2010), we tried to design a visual artifact to open up the conversations on equity in school teaching and learning by depicting lived bodily experiences of schooling (Takeuchi & Dadkhahfard, 2019) previously shared by migrant children. Dimensions of race, power, and politics should be fully accounted for, in the process of participatory design (Vakil et al., 2016). By attending to ideologies that manifest in the process of design, we question the neutrality of designed artifacts and unveil the politics in the design process.

Methodology

Our study was carried out in three interrelated phases. In Phase I, we identified the themes around disciplinary norms in mathematics classrooms, based on our ethnographic findings. The main theme we decided to illustrate involved racialized bodily experiences of migrant children that were censored in the context of institutionalized, in-school mathematics learning (as depicted in textual form by Takeuchi, 2018). In Phase II, in order to challenge such disciplinary norms of the mathematics classrooms, Author 1 (Dadkhahfard) used her graphic design skills to digitally illustrate ethnographic findings described in our earlier works. We decided to make the illustrated story book "wordless" to communicate with audiences from diverse linguistic backgrounds and diverse age groups and the book was repeatedly re-designed. We then used the designed illustrated story in Phase III in the context of teacher education. Interrogating racial ideologies in illustrations was done through iterative cycles of design within Phase II and III. We repeatedly revisited initial illustrations by focusing on racial ideologies (Philip et al., 2018) that are inscribed in multiple versions of illustrations. Reflexivity in the process of participatory design research should be critical. Therefore, we attended to ideologies perpetuating intersectional histories of oppression while also reflecting on "how we see, and how we move differently based on new forms of perception and understanding"

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(Bang & Vossoughi, 2016, p. 181). Arts can invite the emergence of reflectivity, but this process could be experienced with emotions including discomfort as designers/artists deeply examine their taken-for-granted perspectives, and ideologies (Skukauskaite et al., 2021). We treat this discomfort experienced by the designer in the iterative process of co-creating arts with the participants as potential resources for ideological expansion (Philip et al., 2018). In our study, we see this reflexive process as potential spaces for value sharing and challenging power hierarchies between artist/researcher and the participants.

We used the illustrated story designed in Phase II in a teacher education course and facilitated conversations about mathematics, equity, and power. The study in Phase III on which this paper is based was conducted in a teacher education program located in a Canadian city and each teacher candidate was specialized in early childhood and elementary school education. A total of 22 teacher candidates participated in the study and five were racialized teacher candidates. Written responses were collected during in-class activity and follow-up interviews were conducted with five teacher candidates. Interviews elicited how teacher candidates interpreted the illustrated story and whether and how they connected or did not connect with the story. They were also asked to discuss mathematics pedagogy depicted in the illustrated story in relation to their future teaching. During the interview, teacher candidates also draw images of how they would continue the story. Each interview was audio and video-recorded. Video was mostly used to capture gestures and drawings and did not capture the faces of the teacher candidate participants to ensure their privacy. After each interview, we wrote detailed field notes and interview data was fully transcribed. After Phase III, Author 1 engaged in the redesign of illustrations iteratively, based on the conversations she had during the interviews. For the purpose of this paper, we use data from Phase II and III and versions of digital illustrated stories designed by Author 1. We ask the following research questions: 1) How did racial ideologies change in the iterative process of participatory art design? 2) How did the collaboration with the participants help facilitate this change? In our findings, where appropriate, we use the first-person account of an artist/designer to address these questions, along with thematic analysis from video and interview data. Analysis was collaboratively done between the two authors to unveil and reflect on potential underlying racial ideologies perpetuated through illustrations.

Findings

Initial racial ideologies

In the initial design, the illustrated story represented the experience of marginalization and differences in slightly abstract ways and did not explicitly depict race by assigning skin colors to migrant students. To show race implicitly and distinguish between migrant students and their peers, instead of representing explicit racial aspects of the characters by skin colors, I (Dadkhahfard, the artist/researcher) assigned two color themes (blue and pink) to migrant students, their parents, and their homes (Figure 1; Panel 1 & 2). I then used black and white for other students to create a clear contrast (Figure 1; Panel 3). By making characters somewhat abstract for their countries of origin or racial backgrounds, I thought that audiences could have more space to come up with diverse interpretations of the difference and marginalization. This might allow them to construct stories related to their own experiences of mathematics learning, inspired by the illustrated story. By making characters without specificities of their countries of origin or racial backgrounds, I also tried to avoid reproducing stereotypes. As an illustrator, I struggled to represent race in my design. Historically, stereotypical, and simplified images of racialized people have been perpetuated in illustrations and picture books (Edmonds, 1986). In this struggle, I chose the color that was "neutral" to me. However, in this process, I perpetuated racial ideologies of color blindness and white gaze in illustrations (as pointed out by Rogers & Christian, 2007).

Figure 1

Abstract Depiction of Race in the First Version of the Illustrated Story Book

Interactions with teacher candidates

We used the illustrated story book in Phase III to facilitate conversations about mathematics teaching, equity, and power with the teacher candidate participants. Some of the racialized teacher candidates talked implicitly about the role of race in mathematics learning and pointed out a problem of the lack of representation on race in the initial illustration. For instance, Betty said "If there's more, like color involved … Looking at it [pointing at the designed illustrated stories], I wouldn't have guessed that the two students were, like, Filipino. You can tell that they're different than the students." Similarly, Dana said, "Students that are reading this wouldn't understand 'Ooh, you're different than me because you're Black.'" In their conversations with me, racialized teacher candidates suggested that I as the designer should make race more explicit in the illustrations to bring forth discussions on equity in mathematics classrooms. They pointed out that the abstract color schemas highlighting migrant students' experiences were interpreted as indicators of differences, but not as representations of racial dynamics. The depiction of race in the form of visual art and its relationship to the evoking conversation around race has received relatively little attention (Dewhurst, 2010). However, the conversations with teacher candidates suggest that explicit racial representation was essential for advancing the discussion on race and inequity in mathematics classrooms. After the conversations with teacher candidates and the deepening of our understanding around depictions of race, we, the Authors, started to engage in iterative inquiry of what it means to illustrate race and racialized experiences.

The redesign process

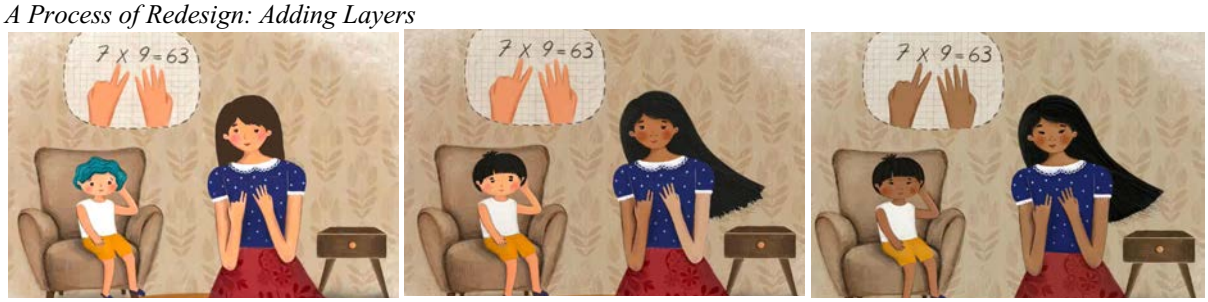
In the second cycle of designing the illustrated story, we started testing different racial representations in the illustrated story. After several back-and-forth attempts at modification, I engaged in watching videos of the participants who were depicted as protagonists in the illustrations with a focus on understanding more about the lived history of these people. I did not focus on skin colors of racialized migrant students but tried to add more complex layers of meaning-making that could depict these students' experiences in the mainstream mathematics classroom (e.g., representing the history of mathematics methods used at home more fully – Figure 2). In the modified illustrated story, I chose to assign color to the characters' skin in complex ways with multiple layers (See the process of adding layers in Figure 3) that were closer to their skin color. However, in this process, we were mindful of not reducing race to skin color. I came to the profound understanding that illustration of racialized experiences in institutional spaces of school should be at the core of the image. In the revision, I focused on racialized migrant children's experiences of being forced to erase and hide intergenerational mathematical knowledge passed on in home environments. I also tried to depict the experiences of subjugation and agency inscribed in racialized bodies.

Figure 2

Depiction of Race in the Modified Version of Illustrated Story Book

Figure 3

A Process of Redesign: Adding Layers



Other considerations for the design to depict racialized experiences are illustrating mothers of color teaching mathematics to their children. This is to counter the history of mathematics that has been constituted as a masculine discipline (Mendick, 2006) that mostly excluded women of color (Leyva, 2016). To counter this hegemonic norm, I described what mothers passed on mathematically to their children (also to be aligned with findings from Takeuchi's (2018) original ethnographic study that was depicted in illustrations).

Scholarly significance of the study

Our study focused on reflexive accounts of an artist/researcher to critically examine her taken-for-granted values, perspectives, and ideologies through her collaboration with participants. Interrogating racial ideology in design can possibly challenge discriminatory design (Benjamin, 2019). Our paper highlights that collaboration with the teacher candidate participants in the iterative process of design can challenge taken-for-granted values, perspectives, and ideologies manifested in the processes. In Phase II, we had to question the neutrality in ideology in our design-based research. Design-based research in the learning sciences were never neutral (Vakil et al., 2016); instead, it can either reinforce or challenge racial ideologies.

Our study depicts iterative, reflexive, and generative processes of designing and redesigning the illustrated story, in order to critically interrogate racial ideologies (Philip et al., 2018) in the process of design. Through ideological expansion afforded in the process of participatory design, we can also move towards designing *tertiary artifacts* that are alternative representations of the world to help us envision the possibilities that are not presently achieved (Wartofsky, 1979). Gutiérrez (2016) discusses the possibilities of designing tertiary artifacts with historical epistemology – the tertiary artifacts that help our "learning to see historically, to imagine new futures for people and their communities" (p. 190). Tertiary artifacts play a significant role in mediating the ways in which influential people like teachers envision the world in new ways. While the scope of this paper was limited to teacher candidates, our future research will depict how racialized parents and children engage in the iterative process of co-designing arts as a way of challenging normative ideologies manifested in mathematics classrooms. This can lead to an envisioning of a more equitable pedagogy in school and beyond.

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International Society of the Learning Sciences

Argumentation with Summary Tables in Geoscience Learning

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Abstract: In this study, we examine the interactions and discourse of a middle school classroom as they use a Summary Table to scaffold the generation of scientific arguments during the implementation of an online plate tectonics curriculum. Creating time and space for scientific discourse provided students with sense-making opportunities around complex science ideas to support their explanations of the phenomenon. The Summary Table scaffolded the development of increasingly sophisticated explanations by structuring students' observations to connect with the driving question of the unit. Specifically, the Summary Table supported small and whole group discussions positioning students to argue and partake in open critique of their claims and evidence in increasingly public ways as they develop sophisticated science explanations.

Introduction

The fundamental vision of Ambitious Science Teaching (AST) is to support students from all backgrounds in understanding core science ideas, participating in authentic science practices and problems, and developing students' ability to learn alone (Windschitl, Thompson, & Braaten, 2018). To achieve this vision, the AST framework incorporates four sets of teaching practices for teachers to invest in as they attempt to make pedagogical shifts in their teaching. One central set is designed for supporting students' evolving thinking, often grounded in public discourse events. Here, the AST framework introduces the Summary Table as a tool to support students' ongoing scientific sensemaking (Windschitl et al., 2018). Summary Tables provide students with a way to structure and organize their thoughts based on classroom discourse regarding an anchoring phenomenon (Windschitl et al., 2018). Students can engage in conversation where they compare ideas in reflective critiques to refine and build new science ideas as they work to complete the Summary Table.

We view this collective critique as a form of argumentation, a subset of discussion with a persuasive nature and necessity of reasonable critics as participants (Shemwell & Furtak, 2010). Students naturally engage in arguments in everyday life, but the AST framework scaffolds students' development of scientific arguments inclusive of talk moves around claims, evidence, rebuttals, and counterclaims (Windschitl et al., 2018). We argue that the framing of the Summary Table includes critical discourse of these talk components that can be instrumental in developing students' explanations and arguments of scientific phenomena. It is with these ideas in mind we ask: In what ways does the use of Summary Tables influence student argumentation?

Methodology

Context

Our study took place in a middle school classroom in the northeastern US, where veteran teacher, Keith (all names used are pseudonyms), taught 82 seventh grade (12- and 13-year-old) students across six classes. Keith was experienced in AST and argumentation, having had ongoing professional learning opportunities in both areas over the past decade through his local college. The summer prior to the study, he participated in a week-long professional learning workshop to support the use of a digital plate tectonics curriculum part of the Geological Models for Explorations Of the Dynamic Earth (GEODE) project. The workshop, designed and facilitated by the authors, centered the Summary Table as a tool for teachers and students to use in developing an explanation of the driving question, "What will Earth look like in 500 million years?" Keith used the Summary Tables in his classroom in iterative phases of small group and teacher-led whole-class discussion. The whole class discussions included negotiating students' ideas into an agreed-upon statement for the class Summary Table which students copied into their science notebooks.

Data and Analysis

Specifically, this study analyzes the classroom discourse associated with the use of a Summary Table during the implementation of GEODE. We captured audio and video recordings of whole-class interactions, audio recordings of small group table talk, video and screen capture of pairs of students using the curriculum, and artifacts produced

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by students, including their Summary Tables and summative scientific arguments (CERs) in their science notebooks throughout 13 90-minute class periods.

To understand how students' interaction with the Summary Table influenced the students' final explanation, we analyzed data from one class period ($N = 24$ students) in four phases. In the first phase, we created event maps (Kelly & Chen, 1999) of the curriculum's implementation to identify the sections of instruction in which the class discourse centered around their Summary Table, resulting in three 90-minute class periods for further analysis. In the second phase, we expanded the event maps; we transcribed discussions to create units of analysis for discrete discourse events in which students discussed a specific scientific idea related to the Summary Table task. We transcribed both whole class and small group talk derived from the conversations of three focus groups of four students who had consented to participate. In the third phase, using grounded theory (Charmaz, 2014), we identified salient themes of ideas that occurred during these discourse events, such as public argumentation and refinement of ideas. Finally, we traced the emergence of these ideas in the discourse through small and whole group talk, students' Summary Tables, and final arguments located within CER Journal entries.

Findings

In this section, we follow the narrative evolution of students working to develop explanations and arguments using the Summary Table. Students collectively refine an observation for the Summary Table, increasing in sophistication during each iteration. Next, the teacher uses talk moves to re-focuses a pair's idea which led to open critique and argumentation in small groups before being brought up during the whole-class discussion. The findings here focus on four students and their teacher, Keith, negotiating an explanation for why some mountains have volcanoes and others do not, one step in explaining the phenomenon of plate tectonics. By following the evolution of this idea through its use in the Summary Table and associated discourse, we see students' explanations increase in sophistication. The structure of the Summary Table document kept track of the different stages of ideas as the students progressed through different activities, instead of requiring them to memorize key observations and claims. We argue that multiple iterations of critique, aided by the structure and documentation of the Summary Table (Figure 1), support the development of students' later arguments.

In a previous class period, students had oscillated between small and whole group discussions to arrive at a class-wide claim of "Everywhere that a volcano forms, you will find earthquakes, but you can find earthquakes alone." Captured in the students' Summary Tables at the end of the lesson, this statement is built upon in the following discussions as part of the patterns and evidence that supports claims about plate boundaries. Here, we illustrate the further evolution of this idea through a case of one small group (Eden, Emily, Cal, and Anna) navigating the relationship between earthquakes and volcanoes through the Plate Tectonics curriculum.

During the Summary Table discussions, students' public thinking was subjected to critique and guidance from other actors in the classroom (peers and teachers) as they argued communal explanations. As the class accepted the observation between volcanoes and earthquakes into the Summary Table, Keith guided students to search for more observations to add to it, building on the relationship between active volcanoes and earthquakes. In their small groups, students split into dyads to explore and discuss. Anna and Eden began looking for connections between the three locations they had explored through the curricular tools (Andes Mountains, Himalayas, and Aleutian Islands), eventually noting that the volcanoes and earthquakes in the Andes are near water (Pacific Ocean) as seen with a data visualization tool. They called Keith over to their table to share the idea. He focused the pair on the types of plates near the Andes and stated there is an ocean plate and a land (continental) plate. Keith then asked about the types of plates near the Aleutians and Himalayas, to which the pair responded with "ocean and ocean" and "land and land" respectively. Although scientific vocabulary around plate tectonics used in this discourse event may be considered unsophisticated, they were building ideas that would likely increase in sophistication (McDonald et al., 2018).

The two pairs at the table were brought back together as Anna interrupted the other dyad (Emily and Cal) at her table, "Emily! You know how in the Aleutians you have ocean and ocean plates? But in the Himalayas, you have land and land. That's why there's not volcanoes [in the Himalayas]!" The foursome then briefly discussed the location of the Aleutian Islands before Cal said, "Wait a second, why does it [the type of plate] matter? 'Cause shouldn't it-." Anna interrupted him and argued, "No, because remember land and land don't cause [volcanoes] because remember when we did the plate (a reference to a simulation in the module), where [we] had two [plates] come together? There were just mountains, there were no volcanoes." Cal then stated that he remembered now and accepted Anna's idea. Anna and Eden's discovery enabled the group to elicit Cal's ideas about plate types, as well as provide Anna with the opportunity to connect her claims to evidence from the module.

When Keith brought the class together to discuss what to place in the Summary Table from their discussions, Anna was the first student to publicly offer an idea, exuberantly waving her hand in the air. She claimed,

> Okay, so what we noticed is that most of the volcanoes are near water. So, then when we did the globe thing [simulation of plates interacting], where we tried to make the Aleutians, we did an ocean and ocean plate, which caused islands of volcanoes. But then we did a land and a land coming together, it didn't [form volcanoes].

In response to this, Keith pressed the whole class to develop a grounded claim for the Summary Table based on Anna's idea, specifically thinking about each of the observed plate interactions. Eden said, "Well for the Andes it's land and water plates but for the Aleutians, it's water and water." Keith began to document these ideas as generalized claims within the Summary Table. As he continued to revoice Anna's ideas, Keith moved away from the use of phrases like "water ones" using the more scientific term, oceanic plates. He documented these refined ideas into the Summary Table's overall claim for the activity (see Figure 1), which served as a connection to the driving question of the unit. Rather than discussing their reasoning as a class, each student used the class claim from the Summary Table as a claim within their CER Journal (see Figure 2), giving them a chance to make an individual argument for the activity while collecting additional evidence from the module.

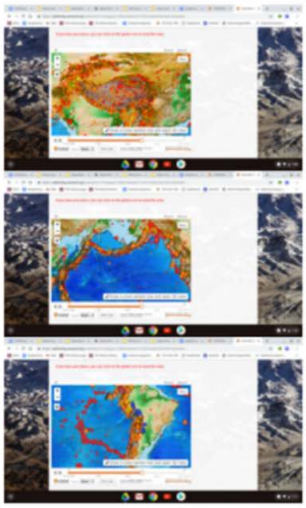
Figure 1

Summary Table entry for Activity 2

Activity	What patterns did we observe? What observations did we make?	What is causing those patterns or observations?	How does this help us understand the earth and what it will look like in the future?
Module 2 - Interrupting Earth's clues	Everywhere that a volcano forms you will find earthquakes **but** you can find earthquakes alone Trenches occur next to volcanic islands Trenches occur next to volcanic mountains Earthquakes occur shallow near trenches and deeper under the volcano as they move farther inland Earthquakes occur at depths less than 200 in the Himalayas		When plates converge (come together) earthquakes and mountains occur. • oceanic and continental results in volcanic mountains and a trench • oceanic and oceanic results in volcanic islands and trench • continental and continental results in **NON** volcanic mountains no trench

Figure 2

Anna's CER Journal – Students annotated their reasoning using the following color codes: Green indicates new science terms, blue indicates thoughts related to the driving question, red indicates questions students have, and purple is where edits/additions were made in later lessons. The yellow highlight added by the student was not part of the class color coding.

Claim	Evidence	Reasoning
When plates come together (converge) earthquakes and mountains occur. • Oceanic and continental results in Volcanic mountains and a trench • Oceanic and Oceanic results in Volcanic Islands and trench • Continental and Continental **NON VOLCANIC** Mountains, and **NO TRENCH**		The elevation goes up when you have an oceanic plate and a continental plate or if you have two oceanic plates. We see this in the Andes mountains and the Aleutian islands because one plate goes on top of the oher one and the other plate goes in a downward way which causes a trench and a mountain. When you have continental plate and a continental plate it won't just push up it like crumbles. In the pictures the ones where you see more of the volcanoes it is near water. The earthquakes are more deeper closer inland or under the volcano and the ones that are more near the water and the trench are more shallow and you can tell because of the colors of the dots. The picture of the Himalayas only has one volcano. Since there is only one volcano in the himalayas it is probably not active any more. How come you don't have as many volcanoes when there is two land plates? When two plates are **Converging** one plate is going under the other and that process is called **Subduction**.

Throughout the evolution of this idea, we saw that students participated in open argumentation around their ideas. Within small group talk, we saw an instance of hesitation when Cal did not agree with Anna's idea, to which Anna argued her position citing direct evidence from the module (Shemwell & Furtak, 2010). As Anna

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argued her position, Cal was able to gain insight into Anna's conceptions and reasoning, seeing a different perspective to establish the communal idea. Anna's ideas then were critiqued in her interaction with Eden, their sharing with Keith, and her debate with Cal, before sharing with the whole group. The Summary Table, scaffolded by Keith's classroom discourse culture, provided three opportunities for Anna to express her idea, receive feedback, and develop a deeper understanding.

We also highlight that Keith served a critical role in focusing and revoicing the students' developing ideas as he used AST teacher talk moves to focus the students' talk to his intended curricular goal of completing the Summary Table (Windschitl et al., 2018). First, we see him situate students to engage in peer-to-peer talk in dyads. When he visits the small groups, he presses students to expand their ideas in pattern finding to bring the notion of types of plates to their explanation. Finally, in the whole group discussion, Keith uses revoicing to bring students' everyday language together with scientific language, such as connecting "water ones" with "oceanic plate." Together, Keith's use of talk moves and the Summary Table supports students' development of scientific explanations for the phenomenon.

Conclusion

Our findings illustrate that creating time and space for scientific discourse provided students with sense-making opportunities around complex science ideas to support their explanations of the phenomenon. The Summary Table scaffolded development of increasingly sophisticated explanations by providing a structure for students to discuss and connect ideas with the driving question of the unit (Windschitl et al., 2018). Specifically, the Summary Table supported small and whole group discussions positioning students to both construct and critique ideas in diverse public ways (Ford, 2008). Ideas which were made public (small or whole group) were able to be debated to improve upon the idea before it became part of students' explanations at the end of the activity (Duschl & Osborne, 2002). Furthermore, the process of publicizing thoughts provided students with access to the conceptions and reasoning of the teacher and students in the class (Windschitl et al., 2018). This allows them to experience unfamiliar perspectives of complex ideas and develop communal explanations of scientific phenomena. However, talking in small groups does not eliminate the non-normative explanations from arguments, as students may not have the knowledge and skills to recognize the inconsistencies in their peers' arguments. Using the findings of Berland and Lee (2012) we see this as less concerning, as students have multiple opportunities for construction and critique of ideas in the iterative classroom discussions supported by the organizational of the Summary Table. This study shows the importance of critical talk between students and teachers framed by the Summary Table. We argue that the Summary Table scaffolded classroom discourse around complex phenomena in ways that supported the development of increasingly sophisticated scientific explanations.

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The Effect of Weekly Writing and Peer Reviewing Upon Students' Writing Competence

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Abstract: The importance of writing competence is being emphasized in society. One way to enhance undergraduates' writing competencies is to increase the number of WID (Writing in the Disciplines) classes. In order to introduce more WID classes and give students more opportunities to write, Park (2017) proposed a class method that utilizes writing and peer reviewing as a preparatory activity. The aim of this study was to find out whether Park's method can improve students' writing competence. Writing performances of thirty-three undergraduates in ten writing assignments were assessed by two raters based on two criteria of 'insight' and the 'flow of writing'. The results showed that the writing performance of students at the end of the semester was significantly higher than that of the students at the beginning of the semester. We hope this study provides a rationale for the expansion of writing education.

Introduction

Writing is an effective tool that allows people to share their events, or feelings, and thoughts with others. Since most of the work conducted in an organization is carried out in teams, the importance of writing, which enables clear communication, is being emphasized. For example, employees spend more and more time on using email and messages, and Amazon holds executive meetings based on six-page reports instead of using presentation slides (Cross & Gray, 2013). In this context, universities endeavor to enhance the writing skills of their students through writing education. Nevertheless, the writing skills of college graduates still do not meet the standards expected in society (National Association of Colleges and Employers, 2010).

In order to enhance students' writing competencies, improving the quality of current writing education as well as providing students with more opportunities to write is needed. One way to do this is increasing the number of WID (Writing in the Disciplines) classes, which are classes that teach writing skills within academic disciplines. This is because increasing the number of classes that teach only writing skills increases the burden on students and makes it difficult to teach appropriate writing for each discipline. Introducing more WID classes in universities can overcome this problem and allow students to organize what they learned in classes in writing, thereby helping them acquire knowledge and develop thinking skills in a balanced manner (Carter et al., 2007).

The reason why WID classes are seldom used despite their high learning effect is a greater burden on the instructors compared to lecture-centered classes. In WID classes, instructors are required not only to teach the learning material but also to select appropriate writing assignments and to assess and give proper feedback. Evaluating and providing feedback to students' writing assignments require more time than other assignments or tests because the content as well as the flow and the structure of the writing needs to be assessed (Herrington & Cadman, 1991). Therefore, some instructors in WID classes either fail to provide appropriate feedback promptly or only give minimum writing assignments to students (Kellogg & Whiteford, 2009).

One way of providing students with frequent writing assignments and feedback in WID classes by reducing the burden on the instructors is to introduce peer-assessment. The effectiveness of the peer-assessment was confirmed through several studies. The quality of the final writing assignments improved when they revised based on feedback from peers. (Liu & Carless, 2006). Also, another study showed that students who received feedback from their peers wrote a similar or better final report than students who received feedback from one expert only (Cho et al., 2008). Another advantage of peer-assessment is that it helps students understand the class content more deeply (Falchikov, 1986). Therefore, introducing peer-assessment to WID classes can reduce the burden of instructors while also enhancing students' learning (Liu & Carless, 2006).

Peer-assessment is usually used in WID classes in which students are required to write four to six-page long essays two or three times per semester. Two or three peer assessments per semester are helpful for students. However, providing only two or three writing tasks and peer-assessments per semester leaves a wide interval in between assignments, which makes it difficult for students to relate the content learned in class to their writings. In this context, Park (2017) proposed a WID class method in which students are required to write essays related to the content to be learned in the next class and to review each others' essays as a preparatory activity every week.

The WID class method developed by Park (2017) has a high learning effect since it includes the three components of effective learning, repetition, spacing, and retrieval (Yeung et al., 2021). Park's WID class method

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makes students learn a topic iteratively with moderate timing through a series of activities: reading, writing, and reviewing others' writings before class, discussing and taking a lecture during class, and finally revising their essays. These whole activities enable frequent retrieval and can also help enhance students' writing skills. However, whether this class can enhance students' writing skills has not yet been verified empirically. In this study, we tried to confirm this possibility by analyzing students' writing assignments from the actual class.

WID Class Method

The Park (2017)'s class method consists of three activities: a preparatory activity including writing and peer-assessment, a class activity with lectures and discussions, and a review activity through revising. First, a week before the first class of the week the instructor provides a writing assignment based on a part of the textbook to be covered in class and related learning materials such as recent research papers or articles. Criteria for peer-assessment, are also given. Students are required to upload a one-page essay along with the questions they had, to the online peer-review system until the night before class. The essays are distributed anonymously to all students, with each student allocated with four other students' essays. Students are required first to assess and provide feedback to the four essays anonymously, then to assess their own essay.

After completing the preparatory activity, students attend 75-minute classes, which are held twice a week (Monday and Wednesday). On Monday, the instructor gives a detailed lecture on the content covered in the preparatory activity. On Wednesday, students have a discussion on the questions selected by the instructor from the whole uploaded questions. To ensure that all students actively participate in the discussion, the instructor divides students into small groups of three or four. The discussion lasts for 50 minutes, and for the remaining time, the instructor asks students to share what they discussed and gives answers to questions that were not solved. From the end of the class on Monday to Friday evening, students evaluate how helpful the feedback they received was, while also revising their own essay based on what they learned from class and the feedback. The above process is repeated every week for a total of thirteen weeks, excluding the weeks for midterm and final exams.

Method

Participants

Thirty-three undergraduates in a university in Seoul, Korea participated in this study. All participants were from "Introduction to Psychology" course in the spring semester of 2018 and consented for participation before the study, which was approved by the university's Institutional Review Board (IRB No. 1805/002-006).

Writing assignment

In this study, ten out of the thirteen writing assignments written by thirty-three participants were analyzed. In the "Introduction to Psychology" course, students were required to write a one-page essay as a preparatory activity every week for a total of thirteen weeks during a fifteen-week-semester. The writing assignment required not only understanding the given papers and textbooks, but also high-order thinking. For example, in the week teaching educational psychology, textbooks explaining the principles of educational psychology and papers related to gamification were provided. Students then summarized the content and presented their ideas and opinions about what psychological points need to be supplemented for gamification to be more effective. Among thirteen assignments, three assignments (assignments for week 1, 8, and 13) were excluded from the analysis. The reason for the exclusion was that in week 1, 8, and 13, more than half of the students did not submit the writing assignment, making a comparison between such assignments and assignments from the other ten weeks difficult.

Evaluation criteria

Both the peer-assessments by the students during preparatory activity and measurement of writing performance of students in this study used the same evaluation criteria: 'insight' and 'flow of writing' on a 7-point Likert scale. The 'insight' criterion measured the novelty of the ideas and criticisms presented in the essays. The 'flow of writing' criterion assessed how well the essay was organized and how well it was easily readable.

Analysis

In order to find out whether the WID class method proposed by Park (2017) was effective in improving writing competencies, the writing performance from the ten writing assignments was analyzed. The writing performance was evaluated by two raters based on the two criteria and then the average score of two assessors was used in the analysis. All evaluation was conducted after the end of the semester without any knowledge regarding who the writer is. Also, in order to prevent the order effect, raters evaluated the writing assignments in

a random order, so that neither the order of students nor the order of the week the assignment was given was repeated. Also, the assessors' agreement measured by ICC was higher than .7 which means that the results of the two assessors' ratings can be sufficiently trusted. Therefore, we used the average score of two assessors to confirm the change in the writing performance of each week, and then conducted a t-test to compare the difference between the writing performance in the first two weeks (week 2 and 3) and that in the last two weeks (week 11 and 12).

Method

Table 1

Mean and Standard Deviation of Writing Performance, 'Insight' and 'Flow of Writing' Score of Each Week

	Number of Essays	Writing Performance	Insight	Flow of Writing
Week 2	29	8.034(*SD*=1.700)	4.069(*SD*=1.132)	3.966(*SD*=1.117)
Week 3	30	8.121(*SD*=1.139)	4.071(*SD*=.825)	4.125(*SD*=.824)
Week 4	28	8.625(*SD*=1.425)	4.464(*SD*=.962)	4.161(*SD*=.695)
Week 5	30	8.367(*SD*=1.852)	4.267(*SD*=1.065)	4.1(*SD*=.968)
Week 6	29	8.371(*SD*=1.323)	4.081(*SD*=.828)	4.290(*SD*=.656)
Week 7	31	8.375(*SD*=1.442)	4.0(*SD*=.833)	4.375(*SD*=.751)
Week 9	29	8.45(*SD*=1.700)	4.101(*SD*=1.321)	4.34(*SD*=.942)
Week 10	29	9.257(*SD*=1.704)	4.657(*SD*=.856)	4.6(*SD*=.976)
Week 11	30	9.086(*SD*=1.396)	4.603(*SD*=.828)	4.483(*SD*=.726)
Week 12	28	9.304(*SD*=1.853)	4.643(*SD*=.922)	4.661(*SD*=1.046)

The mean and standard deviation of the students' writing performance for each week are shown in Table 1. As can be seen from Table 1, students' writing performance in week 2 and 3 was about 8.2 points, which was close to the average. However, in week 11 and 12, which were almost at the end of the semester, the writing performance improved to 9.3 points. Also, the average scores of 'insight' and 'flow of writing' were about 4 points in the beginning, but they improved to 4.6 points at the end. In order to figure out whether the students' writing performance has improved through this WID class, the difference between the writing performance at the beginning and those at the end of the semester was analyzed by the t-test. Before comparing the writing performances of students at the beginning with those at the end of the semester, the difference in scores between the two weeks at the beginning of the semester and the difference in scores between the two weeks at the end of the semester were analyzed first. A t-test revealed that there were no significant differences ($t(55) = .377$, $p = .708$, $d = .060$; $t(49) = .267$, $p = .791$, $d = .133$). This shows that the students performed the writing tasks at a similar level in the first two weeks and the last two weeks respectively, even though topics for each week were all different. Then, we compared the average writing performance of the first two weeks and that of the last two weeks to verify the effectiveness of the WID class method. The results showed that the average writing performance of the last two weeks was significantly higher than that of the first two weeks ($t(112) = 3.559$, $p < .001$, $d = .667$; $M = 9.193$ vs. 8.114). We also conducted a t-test on each criterion: 'insight' and 'flow of writing'. 'Insight' and 'flow of writing' scores of the last two weeks were significantly higher than those of the first two weeks ($t(110) = 3.181$, $p = .002$, $d = .596$; $t(111) = 2.998$, $p = .003$, $d = .562$). These results show that the whole series of processes of the suggested class method can help enhance students' writing competencies.

The above results suggest that the WID class method using writing and peer-assessment as a preparatory activity improves students' writing competencies. Although there was little feedback on the writing assignments from the instructor in this class, the writing performance improved significantly by just providing opportunities to write and review each others' writing assignments. In conclusion, the WID class method of Park (2017) can help improve the writing competencies of students while reducing the burden of evaluation on instructors.

Discussion

The importance of writing, a useful tool for developing thought and sharing ideas, is being emphasized in education as well as in organizations. However, it is difficult to witness major changes aimed at improving writing education. This study introduced a new WID class method proposed by Park (2017), which utilizes peer reviewing as a preparatory activity, and verified its effectiveness. The WID class method proposed by Park incorporates the three components confirmed to be effective in achieving higher learning effect, repetition, spacing, and retrieval. Every week, students study the learning material, write an essay, ask questions, and review other writings before class. During class time, students take a lecture and then discuss with other students. After class, students are required to revise their essays. In order to verify whether the process of this proposed WID class method could improve the writing skills of students, we analyzed the essays from the actual class.

The analysis of ten different writing assignments each performed by thirty-three students showed that the students' writing performance improved significantly at the end of the semester compared to the beginning of the semester. Not only did the 'insight' scores related to class content but also the 'flow of writing' scores related to writing skills improved. Although an absolute comparison of writing performance was difficult since each writing assignment had a different topic, nevertheless the result showed that making students write essays and review peers' essays as well as their own every week throughout a semester helps students write better. Also, considering that such results were obtained with minimal feedback from the instructor, the proposed WID class method can be easily adopted in the educational scene.

The effectiveness of the Park's WID class method can also be supported by the lecture evaluation conducted by students at the end of the semester. More than half of the students stated in the lecture evaluation that the weekly preparatory activity helped them become more accustomed to writing and improve their writing skills. The results of this study may be self-evident, which is that students' writing competencies improved after they wrote essays every week and reviewed each other's essays. However, a point worth noting is that the aforementioned result was achieved with minimal intervention from the instructor.

However, further studies are needed before introducing the Park's method to various educational fields. First, more objective methods for evaluating the writing performance of students are needed. For example, comparing the results from group who were taught with the Park's WID class method with results from a control group taught with a different method can re-verify the effectiveness of the proposed class method. Another room for further development is to increase the credibility of peer-assessment. Some students pointed out in their lecture evaluation that they could not fully trust the evaluation and feedback given by other students. Thus, methods to improve the credibility of peer-assessment should be developed to apply Park's method in various fields.

Despite the above, this study revealed that improving writing competencies via frequent writing and peer reviewing can be achieved without intervention from the instructor. If the effect of the WID class method proposed by Park is re-verified through further studies, we expect that it can be adopted in various educational fields. In conclusion, we hope that this study and follow-up studies will contribute to the development of the proposed class method, and that students' writing skills are improved as universities widely adopt the method.

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Investigating the Relationship Among Solution Quality, Group Variability in Science Confidence, and Reciprocal Participation in Online Science Collaborative Problem-Solving Tasks

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Abstract: The current study examines how group variability in science confidence interacts with perceived reciprocal participation to influence group's solution quality. Thirty-five groups of four adults worked collaboratively on nine science tasks in an online synchronous setting. Surveys were used to gather data on each member's science confidence level and perceived reciprocal participation. We found a significant interaction effect of group variability in science confidence and reciprocal participation on solution quality. Further analyses showed that for groups with low variability in science confidence, the more variability in reciprocal participation, the lower the solution quality they generated. However, the finding for the groups with high variability in science confidence was the opposite – the more variability in reciprocal participation, the better solution quality they generated. The current study underscores the importance of science confidence in collaborative problem-solving activities.

Introduction

Research has suggested the importance of exposing students to numerous collaborative problem-solving tasks in science classrooms. Such activities positively influence learning outcomes (Bungum et al., 2018) and other crucial skills, such as metacognitive self-regulation (Chen & Chiu, 2016) and scientific argumentation (Nichols et al., 2016). However, several studies have acknowledged the challenges of implementing effective collaborative problem-solving because it relies on several factors. Research has indicated that enabling effective collaborative problem-solving relies on (a) group composition (e.g., Kallery & Loupidou, 2016); (b) students' individual and shared learning regulation (Järvelä & Hadwin, 2013); (c) relational and communication skills (Kutnick & Blatchford, 2014); and (d) levels of scaffolding provided for students (Chen & Chiu, 2016). In the current study, we focused on how group composition— particularly the heterogeneity of group members' science-confidence levels—interacts with perceived reciprocal participation (i.e., group members' perceptions of their contribution in providing and receiving clarification, feedback, and help during collaborative problem-solving) during collaboration to influence the groups' quality of solutions.

Several studies have explored heterogeneity's influence on group performance (e.g., Kallery & Loupidou, 2016). However, little is known about the interaction effect of group variability in science confidence and perceived reciprocal participation on the quality of solutions generated collaboratively. Based on the socio-cognitive theory of learning, confidence in an academic subject or content area influences and is influenced by cognitive ability or prior knowledge (e.g., understanding of scientific concepts). Consequently, in a science collaborative problem-solving setting, productive scientific argumentation and discussion are desired and have been found to depend on prior knowledge, confidence, and familiarity with science topic areas (Grooms et al., 2018). Thus, members' science confidence is integral in such a collaborative setting.

In the current research, we conducted a clinical study with 35 groups of four adult individuals working collaboratively on nine science tasks in a synchronous online environment. We aimed to gain more evidence on how heterogeneity in science confidence interacts with reciprocal participation to influence solution quality. The three research questions guiding this study are as follows: (1) To what extent does group variability in science confidence correlate to solution quality generated through collaboration?; (2) To what extent does group variability in perceived reciprocal participation correlate to solution quality generated through collaboration?; and (3) Does the interaction of group variability in science confidence and perceived reciprocal participation affect the solution's quality generated through collaboration?

Methods

Participants and Context. A total of 35 groups with four members each participated in the current study. We recruited these adult participants (age M = 30.88, SD = 11.88) via email. They comprised a broad range of occupations: graduate students, freelancers, engineers, teachers, attorneys, and retirees. Demographically, 60% of the participants were female, 26% male, and 14% identified as non-binary. In addition to gender, 40% of the

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participants were White, 31% Asian, 21% Hispanic/Latinx, 6% Black/African American, 1% Native American, and the remaining 1% identified as Other. Of these participants, 37% reported speaking one or more languages other than English at home. Regarding group information, 60% of the groups were mixed gender, and 69% were multi-racial. In addition, 71% of the groups had at least one multilingual member. The groups collaborated for a total average of 45 minutes to solve nine science tasks. Each group collaborated in a synchronous online environment through the video conferencing platform Zoom.

Scoring Solution Quality and Instruments. The participants completed two surveys: one before collaborating and another when finishing. The science-confidence data of each participant were collected as part of the pre-collaboration survey, and the perceived reciprocal participation data were collected as part of the post-collaboration survey. **Science Confidence**. We asked participants to rate their confidence in five science concepts: photosynthesis, cellular respiration, energy and matter, ecosystem, and earth and space science. **Perceived Reciprocal Participation**. We adopted an instrument developed by Dewiyanti et al. (2007) to measure each participants' perceptions of their reciprocal participation during collaboration. An example item included "I asked for an explanation if other group members gave unclear feedback." The instrument had a Cronbach's alpha value of .841, indicating satisfactory reliability. To obtain the data on group variability in science confidence and perceived reciprocal participation, we calculated the standard deviation (*SD*) based on the four participants' average scores. We used this *SD* value for each group to define the group variability in science confidence and perceived reciprocal participation. **Scoring Solution Quality**. We developed a rubric, and two coders scored the solution quality together. Any disagreements were discussed until they reached a consensus. Hence, we did not compute any inter-coder reliability. **Covariate: Variability in Group Working Opinion**. We wanted to control for group variability in the group working opinion. Participants' group working opinions were measured with an instrument using developed by Dewiyanti et al. (2007). Scale item included "Working in a group is motivating" and "Working in a group is challenging" (reversed item). This instrument had a Cronbach's alpha of .848.

Data Analysis. Pearson's correlation test was run to observe the associations among the variables. The results from these correlation tests were used to answer RQ1 and RQ2. We used multiple regression tests to answer RQ3. Two regression models were tested. Model 1 consisted of all variables without an interaction effect. Model 2 consisted of all variables in Model 1 and an interaction effect of group variability in science confidence and perceived reciprocal participation. If we identified an interaction effect, we then used Model 2 to generate the graph of interaction effect on the dependent variable (i.e., group solution quality score).

Table 1

Full Regression Models: with and without an Interaction Effect

Variable	Model 1: Without Interaction Effect			Model 2: With Interaction Effect		
	b	*t*	*p*	*b*	*t*	*p*
Intercept	85.60	17.90	< .001	95.54	19.44	< .001
GV in Age	0.03	.20	.842	0.11	0.78	.444
Group Mixed Gender Status^S	-2.54	-1.68	.105	-2.54	-1.89	.070
Group Ethnically Diverse Status^S	2.99	1.89	.070	3.66	2.56	.017
Multilingual Member(s) in Group^S	-0.36	-0.23	.821	-0.04	-0.03	.980
GV in Science Confidence	-1.76	-0.45	.656	-21.04	-2.77	.010
GV in Group Working Opinion	3.06	0.56	.581	3.62	0.74	.465
GV in Perceived Reciprocal Participation	-5.81	-2.22	.035	-21.35	-3.61	.001
GV in Science Confidence x GV in Perceived Reciprocal Participation	-	-	-	37.11	2.85	.008
R (R_{adj})	.28 (.10)			.45 (.29)		
F-value *(df)*	1.53 (27)			2.71 (26)		
p-value	.201			.026		
ΔF (Δdf)	-			1.18 (1)		
p-value for ΔF	-			.391		

Findings

Based on the correlation tests, we found that group variability (GV) in Science Confidence did not significantly correlate with the Group Solution Quality Score (r = .09, p > .05). However, we found that GV in Perceived Reciprocal Participation significantly correlated with Group Solution Quality Score (r = -.34; p = .045), and the

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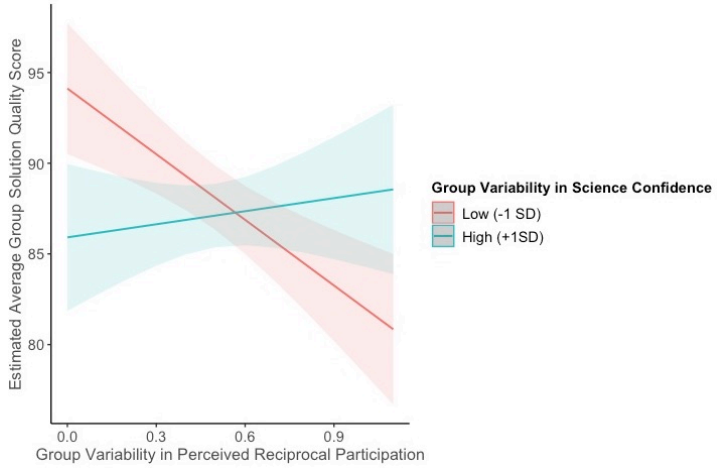
correlation coefficient was negative. These findings hence answered the first and second research questions. Following these results, regression tests were run, and the results are presented in Table 1. First, a regression model without interaction effect (Model 1) was performed first to investigate the main effect of each predictor, including the covariates. Based on Model 1, only GV in Perceived Reciprocal Participation was the significant predictor ($p < .05$) of Group Solution Quality Score. In Model 2, we found a significant interaction effect of GV in Science Confidence and GV in Perceived Reciprocal Participation on Group Solution Quality Score. We also found that Group Ethnically Diverse Status positively predicted Group Solution Goal, indicating that the more ethnically diverse a group, the better the group's solution quality. Figure 1 illustrates that for a group with low variability in science confidence (i.e., group members have relatively similar science confidence), the greater the variability in perceived reciprocal participation (i.e., group members had differing perceptions of their own reciprocal participation), the lower group-solution quality the group generates. However, these variability results did not show whether participants had high vs. low science confidence—low variability could be attributed to two cases: all group members had high science confidence, or they all had low science confidence. Thus, we investigated further by calculating the aggregate mean of group scores on science confidence. The result was 1.96 out of 3 ($SD = 0.25$), indicating that most groups had relatively moderate-high science confidence.

Figure 1

The Interaction Effect between Group Variability in Science Confidence and Group Variability in Perceived Reciprocal Participation on Group Solution Quality Score (Based on Model 2)



Regarding the group with high variability in science confidence, we found that the greater the variability in perceived reciprocal participation (i.e., group members had differing perceptions of their own reciprocal participation), the better solution quality the group generates. In addition, based on Figure 1, the results also implied that groups with low variability in science confidence (i.e., all group members have relatively similar science confidence) and low variability in perceived reciprocal participation (i.e., all group members have relatively similar perceptions of their own participation during collaboration) would generate the best solutions. Again, low variability in perceived reciprocal participation can consist of two cases: either all group members think they actively participated, or all group members do not think they actively participated. Thus, we followed up by calculating the aggregate mean of group scores on perceived reciprocal participation. The average was 3.75 out of 5 points ($SD = 0.33$), indicating that most participants believed they actively participated during the collaboration. Therefore, for the context of the current study, both low group variability in science confidence and perceived reciprocal participation can be interpreted in the context of high confidence and high reciprocal participation groups.

Discussion and conclusion

The current study's primary purpose aimed to uncover the interaction effect of GV in science confidence and perceived reciprocal participation on solution quality generated in a series of science collaborative problem-solving activities. Our study findings suggest two types of group configuration that can be adopted to maximize the solution quality generated collaboratively. The first configuration is when all students in a group have the same level of science confidence (particularly, relatively high) and when all students also have relatively similar chances to participate during the collaboration process (clarifying and providing feedback). Such a group would

be the one that generates a better-quality solution. This type of group composition may also create what González et al. (2003) called group cohesion characterized by social and task cohesion.

The second group configuration that may maximize the solution quality is when a group comprises members with different levels of science confidence and when the members have different chances to participate. This configuration allows group tutoring. Thus, members with higher science-confidence levels (presumably higher science knowledge) have more opportunities to explain and clarify concepts to members with lower science-confidence levels (and presumably lower science knowledge). Therefore, in this kind of group configuration, a relatively steep learning curve arises for the members with lower science confidence, which allow the groups to engage in activities that maintain productive struggle events leading to a better solution quality.

Although the current study was situated in a laboratory setting, we believe that our findings have implications for both K–16 and professional education. For instance, when science teachers implement collaborative learning in a formal K–12 setting, they tend to create student groups based on students' varying levels of science knowledge. Although assessing student science knowledge at the beginning of units is sometimes logistically feasible, teachers often lack sufficient time to gather students' conceptual understanding; diagnosing students' knowledge is labor-intensive. Instead, teachers can use one simple question that asks them to rate their confidence in the science concepts to be learned. Student groups can then be formed based on this confidence level. If students form their own groups after teachers gather confidence-level information, the teachers can also guide these student groups to ensure cohesion is maintained.

We urge the readers to carefully interpret the findings due to several limitations. These limitations include but not limited to study's context, which is situated in a laboratory setting, and small sample size. For future studies, we believe that conducting qualitative analysis and presenting episodes of how members of a group based on science confidence interact during science collaborative problem-solving activities. We believe such data and analysis can substantiate the current study findings.

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Surfacing Collective Pedagogical Content Knowledge for Data Literacy: An Exploratory Study with High School Science Teachers

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Abstract: There is a need for greater focus on the critical aspects of data literacy at the high school level. However, data literacy requires explicit integration between math and science, which high school teachers often aren't experienced with. Thus, teaching data literacy may require different PCK than that typical for high school science. This study adds to underrepresented research on PCK for data literacy by engaging a group of experienced teachers in collaboratively attempting to define PCK for data literacy through discussing their experiences implementing a unit designed to support the development of data literacy in students. Three components of PCK for data literacy are surfaced and examined.

Introduction

In our data-rich world, there are strong calls for greater focus on data literacy as increasingly, 21st century jobs require some level of data literacy (e.g., Gould et al., 2016). Rubin (2020) identifies five critical aspects of knowledge for working with data: a) *data in context*, b) *variability of data*, c) *data in aggregate*, d) *data visualization*, and e) *inferences with data*. For the purpose of this study, a sixth critical aspect highlighted by Kjelvik and Schultheis (2019) has been added: f) *complexity of data sets*. These six critical aspects of data literacy serve as a foundation for what students should know about how to work with authentic data. There has been limited research on pedagogical best practices for teaching data literacy, especially through authentic, complex, messy data (Gould et al., 2016; Mike, 2020). However, Nadelson and Seifert (2017) discussed the importance of highlighting the interdisciplinary nature of data, with connections between math and science classes made explicit. This sort of content integration is not something that high school teachers are often experienced or supported in doing (Kelley & Knowles, 2016), especially when it comes to engaging students with complex authentic data (Kjelvik & Schultheis, 2019). Thus, teachers need support in identifying the pedagogical content knowledge (PCK) required to support student learning with and about data (Kelley & Knowles, 2016). Though some research has been done on PCK for STEM integration (e.g., Vossen et al., 2020), PCK for data literacy is an under-explored concept (Mike, 2020). This study builds on a larger study on integrating bioinformatics lessons into high school science classrooms using student-collected data. We work with a small group of experienced teachers to collaboratively examine their understanding of PCK for data literacy using established methods of surfacing PCK (i.e., content representations and video reflections). This exploratory study seeks to answer the question: what are some components of PCK for data literacy in high school science classrooms?

Background

High school science teachers often have not been given the time or resources to engage students in full authentic investigations which address the interdisciplinary nature of data and as such they may need support in determining the best pedagogical strategies (Gould et al., 2016; Nadelson & Seifert, 2017). Currently very little is known about what PCK for teaching with and about data looks like and what sort of experiences are needed to support it (Gould et al., 2016; Mike, 2020). PCK is defined as the "special amalgam of content and pedagogy that is uniquely the province of teachers" (Shulman, 1987, p. 8) and has been shown to be subject and even topic specific (Smith & Banilower, 2015). As such, PCK for data literacy may require knowledge that is distinct from that which science teachers already hold. The science education community has outlined a model for PCK that identifies three levels of PCK that interact with each other: collective, personal, and enacted, where collective PCK encompasses the common knowledge held by a group of teachers made up of an amalgamation of their personal knowledge and experiences with enaction (Carleson & Daehler, 2019). Additionally, PCK has been shown to be composed of distinct components (e.g., Park & Chen, 2012), the two most commonly studied of which are *knowledge of student understanding*, and *knowledge of teaching strategies*.

Studies have shown that working collaboratively allows teachers to surface deeper and more nuanced PCK (Nilsson & Loughran, 2012; Vossen et al., 2020). Research that has supported teachers in successful identification and growth of PCK often uses one or both of two methods: content representations (CoRes) and video reflections. A CoRe is a template which prompts a teacher or group of teachers to think about teaching a particular topic through big ideas with questions such as: *Why is it important for students to know this? What else*

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do you know about this idea that you do not intend students to know yet? What is your knowledge of students' thinking which influences your teaching of this idea? Studies have found that enabling teachers to make their practice, and their thinking on their practice visible allowed them to then reflect effectively on that knowledge (e.g., Vossen et al., 2020). Using a CoRe as an artifact allows teachers to develop a shared language around the content knowledge and the PCK for teaching a particular topic (Nilsson & Loughran, 2012). Engaging in video reflections prompts teachers to examine and make visible their thinking while enacting a lesson. By combining CoRes and video reflections on data literacy lessons, this study hopes to support a small group of experienced science teachers in surfacing PCK for data literacy.

Methods

Context

This exploratory study exists within the larger context of an intervention designed to support teachers in implementing a STEM-integrated problem based learning unit on bioinformatics in their science classrooms. The unit uses mobile learning through portable air quality sensors connected to a phone app to engage students with active collection of real-world data to address the provided problem of asthma rates in urban areas. The intervention included a summer professional development which took place over four weeks during July 2021, conducted asynchronously on the edX testing platform called Edge. After the summer course, four participating teachers were invited to participate in a PCK Extension Workshop Program which would focus explicitly on PCK. The extension program consists of approximately 20 hours of workshops spread over fall and winter 2021 while teachers are actively engaged in implementing the bioinformatics unit. The series of workshops includes virtual synchronous meet ups with some asynchronous work to support preparation for these meetings. During the workshops, teachers collectively build CoRes on the different critical aspects of data literacy while learning about PCK as a concept and how it can be identified and measured. Additionally, teachers conduct video reflections of their implementation in which they identify examples of enacted PCK and discuss how they support student learning. As the workshop program is still in progress, this paper focuses on initial findings on how participating teachers are conceptualizing PCK for data literacy.

The four participating teachers in this study work in three different public schools in a large urban school district in the northeastern United States in which over 90% of students qualify for free or reduced lunch. The three schools represent typical schools within the district, with large populations of minority students, English as a second language learners, and students who are socioeconomically disadvantaged. The four teachers consist of three who identify as female and one who identifies as male, three who identify as white and one who identifies as South Asian. They have an average teaching experience of 12.75 years with the most experienced teaching for 22 years while the least experienced is only in her second year of teaching in a formal classroom after a number of years working in informal education. All four teachers are implementing the bioinformatics unit in a high school science classroom.

Data sources and analysis

The data sources for this study consist of three CoRes built collaboratively during the extension workshops focused on the critical aspects of *data in context*, *data visualizations*, and *inferences with data*, written reflections completed by teachers after watching two videos of themselves and their colleagues teaching data literacy lessons that focused on those three critical aspects, and transcripts of the sessions during which the CoRes were created and the video reflections discussed. Five sessions, each 90 minutes in length (or 450 minutes total) were used for this analysis. A constant comparative analysis (Glaser, 2008) was conducted on the transcripts of the sessions and the written artifacts to identify emerging themes on PCK for data literacy.

Findings

Teachers have begun to surface an initial set of components of PCK for data literacy. These include two aspects of *knowledge of students' understanding* of data as well as *knowledge of a teaching strategy* that can be applied to help engage those student understandings.

Knowledge of students' understanding of data

Two initial themes that have arisen from teachers discussions of PCK for data literacy are that students: a) are not used to questioning data and b) struggle with the ambiguity of real-world authentic data. Concerning the first theme, while high school science does often use data, students are usually asked to interpret it without being asked to interrogate it, however a primary component of data literacy is being able to place data in its context and

understand how the context might affect the results and interpretations. In order for teachers to effectively teach the context component of data literacy, it is important for them to have strong knowledge of how and why students' predisposition to data may hinder that learning. To surface and build on that component of teacher PCK, the teachers were asked to explicitly identify what they knew and understood about student thinking. In response to a prompt in the CoRe on *inference with data* about student thinking, the teachers wrote, "Students will see "expert" conclusions and assume the expert must know - so why would they need a different conclusion." In the discussion around this understanding Mary stated that, "the whole point of [students] learning data literacy is so that they are not stuck believing that three or four out of four dentists means something really magical." This is revealing knowledge about student understanding, that students are "stuck" seeing data as truth without training to question it or even the knowledge that they can. Hallie added that though students are "able to see the 'what' they don't go for the 'so what'" which is referencing students' tendency to read data, but not question it. The knowledge that students are not used to questioning data also came up while teachers were building a CoRe on *data visualization* and discussing how easily people can be manipulated by "pretty" graphs. Mary said, "[students] are mostly on the receiving end of data and that is a place they can get manipulated by beautiful fonts and fancy bright red." In using the word 'manipulated' to talk about how students interface with data visualizations, she is again revealing knowledge of how students are unused to questioning data and instead accept it as is. By revealing this knowledge, the teachers are making visible a component of PCK which will help them better address students' preconceptions.

With respect to the second theme of struggle with ambiguity, while students are usually conditioned to accept data they see externally as fact and are not experienced in questioning it, they often take an opposite approach with their own data in that rather than accepting data they collect, they assume there is a "right" answer and their data needs to match that. Again, this is important knowledge for teachers to have in order to engage their students with data literacy, specifically with the component of building inferences with data and creating data visualizations to display their findings. When completing a CoRe on *data visualization* teachers wrote that creating data visualizations can "feel wishy-washy for students who are accustomed to 'only one of the choices is correct'" and that when creating data visualizations "students can be overly cautious with taking intellectual/design risks, to the point of paralysis. Many won't start until they know they are doing it 'right'" In further discussions about this understanding that students have about working with data, Manisha brought up the phrase "integrity of data" and how when it comes to their own data students are uncomfortable with ambiguity being okay. Additionally, while building the CoRe on *inference with data* teachers discussed ways to engage this student understanding through having them collect data on tangible objects so that they can see that "data is real and personal" to combat students' need for data to be "right" as measured by an arbitrary authority. Surfacing the knowledge that students struggle with ambiguity of data allowed teachers to verbalize this component of PCK and apply it to strategies for teaching data literacy.

Knowledge of instructional strategies for teaching with and about data

While teachers were building the CoRes and discussing their implementations of the data literacy lessons, they began to identify one particular instructional strategy to work with students' understanding of data as needing to be "right" and unquestionable. The idea of data as a story, or as having a story to tell, surfaced during many of the teachers' conversations. It was discussed as a way to support students in shifting the way they interface with data by thinking about a data set as a text and using text-analysis tools to deconstruct the 'story' the data is trying to tell. One of the big ideas they collectively chose while building the CoRe for *data visualization* was "Data visualizations tell a particular story about a set of data at a particular point in time." Additionally, while discussing the CoRe for *data in context,* Will said, "[students] are looking at one set of data, but there's this whole other world of data that you're choosing to ignore to fit your story and that's what I want them to understand, is you can use data to properly to support any position that you want."

When teachers were discussing a video of Hallie teaching a data literacy lesson, the instructional strategy of unpacking data as if it's a text and using literary analysis tools to support students in gaining experience and confidence critiquing data began to take shape. Hallie explained her emergent thinking on this saying, "If we were reading a short story and we say [...] what's the background we can assume this character might have had because of the way that they speak or whatever." She then connected that to analyzing a data visualization with, "There is a story that it's telling. [...] so, using a kind of text analysis [the students] can ask questions like who were these people? Why were they asking [these questions]?" This led to a larger conversation about different ways that students could be introduced to this process with Mary suggesting, "Offer a data set and invite groups of students to use the same data to tell various stories - don't tell each group what the others were asked to do - and then have students present their visualizations to the larger group." Manisha then added a suggestion to use the sugar refinery association's involvement with the diabetes association as a way to show students competing stories and "not to tell them the other side [at the beginning] and then just drop one bomb of a perspective and make them rethink

everything that they believed before that." Both of these examples are methods of introducing students to thinking about data as telling a story. While Mary's suggestion engages with students' understanding about data being unambiguous, Manisha engages with their tendency to accept data at face value without interrogating or questioning it. The strategy of treating data like a literary story can be used to engage both student understandings addressed in the previous section.

Implications

This paper reports on the initial findings of an ongoing study that investigates the surfacing of collective PCK for data literacy in high school science. As the research wraps up, a more robust analysis of the data will be conducted in order to achieve validity on these initial findings. Additionally, extensive interviews with the participating teachers will be conducted at the end of the workshop series to explore the processes used in the workshop and their effectiveness in supporting teachers to surface and expand their PCK for data literacy. However, the initial findings show that experienced high school science teachers hold some PCK for teaching with and about data and that, in support of previous research on developing PCK (e.g., Nilsson & Loughran, 2012, Vossen et al., 2020), PCK can be surfaced through collective discussion of the critical aspects of data literacy as mediated by CoRes and video reflections. This research hopes to continue to add to the burgeoning literature on teaching for data literacy at the high school level (e.g., Mike, 2020) by working with experienced teachers to understand what PCK for data literacy looks like, how it may or may not be different from traditional PCK for science, and how teachers can be supported to make this PCK visible and accessible. This study will contribute to identifying the supports needed to improve students' knowledge of the critical aspects of data literacy through identifying PCK for teaching with and about data.

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International Society of the Learning Sciences

Does Problem-Solving Before Instruction Reduce the Minoritized Student Achievement Gap?

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Abstract: Despite equal ability, racially-minoritized students disproportionately underperform and drop out of STEM courses. Active learning methods have been shown to help reduce this gap. We examined whether exploratory learning, a type of active learning, has similar benefits. Exploratory learning reverses traditional instruct-then-practice approaches by giving students a novel activity prior to instruction. Undergraduate students (*N*=354) were randomly assigned to learn concepts of statistical variance in explore-first (activity then instruction) or instruct-first (instruction then activity) conditions. Posttest scores improved overall in explore-first compared to instruct-first conditions. However, underrepresented students had lower scores than non-underrepresented students in both conditions. Although effective overall, exploratory learning did not decrease the underrepresented student achievement gap. Certain one-time active learning methods may not be sufficient to promote inclusivity and reduce barriers to underrepresented students' learning.

Introduction

Racially-minoritized students are underrepresented (UR) in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Curry & DeBoer, 2020; PCAST, 2012). Yet, these students are essential for the STEM workforce, and enter colleges and universities aspiring to major in STEM at the same rate as non-underrepresented students (non-UR) (Malcolm & Feder, 2016). UR students show disproportionate underperformance and dropout rates from STEM disciplines (Ballen et al., 2017; PCAST, 2012). Disproportionate retention of UR students in STEM is thought to be due to various factors, such as social isolation, "chilly" classrooms (i.e., instructor dominated lectures that involve little student participation in large introductory classes), low confidence, and stereotype threat (Ballen et al., 2017). Active learning may help to reduce this gap (Saunders & Kardia, 2011).

The current study more closely examined the role a specific type of active learning can play in decreasing the UR student achievement gap in STEM fields. *Exploratory learning* adds a problem solving (exploration) phase before lecture (DeCaro & Rittle-Johnson, 2012), often improving students' conceptual understanding and knowledge transfer to related concepts (Darabi et al., 2018; Loibl et al., 2017). No prior studies have examined whether exploratory learning also helps reduce the UR student achievement gap. Active learning includes multiple instructional methods targeting students' understanding (e.g., in-class activities, low-stakes quizzes) and classroom climate (e.g., collaborative learning; Bauer et al., 2020). Examining how one specific type of active learning impacts UR student learning may provide insight into what factors help to reduce achievement gaps.

Active learning

Multiple studies have shown that UR students are interested, and as capable to excel, in STEM as much as non-UR students (Malcolm & Feder, 2016; Steele & Aronson, 1995). The U.S. Federal Government has called for action to increase representation in STEM (National Academies Press, 2011). One solution is to employ more inclusive instruction in STEM curricula. *Inclusive instruction* is a pedagogical approach that promotes the idea that all students in the classroom belong and possess the ability to be successful (Johnson, 2019). In an inclusive classroom, instructors and students all take responsibility for students' learning. Instructors create a space where students feel supported and encouraged (Saunders & Kardia, 2011).

One way to implement inclusive instruction is to use active learning (Saunders & Kardia, 2011). *Active learning* engages students through activities, collaborative learning, and/or in class discussion, as opposed to passively listening to lectures (Brame, 2016). Active learning encourages students to analyze and critically think about concepts, improving student outcomes such as grades (Ballen et al., 2017; Freeman et al., 2014). Ballen and colleagues (2017) showed that active learning, compared to traditional lectures, closed the UR student achievement gap in an introductory biology course. After adding active learning to the course curriculum, UR students' assessments and grades increased to the level of non-UR students. UR students' science self-efficacy—confidence in their capability to do science—also increased. Similar results have been found in other studies (e.g., Eddy & Hogan, 2014; Haak et al., 2011).

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Exploratory learning

More work is needed to determine which active learning methods lead to these benefits. The current study examined *exploratory learning*, a specific type of active learning in which students explore a novel concept prior to instruction on that topic. Exploratory learning encompasses several methods (DeCaro & Rittle-Johnson, 2012), including problem-solve-instruct methods (e.g., Loibl et al., 2017), productive failure (e.g., Kapur, 2012), and preparation for future learning (e.g., Schwartz & Martin, 2004). A growing number of studies have shown that exploratory learning generally improves students' understanding of concepts; rote problem-solving procedures are learned equally well in explore-first and instruct-first methods (Loibl et al., 2017).

Exploratory learning is thought to benefit understanding through several learning mechanisms (Loibl et al., 2017). First, solving novel problems helps students activate relevant prior knowledge, integrating what they know with the new instruction (Newman & DeCaro, 2019). Second, students realize where they have gaps in their knowledge, calibrating their metacognition, and alerting them that the instruction can help fill those gaps (Loibl et al., 2017). Third, students begin to discern what features of the problem are key, and which are less important, deepening their understanding of the concepts (DeCaro & Rittle-Johnson, 2012; Schwartz & Martin, 2004).

Current Study

We examined whether exploratory learning, as a type of active learning activity targeting conceptual understanding, would help to reduce the UR student achievement gap. We combined data collected for other studies in psychological statistics courses with lab studies using the same materials, and conducted a secondary analysis. Participants were randomly assigned to one of two conditions. Students in the *explore-first condition* explored a standard deviation problem and "invented" an equation to solve it. Then they read instruction on the concept and procedures of standard deviation. Students in the *instruct-first condition* viewed the materials in the opposite order (instruction, then problem). Either immediately after (lab sessions) or one week later (classroom sessions), students completed a posttest that assessed conceptual understanding of standard deviation.

We hypothesized that students in the explore-first condition would score higher on the posttest overall, compared to students in the instruct-first condition. We also hypothesized that any difference in posttest scores between UR and non-UR students in the instruct-first condition would be reduced in the explore-first condition. However, another possibility is that the cognitive benefits of exploratory learning are insufficient to increase inclusive instruction, especially in a one-time intervention in which students work individually. This experiment therefore tested whether exploring alone is a sufficient method to reduce the UR student achievement gap.

Methods

Participants

Participants (N=354) were undergraduate students enrolled in introductory psychology statistics courses (n=263) or who participated in a lab study at the same university (n=91). Students were categorized as UR (n=94; 26.4%) based on their reported race/ethnicity, including African-American/Black, Hispanic/Latinx, Native American, Hawaiian/Pacific Islander, or biracial/"mixed" (Curry & DeBoer, 2020). Non-UR (n=262; 73.6%) participants indicated that they were Caucasian/white. Participants from other racial/ethnic groups (e.g., Asian) were not included in analyses, as they are not typically considered to face the same academic challenges as other minoritized groups (Curry & DeBoer, 2020).

Participants were included in the dataset if they completed both the intervention and posttest. Participants were excluded if they had experience with the learning materials, or if they reported previously learning about standard deviation and scored above 97% on the posttest. Participants were also excluded if they reported that their primary language was not English, due to the large reading component of the study (this variable was not collected from 174 participants; all were included in the dataset).

Materials

The **intervention packet** (adapted from Kapur, 2012; Wiedmann et al., 2012) consisted of three sections that varied in order depending on condition: instruction, activity, and survey (demographics). The **instruction section** included a written text passage giving direct instruction on the concepts and procedures for calculating standard deviation, with two short practice questions. The **activity section** included a problem asking students to determine the consistency of antioxidants in tea produced by three different tea growers over six years (Newman & DeCaro, 2019). Students viewed a table designed to facilitate contrasting cases, to help students ascertain the relevant problem features (e.g., the importance of sample size; Schwartz et al., 2012). Students in the *explore-first condition* were asked to "Come up with a formula for consistency to show which tea grower has the most consistent levels of antioxidants…" Students in the *instruct-first condition* were instead asked to use what they

just learned about standard deviation to calculate consistency. The **posttest** included four essay questions that targeted conceptual and procedural aspects of standard deviation, drawn from Newman and DeCaro (2019) (interrater reliability: Cronbach's alphas > .80).

Procedure

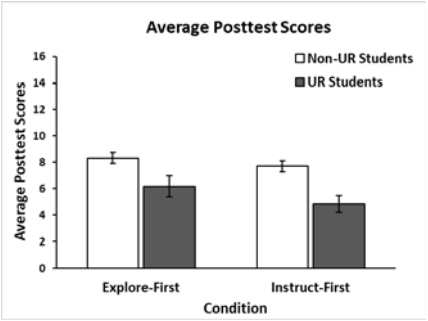
Students were randomly assigned to condition based on the intervention packet given. Students in the *explore-first condition* (*n*=174) completed the activity, then the instruction. Students in the *instruct-first condition* (*n*=180) completed the instruction then activity. Students were given 15 minutes for each section of the packet and 35 minutes for the posttest. Students in the psychology statistics lab classes completed the posttest one week after the intervention. Students in the lab (non-classroom) study completed both packets in one session. Students in classroom studies were debriefed via email and given the option to remove their data from the study. Students in the lab study completed a consent form at the beginning and were given psychology research credit for participation. All procedures were approved by the university Institutional Review Board.

Results

A preliminary analysis showed that the difference between conditions (explore-first, instruct-first) was statistically significant without including representation status as a factor, $F(1,356)=4.25$, $p=.040$, $\eta_p^2=.012$. Posttest scores were higher in the explore-first (M=7.88 out of 16, SE=0.37) than the instruct-first condition (M=6.80, SE=0.37).

Posttest scores were then analyzed using a 2 (condition: *explore-first*, *instruct-first*) × 2 (representation status: *UR*, *non-UR*) between-subjects factorial ANOVA. No main effect of condition was found, $F(1,356)=2.67$, $p=.103$, $\eta_p^2=.008$. A main effect of representation status was found, $F(1,356)=17.83$, $p<.001$, $\eta_p^2=.048$. There was no condition × representation status interaction, $F<1$, $p=.566$, $\eta_p^2=.001$. As shown in *Figure 1*, UR students scored lower on the posttest than non-UR students in both the explore-first condition (UR: M=6.17, SE=0.80, CI[4.59–7.74]; non-UR: M=8.32, SE=0.41, CI[7.52–9.13]) and instruct-first condition (UR: M=4.86, SE=0.64, CI[3.61–6.11]; non-UR: M=7.71, SE=0.43, CI[6.85–8.55]). Exploratory learning did not reduce the achievement gap.

Figure 1 *Average Posttest Scores as a Function of Condition and Underrepresentation (UR) Status (Error Bars=SEs)*



Discussion

This study examined whether exploratory learning would reduce the UR student achievement gap when learning about a statistics concept and procedure across undergraduate classroom and lab settings. Compared to an instruct-first condition, students in the explore-first condition scored higher on a posttest, although the effect was weak. UR students performed at a lower level than non-UR students across both instruct-first and explore-first conditions, demonstrating that exploratory learning did not significantly reduce the UR student achievement gap.

This finding contrasts prior studies showing that using active learning techniques can reduce the achievement gap between UR and non-UR students in STEM courses (e.g., Ballen et al., 2017; Haak et al., 2011). However, these studies included multiple active learning methods used over an entire semester. Thus, it is unclear which specific methods drove these benefits or whether a single lesson using active learning may be sufficient to demonstrate additional learning benefits for UR students. The current results demonstrate that a single exploratory learning lesson—at least as used in this study—is insufficient to reduce the achievement gap.

Several factors may have limited our ability to differentially improve UR students' learning. Our results may be limited by weak implementation of exploratory learning. In addition, students only experienced this learning method once. Perhaps repeated exposure to learning methods known to improve students' conceptual understanding is necessary to have more widespread benefits. Given the challenges of exploratory learning, instructions aimed at a growth mindset may need to be included (e.g., Bauer et al., 2020). Finally, students worked individually in our study, but collaborative learning may be key to an inclusive learning environment. Collaboration encourages relationships between students and instructors, and may be necessary to reduce a "chilly" climate.

Our findings underscore the importance of continuing to discern the key ingredients of active learning that do increase inclusivity and academic performance for UR students. For example, Bauer et al. (2020) argue that instructional methods should target both cognitive and affective aspects of learning. Others (e.g., Lorenzo et al., 2006) focus primarily on the social aspects of an inclusive teaching environment. Exploratory learning may

be useful, but insufficient, without being combined with other aspects of inclusive teaching, to help promote equitable learning for all students.

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Rural Teachers' Computing Attitudes in their Classrooms

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Abstract: The purpose of this multiple case study is to explore teacher attitudes toward and engagement with technology as they participate in STEM professional development and subsequently enact instruction. Using the lens of cultural historical activity theory (CHAT), we examine the ways in which two middle school teachers in a rural community shifted their perspectives on technology during this process. Findings suggest that teacher attitude toward technology can be moderated through the means of a more knowledgeable other who scaffolds teacher learning and integration of technology, providing insights into the professional development needs of rural teachers.

Teachers and technology in STEM education

As seen in new fields such as chemometrics and computational biology, computing is increasingly required in STEM careers (Weintrop et al., 2015). Further, computational thinking is conceptualized as a foundational literacy for the 21st century (Grover & Pea, 2013). Because of this, students need the support of educators in scaffolding computing understanding that will help them prepare for STEM career success in the future. Accordingly, all teachers of young students need preparation to teach computing skills. Unfortunately, current computing experiences in education tend to not include authentic and meaningful integration that is relevant to STEM problems (Pitman & Gaines, 2015). Furthermore, the pedagogical content knowledge that teachers need to engage students authentically in integrated STEM computing projects is lacking. Thus, the teaching of skills necessary to support student interest and learning in STEM is not occurring (Kafai & Burke, 2014) .

Implementing computational thinking tasks into instruction requires that teachers have familiarity with technology, computer science, and the pedagogy needed to support students in making sense of it (Tofel-Grehl et al., 2018). However, teachers often report that they do not have enough competence to engage students in STEM learning around computing (Tofel-Grehl et al., 2021). Thus, additional professional development is needed.

By building in professional development time for teachers to learn, reflect, and apply knowledge and skills related to computing and technology into instruction, teachers are supported to make the shifts necessary to change instruction to more authentic and meaningful STEM learning (Avci et al., 2020). Furthermore, research suggests that knowing teacher attitudes is critical for professional development, because teachers teach what they believe is important (Pajares, 1992). Additionally, knowledge of educator attitudes toward a practice "is critical for understanding teachers' thought processes, classroom practices, [and] change" (Smith, 2002, p. 42). Therefore, to improve STEM learning and career outcomes for students, we must improve STEM instruction to thoughtfully integrate computing and teacher attitudes about such integrated teaching. Gaining this understanding can inform professional development designers in the creation of professional learning experiences that scaffold educators to include technology in STEM education for their community of students. Accordingly, we pose two research questions:

1. What attitudes do teachers express toward technology and computing within their classrooms?
2. How do teachers approach and engage with technology both during professional development and during classroom instruction?

Theoretical framing

Through the lens of cultural historical activity theory (CHAT; Engeström, 1999), this research conceptualizes professional development as activity systems within which teachers (subjects) and professional development (means) jointly endeavor to enrich teachers' understanding of technology implementation in instruction, particularly teachers' attitudes toward, approaches to, and engagement with technology (object). Integral to this activity structure are the tools and signs used to mediate the relation of subject to object. In this case these tools include teacher understanding of STEM instruction and pedagogical skills and strategies used in STEM instruction. The tools of teacher understanding of STEM and pedagogical skills are developed from within the

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activity system but, they can also draw them in from other activities or experiences (Greeno & Engeström, 2014). Thus, teachers may draw on their experiences with technology and other pedagogical constructs as tools to increase their abilities to incorporate technology. Further, as members of the activity system community, teachers are likely to adopt and transform these tools and representations over time (Schwarz & Hershkowitz, 2001) as ways to support future students in their pursuit of learning outcomes. As such, teachers are likely to be more reflective about encounters with these conceptual tools as constructions of meaning new to their instructional design (Koschmann et al., 1998).

Methods

To explore teacher attitudes toward, and engagement with technology, this research uses a multiple case study design to analyze field notes and memos for themes in the data responsive to the research questions. These themes are then explored through reflective interviews with the participating teachers to enhance understanding.

Participants

On the Big Island of Hawaii, the rural town of Nui Huna is located halfway between the two cities on the island and has a 70% free/reduced lunch rate in public schools. The two teachers participating in this study were selected for their prior teaching experience. Amy (pseudonym) is a white woman who moved to the island eight years ago, is certified in multiple subjects, and has been teaching for over 15 years. Jill (pseudonym) is also a white woman who has lived on the island her whole life and has taught middle school for 10 years.

Professional development

Teachers were engaged in a faded scaffold of support for learning and practicing, working with students using STEM and computing skills and competencies. This approach emphasizes the importance of tracing, commenting, and explaining code as a means for developing understanding of these constructs as tools and signs (Lopez et al., 2008; Murphy et al., 2012). Working within the structures of a summer school schedule following initial workshop training, teachers experienced three different roles within the classroom whenever possible. During the first period of the day, teachers were observer learners, making projects alongside students. In the second period of the day, teachers stepped into the role of teacher with the support of the PD provider. At the close of the school day, teachers and PD providers debriefed on the day as well as previewed the coming day. This approach towards training teachers provided them both with the knowledge they need to engage these practices in their classrooms and immediate opportunities to practice teaching with supportive team members standing by. Because teachers often express anxiety or fear at engaging these new approaches (Howell et al., 2016), scaffolding their first coding teaching experience with their PD provider present allows teachers to professionally take risks and expand their abilities without fear of failure.

Design and data sources

This research utilizes a case study design to explore teacher attitudes and engagement with technology in an authentic situation as experienced with learning and implementing coding and computing into instruction.

Analysis

We analyzed fieldnotes, interviews, and audio recordings from professional development and classroom instruction. Data sources were open coded to explore the study's research questions. As themes emerged through open coding, we recorded these to creating memos. Follow up interviews were then conducted to member check or explore further emerging themes found within the data. After completing initial coding analysis, follow up interviews were conducted with both participants to dive deeper into the initial themes.

Findings

The initial codes from the field notes were listed sequentially to identify patterns. The patterns were then described as possible themes. For example, patterns of multiple codes in Amy's personal learning and co-teaching data (e.g., Teaching insecurities, Anxious focus on planning, Anxiety over learning about technology) pointed out an overwhelming concern or anxiousness during learning and instruction. This theme is Anxiety.

A second theme surfaced from the data for Jill. Specifically, the codes Learns quickly, Independent learner, Independent teacher with own ideas, "Frills free and efficient", and Lack of attention to detail all converged around the notion of autonomy in learning. This theme is Independent Learning.

Additionally, when analyzing the code patterns for both teachers, the code Technology is lower priority seemed to precede the code Disconnect between teacher and students. This theme is labeled:

Disengagement.
Hence, the following initial themes emerged in relation to the teachers' attitudes toward, approaches to, and engagement with computing:

1. **Anxiety**: Overwhelming concern toward learning and instruction. In the initial codes, despite her many years of experience, Amy demonstrated patterns of teaching insecurities. She was anxious with a focus on planning. She articulated anxiety regarding learning coding and was anxious about approaching and engaging with technology during instruction.
2. **Independent Learning**: Desire for autonomy in learning. Jill shared ideas of independence to choose the speed of learning and independence to choose her focus during instruction.
3. **Disengagement**: Disengagement with technology precedes disengagement with students. Despite their interest and willingness to engage technology within their classrooms, Amy and Jill also both demonstrated a disengagement from technology or seeing themselves as teachers of technology.

Interview data analysis

Findings from the data analysis of the interviews with both teachers consistently confirmed both the anxiety and independent learning themes. For example, during the interview, Amy responded: "I've always had a hard time conceptualizing coding…the idea that I had to learn this and then, and then like possibly have to answer questions in like help [of students]" and "You're presented with new things and asked to do new tasks that you don't know how to do, you're anxious about it", which confirmed the anxiety theme. Also, the independent learning theme was observed through comments like when Jill said: "I have low exposure [to technology], but I'm kind of comfortable fiddling. I mean, I feel bad if I do something wrong, but like I'm not scared of it" and "I like to have time working independently through something…just because I don't like the pressure of like going too slow, going too fast, that kind of stuff." Of note, through interview the teachers did not perceive their own disengagement but rather focused on the value of the professional development.

When considering the attitudes expressed by teachers both in general and within their classrooms, it appeared that the relationship between the teacher (subject) and their attitudes toward computing with technology (object) were moderated by a specific means (professional development). Amy's initial attitude toward computing and technology was one of anxiety. However, during the interview, she relaxed and was optimistic when discussing time spent in professional development. Specifically, she expressed that the professional development provider was able to answer her questions and provide her with the tools she needed to be successful teaching.

Jill's expression of independent learning also appeared to moderate when discussing the idea of implementing computing into her classroom instruction. She expressed her desire to have help learning how to integrate computing into her curriculum. She felt this could be accomplished by means of professional development. Jill's independence was observed most robustly in the projects during which she engaged most carefully within the professional development. In other words, her independence was mediated by the professional development and her attention to it.

In both cases, the professional development served as means to moderate teacher attitudes by supporting teachers as they developed their knowledge of computing. The dynamics of this moderation resembled action as a more knowledgeable peer that supports others in developing through what Vygotsky (1978) termed the zone of proximal development. For both teachers, their ultimate desire was to enhance and deepen their content knowledge. They approached and engaged with technology from the perspective of using it to effectively teach content. Integration was a critical reason for their engagement with technology, which prompted the creation of a new theme- *Integration*. This replaced disengagement as a theme because it better explained teachers' reasoning. Specifically, computing was an instructional approach that provided these teachers a way to further student understanding of their content knowledge.

Overall, all three themes suggest that getting teachers to engage with the tools (computing and technology) required or will require a more knowledgeable other (Vygotsky, 1978). This allowed Amy to feel confident and secure in integrating computing and technology into instruction and can allowed Jill to see how to integrate computing and technology more fully into her instruction in ways that deepen and enhance the content. It appears the most important moderating factor for teachers to consume and produce with computing during professional learning experiences was the professional development provider (mean). This person provided the means for helping teachers feel confident, capable, and able to implement the new strategy into instruction.

Discussion

This paper showcases the beliefs and experiences of teachers seeking to engage in teaching with technology. Of all the means engaged by the teachers in this study, it was their experiences of the professional development that drove their beliefs about technology. Specifically, we see shifts from anxious and avoidant behaviors to accepting and engaging behaviors that manifest as a function of relational interactions that shift the distribution of labor from isolated engagement with technology on the part of the teacher to a cooperative effort between the teacher and the professional development provider. When asked, the teachers felt that this shift was possible for them because of the support of the professional development provider. This speaks to the value and importance of slow and tailored professional learning for rural teachers.

By meeting teachers where they are *and* fostering their ability through engagement with their interest, professional development provides a unique opportunity to serve as both peer and more knowledgeable other within the space of their own learning. While the beliefs and attitudes experienced by teachers are often shifting, finding means that can facilitate shifts in belief can better support technology engagement and adoption within classrooms.

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International Society of the Learning Sciences

"Design for Co-Design" in a Computer Science Curriculum Research-Practice Partnership

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Abstract: This paper reports on a study of the dynamics of a Research-Practice Partnership (RPP) oriented around design, specifically the co-design model. The RPP is focused on supporting elementary school computer science (CS) instruction by involving paraprofessional educators and teachers in curricular co-design. A problem of practice addressed is that few elementary educators have backgrounds in teaching CS and have limited available instructional time and budget for CS. The co-design strategy entailed highlighting CS concepts in the mathematics curriculum during classroom instruction and designing computer lab lessons that explored related ideas through programming. Analyses focused on tensions within RPP interaction dynamics and how they were accommodated when RPP partners were designing for co-design activities, a critical component that leads to curricular co-design itself. We illustrate these tensions with examples of clusters of activity that appeared repeatedly among the research and practice team members when "designing for co-design".

Introduction

Research-practice partnerships (RPP) are gaining traction as a model for supporting practice-driven lines of inquiry and educational improvement in the learning sciences. While this represents an encouraging development for those interested in working on persistent problems of educational practice, Coburn and Penuel (2016) have also observed that "given new investments in RPPs, we need parallel investments in research on the dynamics and outcomes of partnerships. Studies of partnership dynamics are crucial to enable new partnerships to learn how to do this work and for existing partnerships to learn from each other's experiences" (p. 52). In this paper, we report on early empirical work designed to heed Coburn and Penuel's call to intentionally study partnership dynamics. Specifically, we examine one type of RPP, the design research partnership (Coburn et al., 2013), and specifically the curricular "co-design" model (Penuel et al., 2007; Voogt et al., 2015). Our goals in this paper are to illustrate some of those partnership dynamics interactionally – through actual descriptively analyzed researcher and practitioner conversations - and argue more broadly that a part of that partnership dynamic research should attend to the meta-design work involved in RPP teams designing for co-design.

Framework: Design for Co-Design

While the RPP structure is key to our endeavor, our emphasis is on the work that surrounds the co-design activity itself. As a genre of curriculum development, co-design and related collaborative approaches (e.g., work circles; Shrader et al., 1999) are intended to be activities in which educators and design-oriented education researchers jointly do the ideational and prototyping work of curriculum improvement (Arce-Trigatti et al., 2018), rather than following a more typical sequence of late-term educator involvement using researcher-created curriculum and post-hoc feedback. This co-design configuration can serve to disrupt perceived and common imbalances between researchers and practitioners. However, there are a number of challenges to navigate in co-design because it brings together different communities with distinct histories, norms, and commitments to engage in joint work. Parts of this will ultimately be negotiated during the co-design activity itself, but that opportunity to do that negotiation is itself designed. Thus, we assert that there is an additional layer of design work that takes place to prepare for the co-design activities. We refer to this additional layer of work as "designing for co-design" and show how it is also a critical component that contributes to successful curricular co-design (see Figure 1).

For our partnership (funded by National Science Foundation Grants 2031382 and 2031404), design for co-design was necessary work because the co-designing educators (e.g., teachers) became involved after the grant supporting this RPP had been awarded. However, we contend that designing for co-design is necessary and common work done by RPP teams with longer partnership histories, particularly when new members (e.g., new teachers, district personnel, research assistants) are invited to join and take on active roles following natural turnover. In similarly-oriented work, this type of effort to open up space for full participation in co-design work has been characterized as organizing for teacher agency (Severance et al., 2016) and has lent itself to retrospective

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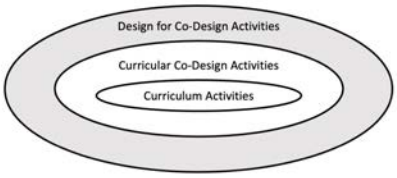
analyses of field notes and artifacts from co-design sessions. The present study complements and is informed by Severance et al., although it examines a different geographical context, a different subject matter and age group, and paraprofessional educators in addition to classroom teachers. Moreover, we articulate in this paper the conditions and constraints that were managed during this case's design for co-design.

Figure 1
Concentric circles of design involved in curriculum design research-practice partnerships.



RPP Context: An Integrated Math-Computer Science Co-design Project

The study context comes from an RPP that seeks to support and co-develop elementary school computer science (CS) instruction that involves paraprofessional educators (whose position title in the district is "computer lab specialists") and classroom teachers in a rural-serving U.S. school district. A key problem of practice addressed in this RPP is that very few elementary school teachers have backgrounds in or comfort with teaching CS. The computer lab specialists were newly being asked to provide the CS instruction. The strategy being pursued by this RPP was to identify and highlight CS concepts in the already adopted mathematics curriculum and then structure the computer lab lessons as activities for exploring the same related mathematical ideas through a computational medium (i.e., Scratch). Adequately supporting the professional learning of paraprofessionals represents another set of persistent problems of practice.

Data, Interpretive Methods, and An Illustration

Our project was designed to study partnership dynamics from conception. Project personnel were assigned to lead an empirical study of the interactional dynamics within the RPP itself. This was in addition to other team members conducting research on educator learning and student experience with the newly designed learning activities. This self-examination component provides the data for this study, which took place during the COVID-19 pandemic when social distancing and remote work measures were in place. As such, virtually all activities up until this writing had taken place via Zoom, and video recordings of these meetings serve as the primary data source. In addition, the team members leading the RPP dynamics research conducted interviews with all participants and collected artifacts such as agendas and common documents. Data included 14 recorded weekly meetings (each 1-1.5 hours) involving 7 university-affiliated researchers (Principal Investigators and Graduate Researchers) from two institutions and 2 school district central office employees (Curriculum Leads). In addition, there were three, hour-long co-design meetings that included three classroom teachers and one computer lab specialist.

The analysis essentially involved recording RPP interactions, coding and curating them, and then engaging in more detailed descriptive analysis of the content of the curated interactions. These analyses were vetted by the larger group. This bears some resemblance to interaction analysis (Jordan & Henderson, 1995), which involves obtaining recordings and iteratively engaging in group analysis and argumentation of clips to forming an interpretation that is justified by evidence apparent in the record (e.g., specific utterances or words used by a speaker).

To illustrate, an example excerpt that was coded as **DESIGNING CO-DESIGN** and curated from the corpus appears below. This example excerpt, while long, is presented to give a sense of the type of interactional speech data that were examined and also to illustrate how **DESIGNING CO-DESIGN** episodes fit the following criteria: 1. The conversation had contributions from members of both the research and practice organizations, 2. The topic of conversation was related directly to how to structure the curricular co-design activities, and 3. From review of other meeting records and artifacts, the conversation ultimately led to a decision about the organization of the co-design activities themselves. In this excerpt, the first co-design meeting was scheduled to take place. It was the first time the classroom teachers and computer lab specialist explored how to design integrations between classroom mathematics content and computer lab instruction. In thinking about this meeting, researcher M raised the concern that it was unclear how to introduce the goals of the planned co-design. Researcher J offered a suggestion, and then district leader B offered her support for J's suggestion. Then B and district leader S voiced constraints: there was a lack of crossover content knowledge between the teachers and computer lab specialist.

University Researcher M: *You know, thinking about this first meeting, and, you know, the teachers as partners, but not overwhelming them. I mean, yeah -- I'm just trying to envision how we can talk about sort of the objectives here and get meaningful input on what units makes sense to them. Any suggestions?*
University Researcher J: *They don't know anything about Scratch or what the capabilities are, it may be hard for them to envision that. So I wonder if there's a way we can kind of, without too much information, but to give them some kind of like overview of some examples in Scratch or something, maybe this other curriculum that you mentioned -- something that gives them an idea, something to kind of think about, they can envision it.*
District Leader B: *I was gonna say, I think that that would really help our teachers, especially where they do have limited exposure to computer science, giving them a kind of a -- an idea of what it looks like, would be helpful for sure. And I know with this team, too, they have interest in computer science, but they haven't had a lot of experience with it. With the classroom teachers, for sure. So I think that would be a great idea.*
District Leader S: *And how much is the computer specialist going to need to understand about the math concepts to teach it properly? That's also going to be a potential constraint.*

In this segment, a common underlying question explored by all four speakers was how to make the work of co-design feel tractable and approachable for the teachers and lab specialist who would, at a designated and time-limited future meeting, begin this work for the first time. Following Severance et al (2016) in wanting to "present the vision" for innovative learning activities as stimulus for curricular co-design, researcher M questioned how the co-design could be presented to "get meaningful input". This question led to articulation of two fundamental challenges for the planned co-design. First was the unfamiliar end goal of integrated lessons needed to be envisioned but the team wanted it to be rooted in the ideas of the co-design team. They did not want to overly constrain the co-design team's thinking nor provide examples that already solved the design problem nor provide poor examples that did not encourage ambitious integrated instruction. Utterances from M and J expressed this, as did other utterances during the meeting. Second was how to negotiate two different content areas while recognizing what knowledge was necessary to teach integrated lessons. On the one hand, CS as a focal topic was unfamiliar to the classroom teachers (speaker B). On the other, the specialists were not assumed to have the degree of mathematical knowledge for teaching that the classroom teachers would have (speaker S).

It ended up taking several additional RPP planning meetings to get there, but a decision was eventually reached to introduce a Scratch programming sample and view it together in addition to a small set of practitioner-facing examples from practitioner publications to express that there were numerous viable possibilities that could be developed. Regardless, this excerpt serves to model the challenge, show the data used, and illustrate how our analysis worked to maintain accountability to the transcript data as we analyzed interactions.

Additional Examples of Design for Co-Design Challenges

As a short paper reporting on a project that is still in progress, our goal is to argue that design for co-design is a component of RPP co-design structures and that it contains worthwhile design questions for learning scientists to explore. While longer post-hoc analysis will come in the future, we consider it worthwhile for the learning sciences community to already begin recognizing and discussing this design for co-design space that many RPPs already have and are encountering. Given that, the remaining empirical examples are illustrative to name some design for co-design challenges. These were derived and analyzed in the fashion briefly modeled above.

Negotiating Technological Infrastructure Across Partners

One recurring set of concerns we have seen across "designing for co-design" meetings, especially leading up to the first co-design session, was how to manage digital systems. A concern among partners was that the university team might appear as having the greatest amount of influence. This extended to what technologies were used and how co-design engaged with those technologies. The university had contracts with various vendors including Box.com, and the university's institutional review board (IRB) required that Box be used for security purposes with human subjects data. This led to the university defaulting to Box for its online storage infrastructure. However, a district team member expressed that Box was not familiar to district personnel: "*I just think it needs to be easy for teachers -- Box is not intuitive by any means. And I think it, you know -- teachers are used to Google drive*." The university team was bound by IRB rules to use Box, yet opted to maintain both Box and Google-based volumes, with Google Drive used exclusively for co-design so that district partners would not feel like they were encumbered with needing to use 'the university's preferred tools'. While this is one decision, there were several others. For instance, the project created a design group email list through Google groups so administrative control and email names did not have the university's address in them, further detaching those aspects of co-design

communications from the university's tools. Elsewhere, it extended to questions about calendaring systems and Zoom accounts to use as those could represent influence in the partnership.

Moving Away from Researcher-favored Dialects

Another topic that came up in "designing for co-design" work was what language to use. While education researchers are currently enthusiastic about RPPs, it is unclear how widely known the term is among practitioners and how enthusiastically it is endorsed. To illustrate, district team member S, who had been part of writing the grant referred to the entire endeavor in a meeting as: "*You know the design, you know the practice design practice partnership*". While we were confident this person valued and enthusiastically supported the partnership, the RPP term itself was not one that seemed of great importance to S. One of the university project leaders was sensitive to this and explicitly acknowledged it during a meeting and at one point mentioned "*the things I'm planning to say -- I'm trying to avoid too much jargon – 'research-practice partnership' would certainly be under the umbrella of jargon*". Thus, the point here is that there are different language communities coming together where terms are bestowed different status. Forcing or policing these could inadvertently signal power or influence on the partnership and in designing the co-design, decisions were made to recognize and avoid giving those signals.

This question of terminology even extended to the terms 'design' and 'co-design'. Researchers, and especially learning scientists, value design and treat it as agentic and generative activity. However, a district partner commented that "design" implied a lot of time and effort. For example, many teachers do not think of their work leading up to classroom instruction as "designing" their lessons but rather "planning" their lessons. This was illustrated by the following comment during a meeting about what to call the team of (what we as learning scientists call) curriculum co-designers.

> District Member B: *I do think that, from the teacher's perspective -- going to the word adapting makes the challenge less overwhelming, because when you're talking to a teacher about designing units -- that's a long-term time-intensive process -- but adapting I think is a better word for that.*

As we, the authors of this paper, are participants in and are addressing the learning sciences community where "design" is discussed, we comfortably use the term here. However, the RPP team that was designing the co-design elected to leave this determination to the co-design team. "Design" was offered as a descriptor, but the teachers and specialist viewed it as "integration". This became part of the collective identity that emerged, and that group even gave themselves the name "Code Math integration group" that did not use the "design" term.

Conclusion

RPPs and co-design have been proposed as newer vehicles for joint work between researchers and practitioners. There is a need and call (i.e., Coburn & Penuel, 2016) to not only study RPP outputs but also their internal dynamics. Among those, we argue, are the steps taken within a design RPP to design for co-design activities. We believe and sought to illustrate that this additional layer of work is productive and that such work is quite common but unstated. Our examples in this paper show what some of this work looks like, and we invite the learning sciences community to further explore this space so that more generative and equitable RPPs can be developed and maintained in the future.

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International Society of the Learning Sciences

Feeling Irregularly White: The Role of Emotions in Activist Learning

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Abstract: Building on learning sciences literature that centers emotions, this paper explores the interplay between learning emotions and learning cross-racial allyship. Research in the learning sciences has often set aside the role of emotions in learning. In recognition that learning to counter White supremacy typically involves a wide range of emotions—from compassion and righteous anger to fear and denial—we explore the affordances of analyzing emotions around activist learning. For this purpose, we analyze a memoir written by Mab Segrest, a White anti-racist activist who learned to become a cross-racial ally with Black activists in the Southern United States. We incorporate affect theory with situated and sociocultural learning theories to conceptualize emotions as both social practices and cultural artifacts. The findings describe how cross-racial allyship learning involves the negotiation of one's own emotions alongside the emotions in one's community.

Introduction

> *I had begun to feel pretty irregularly White. Klan folks had a term for it: race traitor. Driving in and out of counties with heavy Klan activity, I kept my eye on the rearview mirror, and any time a truck with a Confederate flag license plate passed me, the hair on the back of my neck would rise. (Segrest, 1994, p. 80)*

Emotions are core to human experience (Ahmed, 2013). As learning is a fundamental human activity, this means that the relationship between learning and emotions requires attention. This is particularly true in learning how to counter social injustice, as learning scientists have begun to consider the emotional dimensions of learning to be an activist (see Vea, 2020). Specifically in the context of racism, learning to counter White supremacy (i.e., anti-racism) typically involves a wide range of emotions: from compassion and righteous anger to fear and denial. Understanding the complex ways people negotiate this constellation of emotions can shed light on how people learn anti-racism.

This paper focuses on the life of Mab Segrest, a White anti-racist activist who became a "traitor" to White supremacy through grassroots organizing in the 1980s. This work derives from a larger study of how people learn anti-racism. Elsewhere, we have begun developing a methodology for characterizing anti-racism learning, particularly along long timescales (Shah & Hou, in press). Here we focus on the emotional entailments of anti-racism learning—in this case, as Mab learned to become a cross-racial ally with Black activists in the Southern United States. Specifically, we draw on situated and sociocultural perspectives on learning to analyze Mab's shifts from sympathy *for* the Other, to sympathy *with* the Other, as well as the myriad of racialized emotions that followed and expanded beyond empathy (Bonilla-Silva, 2019). The following research question oriented the study: *What emotions mediated Mab's understanding of herself as a White person, and how did they facilitate her learning of cross-racial allyship?* Our findings contribute to learning sciences research by illustrating the affordances of conceptualizing emotions both as social practices (see Vea, 2020) and as sociocultural artifacts. We conclude by discussing how a perspective that accounts for multiple emotions, as opposed to one-dimensional approaches to racial healing, can lead to better designs for learning racial justice activism.

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Conceptual Framework

Here we explore the interplay of learning emotions and learning cross-racial allyship, with an emphasis on emotions specific to racialized societies (Bonilla-Silva, 2019). We use the term "Whiteness" to describe a form of discourse and ideology, rather than individuals with white skin. In other words, Whiteness denotes "the structural valuation of [lighter] skin color, which invests it with meaning regarding the overall organization of society" (Leonardo, 2009, p. 92). We examine Mab's personal and activist journey as she questions the validity of Whiteness and engages in anti-racism.

Our claims around Mab's learning attempt to describe emotions through the perspective of situated and sociocultural learning theories, particularly the concepts of social practices (Lave & Wenger, 1991) and cultural artifacts (Vygotsky, 1978; Wertsch, 1998). The field of learning sciences has often set aside the role of emotions "through outright exclusion or through ways of thinking that separate emotion as an external force on learning" (Vea, 2020, p. 314). However, addressing emotions is imperative if we want to comprehensively understand learning. For this purpose, we incorporate aspects of affect theory with situated and sociocultural learning theories. Through affect theory, emotions become a lens through which to understand human behaviors (Ahmed, 2013). Drawing on situated learning theory, we conceptualize emotions as "[producing] the effect of surfaces and boundaries of bodies" (Ahmed, 2013, p. 194), thereby acting as social practices that bound specific communities together (i.e., communities experiencing joy or grief or other emotions). Through Vygotskian sociocultural learning theories, we incorporate Ahmed's (2013) concept of "stickiness", describing how "the work of emotion involves the 'sticking' of signs to bodies: for example, when others become 'hateful', then actions of 'hate' are directed against them" (p. 13). By extension, emotions convey how different cultural artifacts "stick" to different racialized bodies. We add here to Vea's work on viewing emotions as a form of social practice, "of expression/emoting and emotional management" (2020, p. 315), and explore the parallel affordances of viewing emotions as artifacts.

Method

Our qualitative approach attempts to understand, interrogate, and deconstruct the emotional dimensions of lived experiences (Bhattacharya, 2017). We specifically employed methods designed to analyze emotions from written text. By treating a memoir as data, we examined emotions on an individual scale but also connected to the people and historical events shaping a person's life. We chose Mab's memoir, *Memoir of a Race Traitor* (1994), from a collection of 20th-century U.S.-based anti-racist activist memoirs, which was generated from a larger study of how people learn anti-racism (Shah & Hou, in press). Given the necessary role of White people in anti-racist struggle, we were especially curious about Mab's identification as a "race traitor," and we analyzed a specific excerpt of the memoir where the emotions around being a race traitor were prominent (e.g., Mab's emotions around White individuals and in relation to her mother) (Segrest, 1994, p. 80-82). Our racial positionalities as Han Taiwanese (Hou) and as Brown (Shah) also informed our perspectives around cross-racial allyship.

Set in the 1980s when Mab joined North Carolinians Against Racist and Religious Violence (NCARRV) and participated in anti-Klan activity, our selected data describe Mab's shifting emotions, perspectives, and behaviors as she gradually understood herself as a race traitor. In other words, Mab began to recognize herself (and observe how others recognized her) as a White person who acts against White racial interests. In our analysis, we identified Mab's emotions by focusing on explicit emotion words used by Mab (e.g., fear, sorrow, self-hatred, suspicion). While we recognize that memoirists might not fully disclose all that they are feeling, we believe that using in vivo text provided valuable insight into Mab's emotional landscape.

Findings

First, we analyze events from Mab's life through a lens of emotions as social practices, and then we analyze other events through a lens of emotions as cultural artifacts. Together, the findings show that while emotions are racialized

and situated within racialized societies, emotions evolve alongside a fluidity of racial subjectivities (Bonilla-Silva, 2019, p. 5). That is, in Mab's case, although her emotions were situated in her position as a White lesbian woman, her emotions diverged from White folks around her as she continued her anti-Klan work.

Emotions about Whiteness as Social Practices

> I often found myself hating all white people, including myself. As I took on racism, I also found its effects could be turned on me. The possibility of overt violence or the reality of subtle ostracism gave me a sense of shared risk, not the same as the dangers faced by my friends of color, but close enough. I began to feel more uneasy around other whites and more at ease around people of color. ... Could I find ways to share and appreciate other cultures without mimicking or appropriating them, without denying my continuing white privilege? (Segrest, 1994, p. 80)

As Mab continued to participate in anti-Klan activity with NCARRV, she began to interpret Whiteness differently. Emotionally, she described feeling a growing sense of suspicion towards White strangers, seeing them as threatening and keeping her guard up around them. For example, in restaurants with predominantly White customers, she would sit with her back against the wall and eye White strangers with suspicion (p. 80). As a social practice, her emotion of suspicion described a sense of shared risk with her friends of color and established boundaries between her and White strangers, resonating with the ways that affect "...produces the effect of surfaces and boundaries of bodies" (Ahmed, 2013, p. 194). Mab's participation in suspicion created distance between herself and White strangers and, by extension, Mab noted feeling more comfortable around Black, Indigenous, and other people of color (BIPOC) rather than White individuals. Overall, we view Mab's suspicion towards other White people as a social practice central to the NCARRV community, which in turn bound her away from White people in other communities.

Emotions about Whiteness as Circulating Artifacts

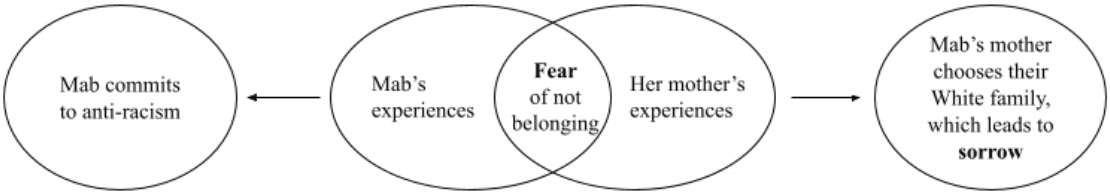
Mab also began to interpret her own Whiteness as a target for self-hatred. She described how her hate for White people began to extend towards herself. Resonating with literature on the "stickiness" of affect (Ahmed, 2013), this newfound self-hatred can be understood in terms of Mab's appropriation of cultural artifacts as she grappled with viewing Whiteness as something to reconstruct or abolish (Leonardo, 2009). That is, she began wondering if it was possible to acknowledge White privilege while reclaiming her Whiteness. For Mab, Whiteness was no longer something that is benign and ignorable, but rather something that necessitated profound change.

As Mab moved about the world as a race traitor, she experienced difficulty finding belonging in either White or BIPOC communities, which led to fears around her safety and belonging (p. 80). We argue that her fear can be viewed as a cultural artifact, made available by Mab's position as a race traitor. Further, appropriating fear allowed Mab to forge an important connection: with her mother and her mother's emotions. Before Mab was born, Mab's mother had been in a similar situation: she had received a job offer as a registrar to *oppose* racist voter suppression but decided to turn it down and maintain her family ties. In reflecting on this life event, Mab's mother said, "When people have to choose, they will go with their own race," (p. 81). This particular experience generated considerable sorrow for Mab's mother, which she later confided to Mab: "My mother was a woman deeply torn by the racism into which she was born. She shared her sorrow with me, often telling me stories of how she and a friend had stopped a Klan rally on the courthouse steps by protesting to the mayor" (p. 81). This sorrow, as a cultural artifact, was available across time and between bodies (see Figure 1). Specifically, when Mab began to feel the fear of not belonging to either White or BIPOC communities, she recalled her mother's similar experiences, which took place years ago. She said, "I had inherited from my mother an awareness of the deep schisms in our culture, and I suspected that it was her attempts to negotiate them that eventually destroyed her. When push came to shove, could I make a different choice?" (p. 82). As Mab negotiated with her fears and her mother's sorrows, she wondered if she could make a different choice

from her mother. In a certain sense, Mab's appropriating the artifact of her mother's sorrow eventually led to a participation shift in social practices, as she furthered her commitment towards anti-racism in comparison to her mother.

Figure 1

Emotions as cultural artifacts in Mab and her mother's lives.



Discussion

This study has explored the affordances of analyzing emotions around activist learning as both social practices and cultural artifacts. We concur with Vea's (2020) prior work highlighting the value of analyzing emotions as social practices. We build on that work by bringing into focus the possibility of examining emotions as artifacts. In particular, we have described how emotions (as cultural artifacts) pass between bodies, traverse time, and shift one's participation in social practices. In relation to cross-racial allyship and anti-racism, this work also shows how such learning involves the negotiation of emotions beyond empathy and the negotiation of one's own and one's community's emotions. In recognition of the role of emotions, we raise several questions for the learning sciences community. With respect to theory, what might an integrated theory that incorporates emotions into learning theories look like? With respect to methodology, when should we choose to examine emotions as artifacts or as social practices? With respect to practice, how do we respond to these shifting emotions in order to create a more supportive environment for anti-racism learning? We believe further research into the role of emotions would be critical to promote better designs for supporting the learning of anti-racism.

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International Society of the Learning Sciences

Exploring the Process of Group-Based Collaboration: A Validation Argument for a Collaboration Model and Observation Rubric for Training Explainable Machine Learning Models

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Collaboration is an important learning process. During collaborative learning, students engage in group activities where they converge on goals, solve problems and make joint decisions. To understand the process of collaboration, we focused on how behavior and interaction patterns contribute to the social-relational space of collaboration. We have designed a multilayered conceptual model for the collaboration process and an observation rubric that identifies behaviors and interactions during collaboration that serves as the foundation for machine learning models that can provide behavioral insight into the process of collaboration. This study reports results on several validation studies performed to establish a validation argument for our collaboration conceptual model and collaboration rubric. Through disconfirming evidence, interrater reliability testing, expert reviews, and focus group interviews, we found that our stratified architecture of collaboration and rubric provide valid accounts and descriptions of human behavior and interactions that can be used to substantiate the collaboration process.

Introduction

Collaborative learning experiences involve interactive peer-to-peer interactions as students solve problems and converge on decisions (Roschelle, 1992) and is comprised of speech-based and behavior-based interactions that intersect for successful product outcomes. Collaboration is a central component of how students learn but presents challenges when determining its role in the learning process. Teachers use speech, namely, discourse and the quality of group products to determine how students negotiate solutions to problems as part of the collaboration process (Roschelle & Teasely, 1995; Guo, Saab, Post, & Admiraal, 2020). For this work, we use machine learning to delve deeper into the behavior-based interactions that students exhibit when collaborating because it is important for students to be mindful of how speech *and* behavior work together for the creation of high-quality group products (Steinbock, 2008). To explore the feasibility and challenges of using behavior to explain the process of collaboration, we have designed a stratified conceptual model for collaboration and rubric that uses nonverbal behaviors and interactions to identify patterns of collaboration to train machine learning models that can provide behavioral analytics for collaboration.

We performed various validation studies of our collaboration conceptual model and rubric to derive a validation argument for valid, reliable, and objective constructs of collaboration. To demonstrate a construct validity argument, we present evidence from disconfirming approaches, interrater reliability testing, expert reviews, and focus groups interviews. Our validation research questions are as follows: (1) How does our concept of collaboration accurately represent theoretically based constructs of collaboration? (2) To what extent do individual key behaviors demonstrate collaboration competencies needed in group settings? (3) To what extent does nonverbal behavioral information from each level of collaboration provide teachers with adequate information for understanding how well students collaborate?

Literature Review

Collaboration As a Process

We describe collaboration as a complex process through which a group of students interdependently and constructively explore ideas to search for solutions, construct new knowledge, and create a socio-cognitive space to generate and share goals, ideas, plans and tools (Roschelle, 1992; Grosz & Kraus, 1996; Child & Shaw, 2015). Our work focuses on two components of collaboration: 1) the process of collaboration (Roschelle & Teasely, 1995), and 2) the nonverbal gestures and behavioral interactions exhibited during collaborative group work.

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Our collaboration conceptual model (Alozie et al., 2020) is based on theoretical models that bring together research on social factors (i.e., behaviors, social cohesion), cognitive science (i.e., social-cognitive systems), and education research (i.e., problem-solving strategies). We broke collaboration down into four building blocks. (1) *Gestures*, where students move their bodies to express an idea or meaning. (2) *Individual awareness,* where students build a community through their understanding of self. (3) *Social and cognitive awareness,* where students engage in cooperative interactions (Johnson & Johnson, 2008), interdependance, and build an understanding of "other" in a group space. (4) *Shared interactive culture*, where students share plans, intensions, goals and tools and work as a team.

Automating Collaboration Assessment Using Speech-based and Behavior-based Analytics.

The use of multimodal learning analytics offers insights into how students learn when performing unstructured tasks like problem solving in the digital and physical world (Blikstein, 2013). Emerging work in speech and textual analytics has shown promise in using machine learning to observe group interactions. Online collaboration assessment has been done through the analysis of peer discourse (Erkens & Janssen, 2008). Other research has collected speech-based data of students working face-to-face to assess collaboration quality (D'Angelo et al., 2015). Behavior analytics for collaboration has made great gains in isolating gestures, sounds, and interactions that can indicate the quality of collaboration (e.g., Subburaj et al., 2020). Visual behavior analytics have focused on evaluating individual facial expressions, group interactions, affect, and task success (D'Mello, 2020). Some studies combined speech and behavior analytics to assess collaboration (Martinez-Maldonado et al., 2013).

Addressing Bias in Artificial Intelligence and Human Interactions

Biased data will create biased machine learning models. If the training data is more representative of some behaviors than others, then the model's predictions would systematically be biased against the under-represented behaviors, and vice-versa (Roselli, Matthews, & Talagala, 2019). We understand that eradicating all bias is difficult and use vetting of the training data to decrease the occurrence of biased annotations (Roselli, Matthews, & Talagala, 2019). To address potential bias due to unequal amounts of data, we perform controlled mix-up data augmentation (Som et al., 2020) which creates additional training samples that use features from existing samples. To expand our sample variation, we recruit students that are diverse in race and gender identification and provide anti-bias training for human observers and analysts. We also use a modular annotation approach to avoid propagating bias across samples and to increase the explainability of each machine learning model.

Methods

Validating the Collaboration Conceptual Model and Rubric Using Disconfirming Evidence and Interrater Reliability Testing. We used discomfirming evidence (Booth et al., 2013) to establish validity of our collaboration conceptual model (RQ1); a procedure whereby the researcher looks for areas of disagreement and for divergent data (Roselli, Matthews, & Talagala, 2019). Two education researchers with expertise in learning science, classroom studies, and STEM education examined the collaboration conceptual model, looking for areas of disagreement. Six different researchers also watched and annotated videos (Barron & Pea, 2013) to establish inter-rater reliability (Cohen's Kappa above 0.6; Landis & Koch, 1977) and look for areas of disagreement. When disconfirming evidence was found, the researchers discussed their responses, came to a consensus, and refined the collaboration rubric.

Validating the Collaboration Rubric Using Participant Focus Groups. To determine the authenticity of our collaboration rubric (RQ2), we convened 9 focus groups that demonstrated diversity in age, race, gender, and occupation. Participants were asked several questions about collaboration. For example, *How do you define collaboration?* and *What do you think are the characteristics of a good collaborator?* We used open coding and selective coding processes to analyze the transcriptions of focus group interviews.

Validating the Collaboration Conceptual Model and Rubric Through Expert Reviews. We conducted expert reviews of the collaboration conceptual model and rubric using a survey and open-ended questions (RQ2 and 3). The expert review was a questionnaire consisting of Likert scale questions about the alignment of the collaboration building blocks to theory-based descriptions and constructs. For example, experts were asked questions like "*To what extent do the building blocks [of collaboration] align with the descriptions [of collaboration]?*" and given choices ranging from *Does not align* to *Aligns very well*. Using qualitative thematic analyses of the open-ended responses and calculating reliability scores of the ratings, we checked for consistency across reviews and then determined a set of revisions based on recommendations.

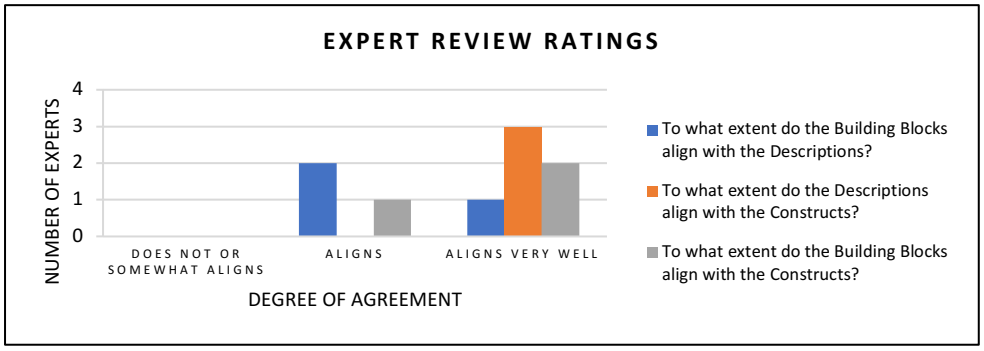
Findings

Definition of collaboration. Most participants stated that collaboration can be defined as shared goals, diversity, inclusivity of behaviors and interactions, distributed responsibilities and roles, an intersection of talents, and opportunities to participate. For example, one participant from Group 7 said, "The bare bones definition of collaboration is just a group working towards a common goal, and everyone bring their own ideas, background and experience in achieving that goal, whether it be through for school or for a personal project or for work." Another participant in said, "Inherency of the intersection of multiple people towards a common goal," and added, "Yeah, and it has to include progress." Similarly, a participant from Group 11 said, "In an ideal world, I would say that a collaborative task is one where you get meaningful efficiencies from having multiple people work on something," then added, "One opportunity for that is differentiated skills, knowledge, expertise, but not necessarily." Common themes among participants about the components of effective collaboration were 1) clear communication, 2) well assigned roles and division of labor, 3) trust and respect among team members, and 4) having shared goals and norms.

Collaboration Conceptual Model. According to the expert responses, our collaboration conceptual model showed alignment with theory and had internal consistency (see Figure 1). However, they commented that the conceptual model should be less linear to show that there is a network of movement between levels.

Figure 1

Construct alignment results from expert review



Collaboration Rubrics. The human annotators achieved above 0.6 Cohen's Kappa inter-rater reliability, showing a convergence in judgement while maintaining variation. However, the experts suggested that a wide range of behaviors would help reduce bias and suggested that the use of descriptions, rather than ratings would be more informative. For example, one expert wrote, "The demeanor codes are unlikely to have all students fitting the description. The codes are fine, but the descriptions are not detailed enough." Our experts pointed to differences in the kinds of interactions that are exhibited among neurodiverse individuals. For instance, one reviewer wrote, "Looking at screen: 'looking at speaker or activity' places significance on one's social interactions. Those who are neurodivergent may not be completing these activities with the same regularity as the neurotypical learners. This is true also of "sustained fidgeting" as well as "sitting still." The experts also recommended measuring heterogeneity of the group using percentage, to allow for group size variation.

Behaviors and interactions of a good collaborator: Emergent themes showed that participants identified a good collaborator as someone that is open-minded and driven, open to critiques, accepting of different perspectives, and welcoming of challenges. Themes also indicated that participants thought that an effective collaborator is considerate and attentive. For instance, a participant in Group 9 said, "[A good collaborator] doesn't just decide on, like, what they want to happen and how they want it to happen and just go for it. With the project, I think people who, like, work to help others express their ideas." Participants also highlighted good communication as important for collaboration. A participant in Group 2 said, "I think good communication from each team member; open mindedness and willingness to share ideas and to discuss other ideas and not force your own opinion based on, like, what you know. So, it's about open mindedness and communication for me." Additional interaction patterns identified by the participants were the ability to provide and follow directions and manage the group dynamics to achieve the articulated shared goal.

Conclusions and Next Steps

Our validation studies provided an effective validation argument for our collaboration conceptual model and rubric. Findings from our studies showed that (1) our concept of collaboration accurately represents theoretically based constructs of collaboration, (2) individual behaviors identified in our rubric effectively measure the

collaboration competencies needed in group settings, and (3) nonverbal behavioral information from each level of collaboration can provide teachers with insightful information for understanding how students collaborate. We found alignment to our working definition of collaboration (e.g., shared goals, co-construction of knowledge, and sharing of tools) and used the recommendations to revise our collaboration conceptual model.

Ultimately, our collaboration conceptual model and rubrics will be used to inform the development of machine learning models that can be used to capture behaviors and interactions in group settings and provide behavioral insights about the collaboration process. Our next steps will be to examine the social structures using epistemic and social network analysis and explore the relationship between talk and gesture. We will also perform machine learning validation tests to explore the consistency, accuracy, and explainability of the machine learning models. Behavior analytics is intended to inform the teacher's exploration of group dynamics- not replace it.

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Learning from Teachers' Concepts of Dialogic Pedagogy

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Abstract: Advocates of dialogic pedagogy advance a certain set of ideas about productive classroom talk. Associated research processes usually begin with researchers' concepts of what dialogue should look like and then examine whether teachers understand and enact them. Following Vygotsky's ideas that concepts are formed primarily through social interaction and that learners are never *tabula rasa*, I investigate teachers' concepts of dialogic pedagogy as they emerged during a professional development workshop. I use thematic analysis to identify seven teachers' concepts, examining whether and how they were advanced during the workshop and investigate the broader contexts that shape them. My examination of teachers' concepts shows that (a) teachers have an eclectic and flexible approach toward dialogic pedagogy, pointing to conflicting pedagogical needs and pressures; (b) teachers' concepts are embedded within classroom affordances and constraints, pointing to their potential role in bridging between researchers' concepts and the realities and limitations of classroom practice.

Objectives

A growing body of evidence points to the potential of dialogic pedagogy for improving thinking and learning in the classroom (e.g., Resnick et al., 2015). Advocates of dialogic pedagogy promote ideas about productive classroom talk (e.g. Alexander, 2020; Mercer et al., 2019) and try to persuade teachers to adopt and enact them. Associated research processes usually begin with researchers' concepts of what dialogue should look like and then examine whether teachers understand and enact them. The following paper aims to examine *teachers'* understandings, assumptions and objectives – their own concepts – of dialogic pedagogy. This investigation builds on Vygotsky's (2012) and his follower's ideas regarding concept formation (e.g., Wertsch, 1991). According to Vygotsky, concepts are formed primarily through intermental processes, grounded in and mediated by social interaction. Importantly, learners do not arrive *tabula rasa* to such processes but have already accumulated experiences, developed ideas and objectives which bound their learning and their appropriation of new concepts. Investigating teachers' perspectives and understandings of dialogic pedagogy, as they emerged during professional development (PD) interaction, would benefit the field in several ways. First, such exploration may help recognize the disparities between researchers' and teachers' concepts. Second, teachers' concepts are embedded within classroom and institutional contexts, giving insights into the challenges of disseminating and enacting researchers' concepts of dialogic pedagogy. Third, teachers' concepts may shed light on shortcomings and blindspots of researchers' conceptual and practical tools and point to directions and sites for future research.

Theoretical perspectives

In recent decades numerous researchers have suggested various conceptual approaches to dialogic pedagogy (e.g., Lefstein & Snell, 2014; Kim & Wilkinson, 2019). In the PD processes investigated here, facilitators presented dialogic pedagogy mostly in general principles as teaching that affords opportunities for students to express their thoughts and ideas, to inquire, challenge, or build upon others' ideas and to reason about and critically weigh multiple arguments and solutions (e.g., Alexander, 2020; Resnick, et al., 2015). Which of these ideas resonated with the teachers? How did teachers relate them to their existing experiences and perspectives? Following Vygotsky, Wertsch (1991) elucidates that a process of concept formation "results in a mastery of abstract forms of reasoning… units are abstracted from their communicative contexts and become objects of reflection" (p. 29-30). Vygotsky indicates that a mastery of new concepts requires addressing the differences, and sometimes conflicts, between learners existing concepts acquired in their everyday experience and the corresponding academic concepts. Following a Vygotskian framework to teacher professional learning (e.g., Grossman et al., 1999), in this paper, instead of beginning with the principles or concepts of what researchers believe productive dialogue should look like, I map teachers' concepts of dialogic pedagogy as they emerged during PD processes, and endeavour to understand them on their own terms. I discuss how teachers' concepts relate to the PD processes they emerged in, the contexts that influence them and what lessons can be learned to advance research and practice in the field.

Methods

Research Contexts

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This research was conducted within a yearlong PD workshop in Israel focusing on dialogic pedagogy in language arts lessons. The process included eight language arts teachers, five instructional coaches and four researchers learning and working together to codesign and develop dialogic instructional units. During the 2018-2019 academic year, I video-recorded 20 biweekly meetings (70 hours total), collected materials and resources, and summarized events in reflective memos. The PD process included iterative cycles of codesigning, enacting, inquiring, reflecting, and refining dialogic instructional units in the language arts (Barak & Lefstein, 2021). Facilitators led the group meetings in line with these different stages, usually not allocating time for directly advancing or deliberating concepts of dialogic pedagogy. However, beyond presenting dialogic pedagogy in general terms as mentioned in the theory section above, during the sessions the facilitators explicitly highlighted three central ideas: (a) that productive discussions involve prompting students' thoughts, ideas and reasoning; (b) that teachers should connect between different lines of inquiry that emerge during discussions and (c) that assuming critical stances is a central facet of dialogic teaching.

Data Analysis

To identify and map teachers' concepts I investigated the workshop data thematically. This analytic process included the following stages:

a. Reviewing the whole data set. This review included moving slowly through the video-recordings of the meetings, identifying interesting episodes and interactions (Rampton, 2006) relating to conceptualizations of dialogic pedagogy.
b. Identifying preliminary codes (Braun & Clarke, 2012) for teacher utterances that relate to classroom talk, noting different purposes and functions that teachers attribute to dialogue.
c. Reviewing the data corpus again, in search of recurring themes that shed light on the teachers' views, ideas and understandings. This process included identifying episodes in which different ideas and views about classroom dialogue were directly discussed by teachers during the PD sessions (a total of 26 episodes of about 15-30 minutes each were identified).
d. Assembling the emerging themes into seven categories that reflect distinct concepts of dialogic pedagogy.

After mapping the concepts, I reviewed the data set to examine pedagogical assumptions and tensions and how the teachers' concepts relate to ideas that the facilitators advanced. I integrated into my analysis also written material produced in the workshop context, against the backdrop of the broader ethnographic data, such as material from the curriculum and other national education resources.

Findings

By following the four-stage process described above, I identified seven teacher concepts expressed during the PD program.

1. **Getting students to talk.** The core of this concept is that getting student to talk is important feature *in of itself*, irrespective of the content or the quality of discourse. While regularly stressing the importance of increased student participation, teachers acknowledged that opening the floor for students is not without its challenges, such as balancing student talk with other pedagogical needs (e.g., lesson structure, teacher authority or educational purpose).
2. Encouraging students to talk among themselves. This concept highlighted the importance of allowing students to talk autonomously, without teacher guidance. The underlying assumption of this stance is that teachers should consciously relinquish the floor and reduce control over topics, structure and purposes of the discussion.
3. **Developing speaking skills.** This objective relates to the first concept – getting students talking – but highlighted a specific focus and justification: getting students to talk to hone their oral language skills. On many occasions, teachers related these skills to formulations outlined in official guidelines for classroom discussions (e.g., Ministry of Education, undated).
4. **Cultivating polite discussion norms.** Teachers claimed that classroom discussions involve establishing a respectful classroom environment. An underlying assumption of this perspective is that teachers and schools are responsible for imparting prosocial behaviors, and indeed teachers agreed that maintaining polite norms is a basic, unambiguous requirement of classroom interaction.
5. **Students arguing their points of view and offering reasons.** Teachers assumed that meaningful classroom discussions involve students expressing ideas, arguments and reasoning together. They stressed that learning to lead such discussions, and being granted the legitimacy to do so, was a significant aspect of the PD program.
6. **Creating interpersonal encounters.** Some teachers related to classroom discussion as an opportunity for encounters on a personal, emotional level. While teachers expressed the notion that such

communication cultivates inclusive classroom environment, they also raised pedagogical tensions it brings about, pointing to difficulties in maintaining focused classroom activity and meeting institutional requirements.

7. **Assuming critical stances.** This concept underlines the notion that assuming critical stances toward texts promotes productive discussions and enhances students' engagement. Interestingly, teachers related to this idea mostly by invoking their own experiences as learners in the PD workshop, especially following sessions that included interpreting, criticizing and questioning texts as preparation for classroom dialogue.

Note that even though some of these concepts interrelate, they point to different underlying purposes and functions of classroom talk and are thus mutually exclusive. Table 1 outlines the episodes in which different concepts were directly expressed and the number of teachers that expressed them.

Table 1

Distribution of teacher concepts

Concept	Total times concept directly expressed	Number of episodes in which concept expressed (from total of 26 episodes)	Number of *different* teachers who expressed concept (out of 8 teachers)
1. Getting students to talk	7	5	3
2. Encouraging students to talk amongst themselves	5	5	3
3. Developing speaking skills	5	3	3
4. Cultivating polite discussion norms	12	7	7
5. Students arguing their points of view and offering reasons	19	9	7
6. Creating interpersonal encounters	3	3	2
7. Assuming critical stances	6	4	4

Notably, some concepts were more prominent than others in the numbers of times they were expressed, the numbers of episodes they emerged in and the number of teachers expressing them. For example, many different teachers expressed concept 5 (students arguing their points of view and offering reasons) as it was central to the PD program and was raised repeatedly by facilitators. Concept 6 (creating interpersonal encounters) was expressed on very few occasions and only by two teachers. On the other hand, concept 1 (getting students to talk), emerged on several occasions but was expressed only by three teachers who repeatedly voiced this idea.

Some of the concepts the teachers expressed, namely concepts 5-7, resonate quite closely with ideas facilitators tried to promote and the research literature. However, at times the teachers ignored some of the notions the facilitators underlined. For example, the facilitators recommended that when students argue their points of view and offer reasons (concept 5) the teacher's role is to bring together the different lines of inquiry – and that aiming for such coherence is fundamental to productive classroom dialogue. The teachers hardly echoed the latter notion during the sessions. This may be explained by the fact that teachers need to simultaneously take on multiple roles as managers of classroom discussions, as evident in the multiple concepts and tensions they expressed. Adding yet another role of connecting between students' ideas may seem an excessive load.

Concepts 1-4 echo also requirements, pressures and educational discourses that relate to classroom talk. For example, the goal of increasing student talk during lessons (concepts 1) resonates with recent reform efforts in Israel to promote a more constructivist pedagogy (Ministry of Education, 2014). The facilitators did not advance this concept in of itself, but acknowledged it as a basic, implicit condition for leading productive classroom discussions. On the other hand, the facilitators encouraged the teachers to avoid concentrating on students' formulations as means for developing their speaking skills (concept 3), instead to try and recognize their thinking and arguments, even when they seem ill-structured or confused. The teachers associated this concept with institutional expectations to appropriate students into academic language and formulations that reflect adequate disciplinary vocabulary and ways of thinking.

Scholarly significance

The premise of this study, following Vygotskian insights into processes of concept formation, is that teachers have important pre-existing concepts with regards to the pedagogical agenda they encounter; that it is important to study and understand (rather than evaluate) teachers' concepts if we wish to introduce them to new ones; and that a crucial site to investigate teachers' concepts, and the negotiations about them, is social interaction (for example, during PD processes). Three central insights can be derived from the above investigation into teachers'

concepts of dialogic pedagogy, their emergence during the PD workshop and the broader contexts influencing them.

First, thinking about dialogue through the concrete classroom lens allows (and indeed in many cases, demands) teachers an eclectic approach. The multiple concepts teachers expressed, and the pedagogical tensions they raised about them, indicate their acute awareness of classroom intricacies. Their approach indicates, in-effect, that leading classroom discussions demands of teachers to take on multiple roles, stances and to lead diverse, at times contradictory, practices. To better understand teachers' possible adoption of researchers' ideas and recommendations, more studies should focus on the nitty gritty interactional realities within the classroom and promote dialogic pedagogy taking these realities and limitations into consideration. Second, teachers' concepts are flexible. Many of the teachers readily espoused different concepts during different sessions, reflecting the contradictions and tensions inherent in school realities. Two central questions for investigation are, what are the conditions that promote particular concepts over other? And how can promoters of dialogic pedagogy enhance teachers' dialogic repertoires?

Third, teachers' concepts relate to broader educational discourses and agenda. In recent decades, classroom talk is receiving more attention from decision-makers who have begun to target it as a lever of instructional change. Ideas and policies, translated and filtered through PD processes and resources influence teachers' understandings and perspectives regarding dialogic pedagogy. This paper points to diverse resources, such as reforms (e.g., Ministry of Education, 2014), official guidelines for classroom discussion (e.g., Ministry of Education, undated) and other national programs, as resonating in teachers' concepts of dialogic pedagogy. The findings presented here calls for more trans-contextual studies in the field, to investigate how different discourses shape and bound classroom talk, and for promoters of dialogic pedagogy to engage more closely with these educational trends.

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Biology teachers' reflections on the benefits and challenges of using scanning electron microscopes in a biology classroom

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Abstract: Calls have been made to give K–12 teachers and students access to current methods used in biological research, including advanced microscopy. The scanning electron microscope (SEM) is a powerful tool that can be used for either remote or onsite inquiry experiences for students. To use this microscope in a way that promotes students' understanding of biological concepts, teachers should be informed about its capabilities, benefits and limitations as an instructional tool. Therefore, we introduced SEM to in-service biology teachers through a teacher-training workshop where they experienced activities using the SEM. We then assessed their views on the possible benefits and challenges of the SEM in high-school biology class, and particularly while teaching the relationships between structure and function. The participants' insights are described and discussed here, shedding light on what biology teachers should take into consideration while planning and engaging their students in activities using the SEM.

Introduction

Scanning electron microscopy in biology and science education

The scanning electron microscope (SEM) is a powerful tool used by scientists from various disciplines to observe and chemically analyze the surface and near-surface regions of specimens down to the nano level. Similarly, the SEM may allow teachers and students to investigate the finest details of biological structures, thereby facilitating exploration of the relationships between structure and function—a central concept in many biology curricula worldwide (reviewed in Zer Kavod, 2018). Unfortunately, there are many structural aspects pivotal for the understanding of biology that cannot be observed directly by teachers and students, as they are at the micro level. Scanning electron microscopy can reveal the micro (and even nano) structures, enabling an exploring of their possible relationship to function. This can enrich the teachers' toolbox and allow them to provide their students with more complete information. For example, concrete observations of real cells followed by a modeling process enabled students to explore the different functions of the cellular structures and complex interrelations within the cell (e.g., Verhoeff et al., 2008). Direct observations of biological structures by scanning electron microscopy may also allow students and teachers to experience authentic scientific practices, which is one of the goals of many policy documents worldwide (e.g., European Commission, 2011; National Research Council, 2012).

Like other authentic scientific research technologies, the SEM is usually not available to school teachers. With the ease of use and reduced size and cost of the newer SEMs, together with a higher awareness of the value of such authentic technologies to science teaching, scanning electron microscopy is finding its way into high-school programs. However, despite various projects aimed at using SEMs to acquire content knowledge, most of the published papers discussing them refer to chemistry and earth science activities, and only a few to biology (e.g., Cady et al., 2015). Furthermore, most of the published papers report only the affective gains of using the SEM, such as increased engagement, motivation and interest in science, or increased inquiry skills (e.g., Cady et al., 2015; Childers & Jones, 2017). There is a lack of information on the SEM's possible contributions to teaching biology or on the challenges of using it. Providing teachers with opportunities to experience a certain technology first-hand, learn about it, and observe its pedagogical benefits can help shape their attitudes and views toward applying that technology in their classroom (Mishra et al., 2019). We therefore exposed biology teachers to the SEM so that they could gain first-hand familiarity with this technology and evaluate its pedagogical potential. We assessed their views regarding the SEM—its benefits and the challenges that it poses. This is particularly important considering the lack of information in the literature regarding these aspects of using the SEM.

Goals of the study

The main goals of this exploratory study were to introduce the SEM to biology teachers, and to assess these teachers' views on the potential benefits and challenges of using the SEM as an instructional tool for teaching biology in high school, following their own experience with the SEM.

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The context of the study

Participants and workshop description

Participants included 10 high-school biology teachers (6 females, 4 males) who participated in a teacher-training workshop on scanning electron microscopy. The teachers came from different schools in Israel and had 5 to 31 years of teaching experience. All the teachers voluntarily chose to participate in the workshop and in the accompanying research.

The workshop was part of a more comprehensive 4-day, 30-hour professional development (PD) course during the summer vacation (2019). The 4-day course was designed to expose 10 high-school chemistry and 10 biology teachers to the SEM as an instructional tool, and to involve them in developing SEM activities for students (Yonai et al., 2022). On the first day, all of the teachers familiarized themselves with the SEM (the Thermofisher Phenom desktop SEM). Each day they experienced a different workshop with a different activity. Some of the activities were chemistry-oriented and one was biology-oriented. After experiencing each activity, the teachers were asked to provide their inputs and to suggest how to adapt the activity to high-school students. The current study refers only to the 10 biology teachers' insights following the biology-oriented activity.

The rationale of the biology-oriented activity

The activity was developed by a team of life scientists and science education researchers. The goal of the activity was to investigate the motility of the emmer wheat's seed-dispersal unit, based on research by Elbaum et al. (2007), which demonstrated structure–function relationships. In their study, using scanning electron microscopy, Elbaum et al. (2007) identified the mechanism underlying the unit's movement, as the awns move in response to the day–night changes in humidity, thereby dispersing the seeds.

The activity was designed to address the major obstacles to implementing new technologies in the educational system: lack of teachers' familiarity with the technology, and the need for teachers' recognition of its contribution to their work (Mishra et al., 2019), and following the guidelines suggested by Luft & Hewson, 2014. We constructed the SEM activity while taking into consideration the following design principles: (1) Choosing a biological phenomenon that can be observed at the macro level, but whose underlying structure is only observable at the micro level; (2) choosing a topic that would be new and intriguing to the teachers, even the more experienced ones, yet can be related to the biology curriculum; (3) making the SEM an essential tool for exploring the phenomenon (observing the micro-level structures with another tool would not provide a complete explanation); (4) making room for teachers' own ideas, based on their pedagogical experience and the context of their schools; and (5) creating an activity that the teachers could perform with their students in a biology class (after adaptations to suit students' cognitive abilities and knowledge). The activity included four different hands-on tasks, each of which was a key to understanding an aspect of the explored phenomenon. Each task was accompanied by a set of instructions and questions designed to evoke the participants' thinking about the likely relations between the structures they were observing and their possible contribution to the seed's motility (function). Two tasks included macro-level observations, and two tasks focused on micro- and nano-level observations, using binoculars and the SEM. The process was guided by a scientist, who showed the participants how to operate the SEM, and when needed, where to look and what they were seeing. In the summary session, the conclusions from the different tasks were brought together to create the complete picture of the motility of the wheat's seed-dispersal unit. The scientist also discussed the implications of the phenomenon for current research and challenges faced by society.

Data collection and analysis

Open-ended pen and paper questionnaires were used to assess the participating teachers' views on using the SEM as an instructional tool for teaching biology in high school. The questions, adapted from Margel et al. (2004), asked the teachers: Based on your experience in the PD and in class, (1) what is the unique value (benefits) of using the SEM as an instructional tool for teaching biology: (a) for the teacher? (b) for the students? (c) for teaching the relationships between biological structure and function? (2) what difficulties (challenges) could students encounter while working with the SEM? The questionnaires were voluntarily filled out by all of the biology teachers (n=10) in the summarizing session of the course. The teachers' answers to each question were categorized, and the categories were counted to identify the most prevalent themes. In order to anonymize the analysis of the questionnaires, each teacher was assigned an identifying serial number (#1-10). When we refer to statements of teachers, we follow those teachers' statements with their serial numbers, within parentheses.

Results

Teachers' views of the SEM as an instructional tool for teaching biology

SEM's unique value and benefits for teachers and students

When describing the possible benefits of using the SEM for their teaching, the most prevalent theme was that the SEM is valuable for the teaching of biology, as it enables visualizing biological structures that are otherwise abstract or only visualized in pictures. Some teachers (#2, 3, 6, 8, 9) wrote that seeing objects in "real time" would make the data more credible for the students and would help them understand the learned biological phenomena better. The following frequent theme was that the SEM allows teachers to deepen or expand their explanations of phenomena. For example, a discussion about structures and mechanisms involved in the phenomenon at hand, referring to the chemicals involved (using SEM's ability to perform chemical analyses). Some referred not only to content knowledge but also to describing past and current research. Several teachers wrote that using the SEM may allow them to engage their students with cutting-edge, authentic technology (#5,7,9,10). They wrote that this, and the ability to see the real biological structures, can help them evoke their students' curiosity and excitement (#2,3,7,8,10). When asked about the value of the SEM for the students, most of the teachers wrote that using the SEM may allow students to better understand the learned phenomena and the relationships between structure and function. It may allow them to form a more coherent view of the content knowledge, to connect the pieces of data in a more realistic way. They attributed this to the ability to observe the structures with their own eyes, not only through models or learning about them theoretically (#3,6). Some teachers referred to high engagement of students, in contrast to passive learning (#3,5,8,10), and the affective gains of using the SEM (these were referred to as benefits both for the teachers and for the students).

All of the teachers wrote that use of SEMs in a structured activity is important for a deep understanding of structure–function relationships. They wrote that in the activity, the structures and their relationships to function become observable and therefore more vivid. For example, teacher #9 wrote that "many properties are not observable using a light microscope. Students compensate for this by learning from pictures or videos, but it is not in real time, like scanning electron microscopy observations, and therefore less effective for understanding the structure–function relationships." Nevertheless, three teachers restricted their answers by noting that scanning electron microscopy may contribute to this understanding only with proper direction from the teachers, and that using scanning electron microscopy is beneficial, but not necessary. Some suggested exploring the structure–function relationships underlying specific processes, mostly plant-science related, such as the way the unique microstructure of each pollen contributes to its distribution.

The challenges of using the SEM – possible student difficulties while learning biology with the SEM

Describing the challenges of using the SEM for their teaching, the majority of the teachers wrote that their students may experience technical and technological difficulties operating the SEM or preparing the samples. All of the teachers referred to difficulties resulting from the highly detailed images produced by the SEM: Some wrote that the image contains too much information (#2, 4). Most of the teachers anticipated that students would be confused and disoriented by the visual overload and would not be able to understand what they are seeing without guidance (#2, 4, 5, 6, 8, 9). According to the teachers, this may distract them from the structure and phenomenon that are the focus of the lesson. Some teachers (#3, 5, 10) referred to difficulties in understanding orders of magnitude and scale. A few teachers (#8, 9) wrote that students may have difficulties relating the structures they observe at the micro level to the observations and phenomena at the macro level. Teachers wrote that considering these challenges, it is important to prepare the students in advance as to what they are expected to see, to provide them with particularly accurate instructions for the activity, and to closely guide them through the process.

Discussion and implications for practice

In view of the calls for using technology in biology class, many initiatives aim to provide students with access to cutting-edge technologies, including SEMs. Our findings imply that while biology teachers see the unique value and contributions of the SEM as an instructional tool, they also predict several challenges for using it in their classroom. These challenges are not often discussed in the literature, and thus this study may assist in filling this gap. The main benefits that biology teachers attributed to the SEM suggest that teachers can harness its visualization abilities to increase their students'—and their own—better understanding of biological phenomena. Particularly of the relationships between structure and function, and topics for which there are not enough opportunities for hands-on activities, or which are typically less interesting for students, such as plants (Krell & Schmidt, 2020). However, based on the challenges that the teachers themselves experienced during the activity, our findings indicate potential challenges for students working with the SEM, which may inhibit their learning

process. This stresses the importance of using the SEM only if its benefits are substantial and necessary for the learning process. Otherwise, it may not contribute, or may even inhibit students' understanding, due to cognitive overload (Sweller, 1994). Therefore, it is recommended that the teachers and other activity developers make the SEM essential for discovering the discussed biological phenomena. For example, when teaching about a biological phenomenon involving structures that can only be seen by the SEM. Teachers can use scanning electron microscopy for concepts that they have already discussed with their students but lacked the means of visualization, or compare the images obtained from the SEM with the simplified models. To minimize the difficulties and increase the educational gains from activities with the SEM, the teachers expressed their need to construct accurate and detailed instructions and be able to offer close guidance to their students. Teachers' guidance throughout the process is pivotal to preventing student confusion or disorientation. Teachers should explicitly communicate to the students the aim of the activity and what it is that they are seeing, and discuss the relationships between the structures seen by the students and function. Thus, this study reaffirms the teachers' central role in exposing and mediating technologies and their uses to their students (e.g., Waight & Abd-El-Khalick, 2018). Therefore, teachers should be trained to use the SEM, both technically and pedagogically, while explicitly discussing the possible benefits and challenges, such as those presented above. Teachers can also take part in designing activities and adapting them to their students' needs, to their teaching goals, and to their curricula (Luft & Hewson, 2014). The insights from this study can give teachers a better view of the benefits and the challenges of using it from their peers' point of view, which may encourage teachers to use the SEM and support their teaching practice.

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How Inquiry-based Learning Approach Affect the Impact of Augmented Reality on Science Learning

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Abstract: Despite the potential advantages of using Augmented Reality (AR) in education, most of the existing AR studies have failed to analyse the impact of pedagogical approaches as well as the pedagogical strategies of implementing AR in teaching and learning. An inquiry-based learning framework, coined QIMS, was proposed in this study by considering AR affordances. Through a quasi-experimental design, this study compared three conditions for science learning in a primary school. Results indicated that though students did not demonstrate statistically significant improvement in their academic performance when AR was used, students' self-directed learning and creative thinking skills did significantly improve via experiencing the QIMS inquiry-based learning activities. The use of AR played a more significant role in enhancing students' critical thinking and knowledge creation efficacy. Integrating QIMS and AR was more effective for students with lower abilities. The study provided suggestions on how to integrate AR with inquiry-based learning in science learning.

Introduction

Augmented Reality (AR) technology, with its current advances, has become readily available in education. While technology can be a catalyst for transforming the nature of teaching and learning, it needs to be utilised with appropriate pedagogies, as pedagogy is a crucial component in the employment of AR technology (Chadeea & Prinsloo, 2019). Inquiry-based learning (IBL) is one of the most common pedagogies in AR interventions (Wen & Looi, 2019; Garzón, et al., 2020). AR-enabled inquiry activities could engage learners in an immersive context that enhances scientific investigations –where students can collect data outside the classroom, interact with an avatar, or communicate face-to-face with peers in a more authentic setting (Dunleavy et al., 2009). Despite the potential advantages of using AR in education and its suitability for supporting science learning through simulation activities, AR's concrete uses are relatively not as well understood as that of other technologies (Wu & Wen, 2020). Most existing studies have failed to analyse the impact of pedagogical approaches as well as the pedagogical strategies of implementing AR in teaching and learning (Garzón, et al., 2020). To respond to this need, this study works on investigating how the IBL approach can be integrated with AR-supported formal science learning and if and how it can help to improve students' academic performances and 21st century skills.

AR-based Inquiry-based Learning Activity Design

QIMS inquiry framework for guiding AR activity design

In this study, we articulated a framework for science learning leveraging AR technologies: Questioning, Investigating, Making and Synthesising (QIMS). With reference to Kolb's cycle (2014) in the comprehension and transformation dimensions, students learn in the AR environment to address our proposed QIMS framework. (1) Questioning: Students are guided to raise questions in a topic; (2)Investigating: They will have a concrete experience of the phenomenon through AR simulations and reflect on that experience; (3) Making: They will apply the formation of abstract concepts (analysis) and generalisations (conclusions) which are then used to test hypotheses, resulting in new experiences and inquiries; (4) Synthesising: They conclude their findings to summarise knowledge to capture both comprehension and transformation dimensions.

Learning package of plant reproduction

The learning package on the topic of plant reproduction was designed based on the QIMS framework, meant for grade 5 students. It is centred on a story where a group of aliens need help in growing plants, as their planet is in

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trouble and their plants are unable to thrive there. The students were tasked to help the aliens, with their acquired knowledge on plants. The QIMS cycle includes (1) Questioning: Students ask questions about the alien's planet and on the topic of plants; (2) Investigating: Students concretise their experience of the phenomena by using AR tools and conduct experiments related to the topic. They also note down their reflections and complete some worksheets on the subject; (3) Making: Students create a plant to save the aliens' planet. They develop hypotheses on why their creations can save the planet by applying the concepts they had learnt; (4) Synthesising: They conclude by presenting their plant creations with supporting explanations on why their plants are feasible.

The Plant Lifecycle AR App was developed for the topic of plant reproduction, built using the Unity3D engine, with AR functionality provided by the Vuforia plugin. The Plant Lifecycle AR app comprises three activities: (1) Flower Anatomy, (2) Seed Dispersal, and (3) Plant Engineer.

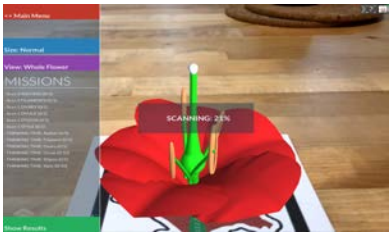

Fig. 1a. Flower anatomy activity

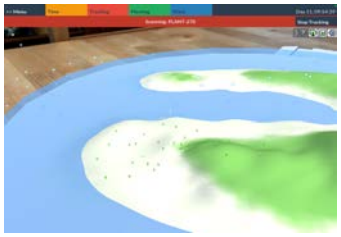

Fig. 1b. Plants dispersed by wind in a characteristic pattern

Fig. 1c. Example of a completed plant model

Fig. 1 the developed Plant Lifecycle AR App

Methodology

A quasi-experimental design method was used to set up an experiment that lasted for 2 weeks to determine whether AR-supported IBL significantly improved pupils' science learning performance and learning competencies better than inquiry-based learning without AR or non-inquiry-based learning. Two research questions were proposed to investigate the students' academic performance and 21st century skills in different learning design conditions. They are: (1) Did AR-supported inquiry-based science learning generate a more positive impact on pupils' learning outcome? (2) Did AR-supported AR-based inquiry-based science learning have a more positive impact on pupils' 21st skills? Which aspects were these reflected in?

Participants

Student participants in the study were 117 grade 5 students from a Singapore government primary school (see Table 1). They belonged to 3 different grade 5 classes and were of similar academic abilities.

Table 1: Participants and learning design conditions.

Class	No. of students	Learning design conditions	Teacher involved
Class A	39	AR + QIMS framework	Teacher A
Class B	38	QIMS framework without AR	Teacher B
Class C	40	No AR, No QIMS	Teacher C

For class A, the teacher introduced the story with a problem scenario – aliens had visited the students' for help. Upon setting the context, the teacher got students to ask questions that they were curious about (Q-questioning). For (I-investigating), the students were given various tasks and encouraged to "think like a scientist". Students learnt about the structure of plants independently, through The Flower Anatomy activity (Fig. 1a) of the Plant Lifecycle AR App. There was little formal instruction from the teacher. The AR app allowed students to self-direct their own learning through self-discovery and active participation instead of just relying primarily on the teacher for information. Students had to examine a virtual flower using the app, identity and scan parts of the flower according to "missions". After successfully scanning the correct flower part, the app displayed pop-up descriptions of the plant. The teacher also brought actual flowers to the class to review and "verify" that the virtual plant had the same structure as a real-life plant.

The second activity was framed through the same problem scenario, illustrating the concept of seed dispersal. Students learnt about the methods of seed dispersal via a simulation activity, the Seed Dispersal activity (Fig. 1b). Students could control the direction and speed of wind by manipulating AR markers. These tasks were designed to be open-ended and intended for students to explore and investigate independently before the teacher gave them the answers and explanations.

The last activity was to review and consolidate what students had learnt (S-synthesising). Students related what they had during learnt during the plant reproduction lessons to a previous topic, Plant transport systems and explained how the two topics were connected. With the AR app, students designed a hybrid plant that could survive and reproduce in the harsh conditions of the aliens' planet (Fig. 1c) (M- making and S - synthesising). Thereafter, the students presented their plant to their classmates and were encouraged to be as creative as they could.

Similarly, the teacher in class B framed the lesson with the same story of the aliens. She did not use the AR app but led students in a cycle of questioning and investigating. She brought different types of seeds for students to touch and feel, guiding them to think about why and how the seeds could help the aliens learn more about pollination and seed dispersal. After investigating, the teacher recapped all the concepts and related it back to the story of the aliens, as well as to the previous topic of plant transport systems. The teacher in class C did not relate the story of the aliens, nor did she make use of AR or QIMS. As in traditional classes, she employed a more teacher-led and direct instructive approach. The students did conduct experiments but were given more explicit instructions.

Instruments

The pre-test checks students' existing conceptual knowledge of the topic of plant reproduction before the intervention. It was a pen-and-paper test with a total score of 16 marks. The test had ten questions and the students were given about 20 mins to complete it. The survey questionnaire, adapted from Chai et al. (2015) measuring students' perceptions of 21st century learning practices, was administered to students after the intervention. The post-survey, consisting of 5 scales, was administrated online in the week of the last intervention. A total of 112 students' responses were collected and analysed. The Cronbach's alpha reliability coefficients for the survey was 0.966, and the Cronbach's alpha reliability coefficients of each scale are above 0.8.

We also conducted online interviews with teachers. The three teachers were interviewed individually via zoom. Each interview lasted about an hour. The teachers' interviews were conducted in a semi-structured format including questions such as – how they perceived students' attitudes towards the use of AR; their opinions on the use of the QIMS framework.

Results

Impact on learning results

We performed an analysis of covariance (ANCOVA) to examine the significance of the mean differences among the three learning design conditions. The post-test score was used as the dependent variable and the pre-test score was used as covariance. The results indicated no significant difference in learning outcomes among the three conditions, F (2,111) = 0.303, p = 0.739. Though the estimated marginal mean of the class using AR with the QIMS framework was higher than the other classes, the LSD post-hoc comparisons showed that there were no significant differences among 3 classes.

Impact on students' 21st learning skills

To interpret whether and in which aspects AR and QIMS had an impact on students' 21st learning skills, we conducted separate analyses of variance (ANOVA) for each scale. As shown in Table 2, there are significant differences among classes in **self-directed learning** [F (2,109) = 4.040, p = 0.020], **critical thinking** [F (2,109) = 3.142, p = 0.047] and **creative thinking** [F (2,109) = 4.079, p = 0.020], but no significant differences among classes could be found in other scales.

LSD Post-hoc tests further revealed that there were no significant differences between the experimental classes with or without using AR in all the scales. However, the pairwise LSD comparisons revealed that there were significant differences in mean values between the class using AR with QIMS and the control class in self-directed learning (p= 0.012), creative thinking (p = 0.007), critical thinking (p = 0.018), and knowledge creation efficacy (p= 0.036). There were also significant differences in mean values between the class using AR without QIMS and the control class in self-directed learning (p= 0.021), creative thinking (p= 0.048), and authentic problem-solving (p= 0.021).

The findings suggested that there was little difference between the class using AR with QIMS and the class without using AR but with QIMS. Yet integrating AR with QIMS had a more significant effect on students' self-directed learning, creative thinking, and critical thinking skills, especially for the low progress learners. This is consistent with the findings drawn from the teachers' interviews. According to the teacher B who used QIMS, the activities based on QIMS provided students the opportunity to be creative, as they were able to do their own questioning and generate their own ideas on how to solve a question or problem. Though IBL was emphasised in

the curriculum, the teachers pointed out that the QIMS was more student-led. Teacher A using AR also mentioned that "with the use of AR, we need to be able to give students autonomy for their own learning."

It was worth noting that the use of AR did not affect students' perceptions on authentic problem-solving. On the one hand, this finding might indicate that the immersion of paper-based AR was not sufficient. On the other hand, this might suggest that instead of replicating real-world experiments or being limited in the classroom, our subsequent AR activity design should further strengthen the link with the living environment. Besides, although the experimental Class A had a higher self-rating in the scale of collaborative learning, there was no significant difference among the three classes. This might indicate that the collaboration script embedded in the AR and QIMS-based learning activities could be further improved.

Discussion and Conclusion

The aim of the study was to investigate how to integrate IBL with AR in science learning to improve students' learning performance and 21st century skills. This paper presents an inquiry-based learning framework (QIMS) that consists of interactive processes of questioning, investigating, making and synthesizing. Instead of approaching inquiry as purely discovery on one's own, Mayer (2004) has stated that there should be guidance, structure and objectives stated in the inquiry-based activities. The paper reports an empirical study to demonstrate how the QIMS framework was used to guide AR learning activity design, and the impact on grade 5 students' learning outcomes and development of soft skills. The findings indicate that the class using AR did not outperform the class following QIMS without AR. However, the two classes engaging in QIMS activities outperformed the class without QIMS. Though students did not demonstrate statistically significant improvements in their academic performance, their self-directed learning and creative thinking skills did significantly improve via experiencing the QIMS inquiry-based learning activities.

This study has several important limitations. The main drawback is the limited time of intervention. Secondly, as the AR app is self-developed, the user interface and 3D animations can still be further polished to better engage learners. Our initial hypothesis is that the class using both AR and QIMS could outperform the other two classes. However, this is not supported by the data of this study. It may be caused by the intervention time and/or the AR app design. The AR app will be further updated, and relevant work has been planned and will be conducted in more schools. The following studies will also explore the impact of AR-based QIMS learning packages on different topics. Besides, future research will pay attention to how students interact during the learning processes to further explain how individual differences influence on the success of the AR activities and how to design AR activities to benefit diverse learners.

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Identifying productive reflection in ill-structured problem solving

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Abstract: Ill-structured problems are common in the workplace but difficult for undergraduate students to learn. Within engineering, one ill-structured problem is engineering estimation, which involves determining an approximate value for a physical quantity in a system. Researchers have developed multi-phase modeling-based learning environments to support the learning of estimation. Although this software scaffolds the steps involved in estimation for students, it is still an open question as to how students engage in these learning processes. In this work, we analyze the interaction sequences of students during the engineering estimation process and how they relate to performance. High performing students engage in significantly more patterns of evaluation and planning concurrently with modeling, compared with lower performing students. These findings highlight the importance of additional interventions to trigger the evaluation and planning processes among learners.

Introduction and Related Work

Consider this problem*: "You have to design a light aircraft of maximum take-off weight of 15000 kg. It should be able to take off in 1000 m and less than 30 seconds. Its air speed at 40000 ft above sea level should be about 750 km/hr. Estimate the power of the engine you need to design such an aircraft."* This is an example of an ill-structured problem as it has multiple solutions, solution approaches, uncertainties and evaluation criteria (Jonassen, 2000). Such ill-structured problems are common in engineering when there is incomplete information about the exact operating conditions and the features of the machinery (Linder, 1999). In these situations, experts solve problems by understanding the problem space, making assumptions and scoping the problem, generating possible solutions and selecting one, and implementing and monitoring the solution (Jonassen, 1997). Monitoring their progress and intermittently evaluating their goals is an integral part of the expert problem-solving process (Kothiyal, Murthy & Chandrasekharan, 2016). Students have difficulties with ill-structured problems because solving them requires students to regulate their cognition by planning and evaluating their goals, and monitoring their progress (Shin et al., 2003). Scaffolding these processes can help students learn ill-structured problem solving (Ge & Land, 2004). Researchers have developed learning technologies to scaffold these problem-solving processes (Tawfik et al, 2018), but less is known about how students use these tools for effective learning.

For scaffolds to be effective at supporting student learning, we need to understand whether and how students engage with these scaffolds. Previous work has begun to investigate these learning processes and researchers have found that successful students are able to connect task activities to domain knowledge (Wen et al., 2018), follow incremental approaches (Blikstein et al., 2014), and use more cycles of testing and pausing (Perez et al., 2017) compared with less successful students. These examples support that students who engage in more reflection while problem solving may have higher learning. However, it is an open question of how these results may transfer to another ill-structured problem-solving context, as the frequency of reflection required may vary for different kinds of problems. Therefore, an analysis of students' learning processes is necessary to better understand the interplay between problem-solving and reflective activities within a scaffolded ill-structured problem-solving context, and how that relates to learning. Such an analysis can support our understanding of when to intervene in the learning process to effectively support student learning.

The goal of this work is to investigate the differential sequential action patterns of students who succeed vs those who do not at engineering estimation problem-solving, which is an ill-structured problem where engineers need to determine an approximate value for a quantity (such as power required by the aircraft in the example above). To investigate the sequences of actions that students engage in during learning, we used the modeling-based estimation learning environment (MEttLE) which divides the learning of estimation problem solving into six phases (Kothiyal & Murthy, 2018) with scaffolds to support every phase of the problem solving such as question prompts and hints (Ge & Land, 2004). We address the research question, what are the sequential action patterns of learners as they learn estimation problem-solving, and how do they relate to performance? Specifically, we are interested in how learners engage in problem understanding and reflective actions during problem solving and revisit previous phases. We hypothesize that students who have higher performance would interplay more frequently between modeling and reflection activities, and revisit previous phases more as they reflect on past actions.

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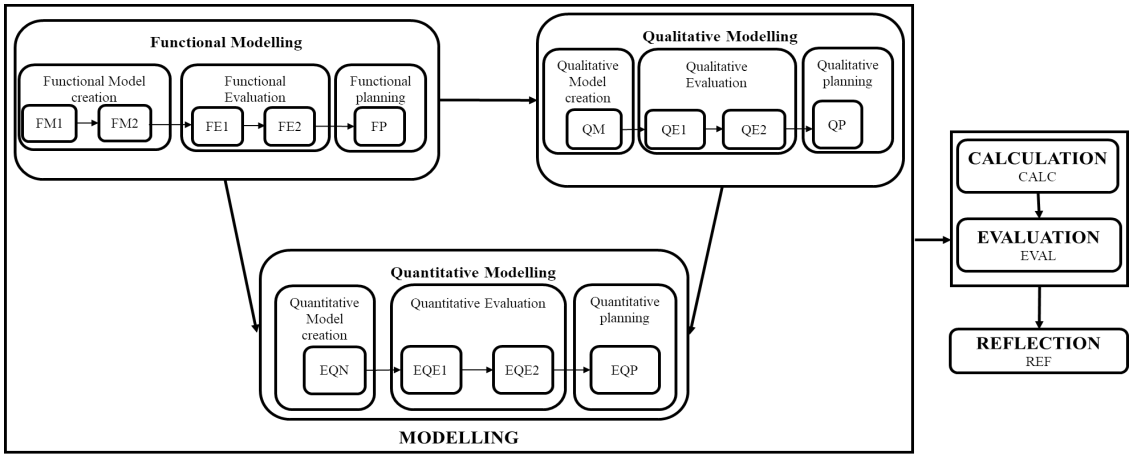
Methods

Learning Activity

MEttLE structures engineering estimation problems into six tasks (three modeling tasks, a calculation task, a final evaluation task and a reflection task) with the modeling tasks being further divided into three subtasks, and some subtasks having multiple steps (Figure 1). The three modeling tasks, based on the expert estimation process (Kothiyal, Murthy & Chandrasekharan, 2016), are called functional, qualitative and quantitative modeling. Within each modeling task, students have model creation, evaluation and planning subtasks (details and screenshots of the software are available in Kothiyal and Murthy (2018)) that include questions for triggering the metacognitive processes of monitoring the model, evaluation and planning such as *"While estimating power for a design, would you determine the maximum, average or instantaneous power required? Why?"*. The functional and qualitative model creation together constitute problem understanding. The final evaluation task includes questions for triggering the evaluation of the calculated estimate. The problem is considered complete when the estimate passes given evaluation criteria. After solving the problem, students complete a reflection task which includes questions asking them to reflect on the estimation process. MEttLE is an open-ended intervention in which students can do a task/subtask at any time, use the affordances as they see fit and do the (sub)tasks as many times as they wish. During the process, all actions are logged by the system.

Figure 1.
Task flow showing the sequence of the engineering estimation learning tasks, subtasks, steps and their codes within MEttLE



Participants and Data Collection

We analyzed data from a field study in an engineering college with 72 second year students (50 mechanical and 22 electronics engineering) who solved a problem in MEttLE as part of a workshop. The average age of the learners was 20 years. The study began with informed consent being gathered from all participants. Afterwards, participants individually solved one problem in MEttLE, namely, *"You are participating in an electric car race in which you are required to design an electric car of weight 5kg with wheel diameters of 4" that can traverse a track of 50m in less than 5 seconds. Estimate the electrical power needed to achieve this performance."* While solving, students were not allowed to use the internet but could use all the resources in MEttLE and ask the researcher for technical help. As a posttest, participants individually solved an estimation problem on paper similar to the one in MEttLE, without any additional resources or help. We collected logs of participants' interactions in MEttLE, including entered data with timestamps. Owing to technical issues, we were able to recover the logs of only 22 participants, which are used in our analysis.

Analysis Approach

We graded the posttests using the rubric for assessing estimation given in Kothiyal & Murthy (2018). For every criterion that was satisfied, we awarded one point, for a total of three points. Participants who scored three points were classified as high performing students and all others were classified as low performing students. We had three learners in the high performing group and nineteen learners in the low performing group.

To identify interesting behaviors that are associated with the engineering estimation process and can be used to differentiate high and low performing students, we used differential sequence mining (DSM) (Kinnebrew

et al., 2013). DSM identifies sequences of actions that are common within a group of students and by comparing these action sequences between groups, we can better understand how they are associated with performance. To perform the DSM, we used the log data from MEttLE to get all student actions and coded each action as the step the student was working on to align with the flow seen in Figure 1. For example, the functional model creation subtask is split across two steps and any student action in step 1 is coded FM1 and any action in step 2 is coded FM2. Thus, the action coding corresponds exactly to the problem-solving step the student is at. Some steps have multiple questions that require inputs leading to sequences such as "FE2 -> FE2 ->FE2", which indicate either that a student entered responses to different questions on the page or revised their previous response. These sequences of coded student actions serve as the input to the DSM algorithm that identifies the most frequent patterns. We implemented the algorithm using the LASAT tool (Mishra et al., 2019) with the s-support set to 0.5, which means that the algorithm returns all patterns that are 1) present in at least 50% of the teams in at least one group, high or low performing and 2) whose frequency of occurrence in a team (i-support) was statistically significantly different between the two groups.

Findings

Table 1

Top-10 frequent patterns of high and low performing students

No.	Pattern	S-Frequent Group	t-test (p value)	I-Support (Hi)	I-Support (Lo)	Effect Size
1	FE2 -> FE2 -> FE2 -> FP -> FP	High	6.85E-06	1	0.32	1.51
2	FM1 -> FE1 -> FE1	High	2.95E-04	1	0.47	1.08
3	QP -> QP	BOTH	7.94E-04	1	0.53	0.97
4	FP	BOTH	0.0012	2	1.16	0.93
5	FE2	BOTH	0.0018	3	1.8	0.89
6	QE1 -> QE1 -> QE1 -> QE2 -> QE2	BOTH	0.002	1	0.58	0.87
7	QE2	BOTH	0.0045	1	0.63	0.78
8	EQN	BOTH	0.02	1	0.74	0.61
9	QE1	BOTH	0.02	1	0.79	0.61
10	FE1	BOTH	0.03	1	0.84	0.58

From our sequence analysis, we found six main findings related to our research question of how learners engage in reflective actions during problem solving. *1)* High performing group shows significantly more sequences of functional model creation, evaluation and planning than the low performing group (see Table 1, rows 1-2). *2)* High performers had more attempts at the functional evaluation questions (rows 5, 10), and immediately after the functional model creation (row 2). *3)* High performers attempted the questions on the functional planning (row 4), and did so immediately after the functional evaluation (row 1). *4)* High performers had more sequences of qualitative evaluation and planning than low performers, meaning that they attempted the qualitative evaluation questions (rows 6, 7, 9) and the qualitative planning (row 3), although it is not clear when they did the planning questions. *5)* High performers attempted quantitative model creation (row 8) more frequently, but we did not find any frequent sequences of quantitative evaluation and planning or final evaluation and reflection among either group. *6)* Contrary to what we hypothesized, we found that there are no revisits to previously completed tasks by learners in either group that meet the s-support criteria.

Discussion and Conclusion

In this work, we investigated the estimation learning processes of students, a kind of ill-structured problem commonly encountered in engineering education. Specifically, we used differential sequence mining with data from students working with the MEttLE learning software to investigate how high and low performing students use reflection and revisiting actions in their engineering estimation learning process. Experts tend to spend more time exploring and re-representing the problem, and intermittently evaluate their work (Wankat & Oreovicz, 2015; Kothiyal, Murthy & Chandrasekharan, 2016), and we found similar problem-understanding and reflection patterns with our high performing students. These actions are promising to find within the engineering estimation process, as these behaviors are known to be productive for ill-structured problem solving (Wankat & Oreovicz, 2015; Shin et al. 2003; Jonassen, 1997). More concerning is the fact that these same actions were present to a significantly lesser extent with low performing students as these actions were explicitly scaffolded inside of MEttLE. The students were provided with question prompts at frequent intervals to trigger the problem-understanding (functional and qualitative model creation) and reflection (model evaluation and planning) processes. However,

only high performers used the scaffolds and performed problem-understanding, evaluation and planning. These results are interesting because it is not that low performing students tried to engage in these types of actions and still did not perform well; this makes it much more likely that the lack of problem-understanding and reflection actions may be directly connected to the low performance. It may then be the case that providing scaffolding in an open-ended intervention is not enough. More meta-cognitive scaffolding may be needed to guide students to do these problem-understanding and reflection actions at regular intervals until they are able to build these processes into their implicit problem-solving process.

Although there are several limitations to our study, the work shows promising results in understanding the impact of students' problem-understanding and reflective actions and the role that learning scaffolding plays in this process. First, we did not find that students engaged in reflective quantitative modeling and final evaluation, and cycles of modeling, evaluating and planning, which may be due to students not having enough time. Additionally, we had a small sample size of 22 students and a skew with 3 high performers and 19 low performers. All of these factors may have had an impact on our results. However, these results add to the current literature by both replicating the importance of problem-understanding and reflective actions within ill-structured problem solving, and extending the literature by showing the limitations of scaffolding this process without explicitly providing support for students who may not have the skills to know when and how to engage in these productive problem-solving processes. Future work is needed to explore how additional guidance should be incorporated to ensure that students do the problem-understanding, evaluation and planning tasks.

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Student Engagement in Collaborative Problem Solving through Media Arts Production

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Abstract: Collaborative problem solving skills are essential skills for young people that can be gained through artistic media production, yet many educators do not feel prepared to assess media projects. We draw upon examples from two case studies in media arts production to examine collaborative problem solving skills. Building on the PISA framework for collaborative problem solving skills, we demonstrate where and when different skills take place during media production creating directions for classroom assessments.

Major Issues Addressed

To cultivate equitable education systems for the 21st Century, it is essential to teach young people collaborative problem solving skills (Ito et al., 2020; Graesser et al., 2017). Media arts productions can be integrated into classrooms to help students concurrently gain collaborative skills through the act of solving problems with peers (Lee et al., 2015). Yet, teachers often do not know how to assess media productions (Reilly & Atkins, 2013). To address this obstacle, we examine collaborative problem solving at different stages of the production process creating direction for classroom assessments.

Collaborative problem solving through artistic media production

Media production projects often require the collaboration of individuals in assigned roles with specific duties (Barron et al., 2014). Collaborative learning creates positive results for learners' cognitive, meta-cognitive and social aspects of learning (Johnson & Johnson, 2009) and helps learners achieve higher learning outcomes (Chen et al., 2018) and develop teamwork skills (Curşeu et al., 2012). We adopt Roschelle and Teasley's (1995) definition of collaborative learning as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (p. 70) as media arts production creates an iterative set of problems to be solved. Well-structured, collaborative problem solving tasks require distinctive roles and interdependency of the group members (Graesser, et al., 2017). Media arts productions create prime opportunities for collaboration as students concurrently gain collaborative skills through the act of solving problems with peers (Lee et al., 2015).

Learning through arts production processes are inherently deep and robust constructivist learning experiences (Halverson, 2013), providing students with opportunities to construct meaning of content while simultaneously gaining exposure to skills gained through the instruction of these art forms (Gullatt, 2008). Production also lends itself to interdisciplinary learning, where creators make sense of a specific domain or topic while also acquiring literacy practices across domain areas, including: new media literacy, technology fluency, artistic expression, traditional computer courses, or media education (Peppler, 2010).

Pulling from our combined experience in media production and our research in two creative production classrooms, we set out to answer our research question: What collaborative problem-solving processes do students engage in through artistic media production?

Assessing artistic media production

While many educators today integrate media production into their classroom, they often feel unprepared to assess media (Reilly & Atkins, 2013). As a result, they either do not assess the assignments or assess production based on the acquisition of factual content creating a decoupling of production practices and assessment (Silseth & Gilje, 2017; Aagaard & Lund, 2013). With the demands of the formal classroom environments, it is difficult to assess media production as it should be: both embedded into the process and product (Halverson, 2012). Through evaluating collaborative media arts production, educators can create assessments that will help shape what students see as valuable to learn (Silseth & Gilje, 2017).

In this paper, we demystify assessment for media arts production by demonstrating what collaborative problem solving skills to assess throughout the production process. We use the definitions from the PISA collaborative problem solving framework, which guides assessment of an individual working with a group rather than the group as a whole (Graesser et al., 2017). The PISA framing assesses students' collaborative problem solving along two dimensions: collaboration (first horizontal column) and problem solving (top row), resulting in

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12 specific skills (see Table 1). The PISA framework allows us to map particular moments of production to the collaborative, problem solving processes and quantify the acts taking place during the production process.

Table 1
Adapted PISA Matrix with color-coding system for production stages. Red: Pre-production; Yellow: Production; Green: Post-production; Purple: ongoing in all three stages. Original source: Fiore, S.M. et al. (2017).

	1) Establishing and maintaining shared understanding	2) Taking appropriate action to solve the problem	3) Establishing and maintaining team organization
A) Exploring and understanding	A1) Discovering perspectives and abilities of team members	A2) Discovering the type of interaction to solve the problem, along with goals	A3) Understanding roles to solve the problem
B) Representing and formulating	B1) Building a shared representation and negotiating the meaning of the problem (common ground)	B2) Identifying and describing the tasks to be completed	B3) Describing roles and team organization (communication protocol/ rules of engagement)
C) Planning and executing	C1) Communicating with the team members about the actions to be/ being performed	C2) Enacting plans	C3) Following rules of engagement (e.g. prompting other team members to perform their tasks)
D) Monitoring and reflecting	D1) Monitoring and repairing the shared understanding	D2) Monitoring the results of action and evaluating success in solving the problem	D3) Monitoring, providing feedback and adapting the team organization and roles.

Production Process Stages

Media production involves the process of turning one's ideas, knowledge, and skills into a digital representation, from the initial spark to a final product (Jocson, 2012; Halverson & Gibbons, 2010). While production is an iterative practice, most practices fit into three stages: pre-production, production, and post-production (Jocson, 2012). Table 1 reflects the collaborative problem solving skills tied to the three stages of production.

Pre-production involves conceptualization from brainstorming, storyboarding, and creating a plan of action. Initial planning creates direction while students set goals (A2), determine tasks to be completed (B2), and assign roles (A1, B3). During production, students collect materials and lace together all of the elements, often readjusting their initial ideas (Jocson, 2012). Students communicate with group members (C1), negotiating and renegotiating roles and plans (C2, C3) to meet their larger goal (B1). Post-production involves refining and modifying the artistic representation toward the final goal (D1, D2). As production is an iterative process, monitoring, providing feedback and adapting the team organization and roles can occur throughout (D3).

Methodological Approaches

Data Sources

Our research examines two case studies from unrelated media arts productions in public schools in the Midwest region of the United States. In both cases, we individually served as participant-observers engaging and collaborating with teachers and students throughout the production process. We both used ethnographic field notes from classroom observations and semi-structured interviews with teachers and students to understand more about group roles in these two collaborative productive experiences.

Collaborative Video Production

One study took place in a 9th grade high school introductory video production class in a small project-based, public charter high school in the United States. This case study follows Marty, Chris, Sigrid, and Mariah as they produced their silent film. "Anxiety". The film is about a young woman who suffers from social anxiety and is unable to leave her apartment. The film shows the character struggling to leave, confronting their own anxiety, and eventually leaving their apartment to join their friends at a party.

Collaborative Puppet Documentaries

The second study took place in a 2nd grade classroom participating in a STEAM residency program in the United States. The researcher worked as a teaching artist with two classroom teachers who co-taught 48 students. Students worked in production groups to create puppet-hosted mini documentaries about weathering and erosion, while learning about the digital media production process, puppet building and performance.

Data Analysis

To understand what collaborative problem solving processes students engage in through artistic media production, we used a multiple-case study approach to determine how the production processes compared in these to very different productions (Yin, 2003). We broke down the two cases into three stages: pre-production, production, and post production (Jocson, 2012). Through deductive coding using each of the categories of the PISA matrix, we determined where and when collaborative problem solving activities took place. We then triangulated data by jointly reviewing the two cases using the PISA matrix adding a color-coding system to the matrix based on production stages.

Major Findings

In this section we use examples from the video production project and puppet documentary to demonstrate the collaborative problem solving skills found in the pre-production, production, and post-production stages. We tie moments of each stage to particular skills in the PISA framework, labelling each with the corresponding letter and number from the matrix (see Table 1).

Pre-production

In the second grade classroom, while the students were skilled at using technology for project-based learning, they were novices to the media production process and being part of a production team. The teachers and teaching artist worked collaboratively to devise production roles for the students. Roles were assigned based on input from students on their preferences and interests, as well as the teacher 's perspectives of abilities and group balance (A1). Crews were formed of six students made up of two partners to each role: puppet designer, set/prop designer, and writer. These were structured to be interdependent roles to support their collaboration while meeting all the needs of the production (A2, A3). The students each had their own tasks to work on to bring the creative vision together (B2). Adult guides helped in supporting alignment to a single vision as well as group communication. However, the need for alignment and communication became readily apparent to the students; as they collected resources and began writing, they realized the need to communicate and work together to a shared creative vision - for example, the writers needed to be on the same page as the puppet designers to write the character properly (B3).

Production

Marty, Chris, Sigrid, and Mariah set out with inspirational goals of overlapping two videos in order to see the same character directly behind the other character. Their process included trials, revisions, and reshooting as nobody in the group had attempted this before. They started by filming the actor once in front wearing all white and again in the back wearing all black, but they realized two problems (B1): 1) the set of the two videos was inconsistent and 2) the two films were inconsistently shaky making it more difficult to match up the two videos. To remedy this, they discussed the actions needed to remedy the inconsistencies (C1) and enacted these plans (C2): they had to refilm, figure out a way to stabilize their iPad without a tripod, and re-examine the set to make sure everything was consistent. Marty, the director, helped direct the other group members in their roles from directing the actor’s movements to prompting others to move parts of the set to create more consistent backgrounds (C3).

Post-production

Marty, Chris, Sigrid, and Mariah had to figure out how to overlay video footage to create the impression that the two characters were in the same room. First, they had to learn how to use new software to create the complicated shot using online tutorials and seeking assistance from their teacher. During editing, the group had to return to production and refilm a few shots for consistency (D2). The group also participated in critique with their classmates where they received feedback that conflicted with their shared vision. The most significant feedback they received was that their peers felt the character in the film seemed angry or indecisive rather than anxious. The group therefore returned to refilming, editing, and added additional music and filters to portray the feeling of anxiety (D1).

Significance of Work

This work has important implications for teachers integrating media arts production into their curriculum. First, by designating specific collaborative problem solving skills into particular stages of production, teachers can pinpoint moments in production to assess specific skills creating more direction for those teachers who are unsure of how to assess media (Reilly & Atkins, 2013). Second, recognizing that media arts production involves the social construction of knowledge (Silseth & Gilje, 2017), our work provides direction for assessing collaborative problem solving as a process.

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"The Game was Designed to Learn to Think" – Player Perceptions of Learning in an Educational Game

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Abstract: Learning within videogames is often examined using pre-test and post-test, and/or by evaluating players' responses within the design of the game. This study examines young players' perceptions of learning within an educational videogame by analyzing their reactions and responses captured during gameplay and in an interview after the gameplay session. Our findings indicate that different players perceived different elements to be learning outcomes of playing the game. We argue that educational game designers should consider having different elements such as storyline, content-based puzzles, strategy, social skills, and problem-solving to engage players with diverse interests and prior experiences within the educational game design.

Introduction & Theoretical Grounding

The videogame industry is one of the fastest growing entertainment sectors. Games are also increasingly recognized as effective environments for learning (Clark et al., 2016; Dindar, 2018). A significant body of research has found the positive effects of playing videogames focusing on four main domains: cognitive, motivational, emotional, and social (Granic et al., 2014). Game based learning (GBL) literature includes accounts of several studies designed to test games' affordances for learning and skills development. For example, Shute et al. (2015), showed playing a puzzle game could improve players' problem solving, spatial skills, and persistence. Barr (2018) studied how undergraduate students perceived commercial game for developing skills and found a broadly positive perception of the games' efficacy for development of skills such as communication skill, resourcefulness, and adaptability. The literature shows that videogames can be a powerful tool for learning; however, there are two related gaps: 1) there is a lack of focus on micro-level interactions that players have with GBL; and 2) there is no work that ties designed elements to the perceived learning experiences of games. Thus, there is a need for empirical work about what players perceive as learning within a game designed for learning which we address in this study by examining the following research question: *What game mechanics are recognized as learning elements by players?*
Our study contributes by expanding prior work on game-based learning in two ways: 1) understanding players' perceptions of learning within a game, i.e., to identify what players view as learning and 2) providing implications for designing an educational videogame to increase the engagement of players coming from a diverse set of experiences.

Method

Data was collected from 17 participants between the ages of 11 to 14 (7 females, 10 males), recruited through a list-serve associated with the University of Maryland as well as advertisements sent via the local library. 3 participants identified as African American or Black, 4 as Asian or Pacific Islander, 6 as White or Caucasian, and 4 participants didn't report their

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racial identities in the demographic survey.

The data was collected using a Zoom interface where each participant shared their camera and microphone as well as their screen during the gameplay session. Each gameplay session was recorded. Each of the data collection sessions were approximately an hour long including ~40 minutes of gameplay and ~20 minutes of follow-up interview. During the follow-up interview, participants were asked about their impressions about the game and its possible learning outcomes of playing the game. The open-ended questions allowed the participants to discuss what they perceive as learning in videogames, specifically our game, *HEX of the Turtle Islands* (*HEX)*. All procedures were approved by University of Maryland Institutional Review Board.

A constructivist grounded theory approach guided the data analysis process (Charmaz, 2014). Our analysis took place over an iterative process using open, focused, axial coding, and memoing throughout the data analysis process (Strauss & Corbin, 1990).

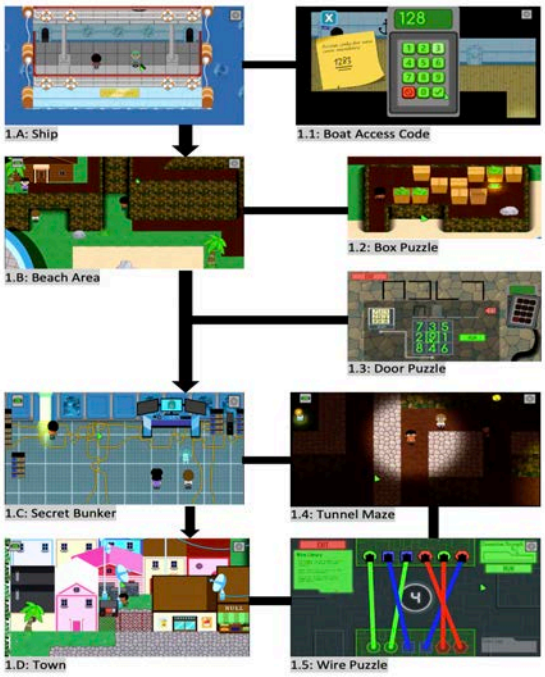

Figure 1: A map of action through the game. Labels A, B, C, and D represent locations that the player explores throughout the game (the Ship, Beach, Bunker and Tunnel, and Town). Labels 1, 2, 3, and 4 represent puzzles that the player encounters in each location (the access code, cipher, box pushing, and wire puzzles).

HEX of the Turtle Islands

HEX is an under-development game designed to introduce youth (11-14 years) to the domain of cybersecurity. The version of the game used for this paper represents an early prototype of the first level of the game which was being tested with players to get feedback for the larger design process. *HEX* is a single player, two-dimensional videogame that combines rich narrative through exploration of scenarios and puzzles rooted in cybersecurity concepts. The player takes on the role of a student investigating a larger conspiracy involving an evil corporation known as *HEX*. Throughout the gameplay, the player encounters cybersecurity scenarios that they must solve to find out what is happening, rescue the crew, and help to save the world in the process. The sequence provided in Figure 1 is roughly the intended pathway through the game for a player.

FINDINGS

Our analysis revealed five main learning themes that emerged from responses about what players thought the game was designed to teach – ecological storyline (one thread of narrative in addition to a larger cybersecurity related plot), content specific puzzle, strategy, social skills, and problem solving. These perceived learning outcomes are not mutually exclusive as some players reported more than one learning outcome of playing *HEX*.

Ecological storyline:

This theme refers to players identifying the narrative elements of *HEX.* For example, Adam recognized the ecological storyline as such, "*In the beginning, there was a little bit about [sea turtles–] ... the depth of the water with time the sea creatures came out*..." Here Adam is responding to hints that are placed in the game world about the impact that *HEX* is having on local sea turtle populations. Three players reported that they identify the learning outcome of playing *HEX* is to learn about the ecology on the islands.

Content Specific Puzzles:

The content specific puzzle theme emerged from six players' responses indicating specific content (e.g., code, logic, etc.) related to the domain of the game to be the learning element. For instance, Daniel shared, "*I learned about the logic gates and things from the puzzles* (Refer to Fig 1.5)." Another player, Maya, mentioned in her interview, "*I definitely think the [cipher] code* (Refer to Fig 1.3)." Daniel's response indicates that he recognizes the logical content involved in the wire puzzles whereas Maya's response emphasized the cryptography content involved in the cipher puzzle. These responses indicate that players pay attention to the content of the puzzles especially if they can identify the objective of having those puzzles in the game.

Problem solving:

Players' responses indicated that problem solving was the most prevalent learning outcome of playing *HEX*, nine players' responses indicated reference to the different elements of problem solving. For example, Matthew shared that, "*I think it was designed to help you to solve different problems*." Another player, Susan, responded that the learning outcome of playing the game is "*how to solve problems – Critically*." The problem solving was a larger theme with implicit references to high level concepts involved in problem solving such as 'critical thinking', 'logical thinking', 'decision making', and 'remembering' things to apply those later in the game.

Strategy:

The responses where players refer to applying strategy to make efficient use of available resources was labelled as strategy. This category was distinguished from problem solving because responses in problem solving referred to a collection of high order thinking skills whereas strategy was referenced to a specific form of ability. For example, Ben responded that "*Probably learning to use your resources and figure out what you could do with your situation with what you had*." His response indicates that while playing, players are required to use strategy to figure out how to make efficient use of the available resources. This theme points to a broader implication of what players do in the game environment can apply in their real-life scenarios.

4.5 Social Skills:

The responses where three players refer to social skills such as being friendly, interacting with people, and seeking help from others were labelled as social skills. For example, Ethan perceived the learning outcome of playing *HEX* is "*to be friends with people or ask for help.*"

This response indicates being social in the game can lead to being social in the real world.

Discussion & Conclusion

We found that players perceive learning within *HEX* in reference to different mechanisms involved in the *HEX* design: ecological storyline, content specific puzzles, strategy, social skills, and problem solving. These findings signify that different players attend to different mechanisms while playing a game. Even though there are similarities in some players' perceptions of learning outcomes associated with playing the game, differences in their responses indicates the 'emergent experience' of the gameplay (Squire, 2006). Our findings suggest that as designers of educational games we cannot assume that every player will have a similar learning outcome while playing a particular game.

The findings of this study are limited in certain ways. The potential learning outcomes emerged from this study are not an objective measure of all possible learning that happened to the players during gameplay. These learning outcomes are situated in the designed elements of *HEX*. Different videogame genres provide different kinds of affordances to players in the game. Future research needs be conducted to study how players perceive learning happening in other videogames to address these limitations. Our study is an initial step to understand learning in game-based learning from young players' perspectives, but we need more empirical studies to see effects of gameplay experiences on a player's perception of learning outcomes.

To conclude, our study findings indicate that different players identify different game mechanics to be associated with learning within the game. Thus, we argue that educational games should have multiple elements such as storyline, content-based puzzles, strategy, social skills, and problem-solving to engage diverse learners in the gameplay.

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Innovative Game-Based Fraction Curricula for All: Design, Development, and Feasibility of Dream2B

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Abstract: Simulated learning environments have the potential to significantly enhance engagement and conceptual understanding for all students, including students with learning disabilities and difficulties. Dream2B, a web-based video game designed with the Universal Design for Learning framework to maximize access, advancement, and power, includes for fourth through sixth grade students in supplemental mathematics instructional settings. Considerations for Dream2B's design and development are shared as well as planning for and results of feasibility testing in 4th grade classrooms.

Keywords: mathematics, universal design, supplemental instruction, gam-based instruction, fractions, learning disabilities, equity

Promoting diversity in the workforce is paramount for U.S. innovation in Science, Technology, Engineering, and Mathematics (STEM) and Information and Communications Technology (ICT) fields. Individuals with disabilities are underutilized members of the STEM and ICT workforce (e.g., National Science Foundation's National Center for Science and Engineering Statistics, 2019), even though these individuals exhibit unique traits and skills that are particularly beneficial in these careers (Dreaver et al., 2020). For example, Scott et al. (2019) noted these individuals often exhibit: 1) sustained attention to detail, 2) systematic procedural knowledge and skills, and 3) the ability to conceptualize outcomes and solutions to complex problems. The underutilization leads to an inverse relationship between worker supply and workforce demand and perpetuates disparities, especially for underrepresented groups.

Students with learning disabilities (LD), in particular, are one of the largest subgroups of individuals with disabilities and receive supplemental services to remediate areas of difficulty, such as fractions and rational numbers. Yet, this group exhibits reduced engagement and attendance in mathematics and science courses when compared to their peers in tier 1, often due to boredom (Sparks, 2015). The reduced engagement is likely an issue of access. Students with disabilities often require access to different tools to learn or express their STEM knowledge (Author). They also benefit from problems that allow for novel solutions because of the unexpected prior knowledge they bring to the classroom (Author). Both instructional design elements position students' knowledge as important and valuable. Unfortunately, many learning environments afford students with disabilities a one-size-fits-all procedural instruction with little opportunity to engage in and express their unique reasoning (Lambert & Tan, 2017).

In this paper, we report on the design, development, and initial testing plan of Dream2B, a game enhanced supplemental mathematics curriculum. Developed using the Universal Design for Learning (UDL) framework, Dream2B is designed to maximize accessibility and engagement by providing fraction conceptual understanding challenges rooted in authentic STEM careers. Tutorials, action adaptive prompting, and authentic formative and summative assessments are included within the user interface. Game-based problem-solving and after-game play discussion activities promote connections and strategically link to academic curriculum standards. The research questions are: (a) What were student perceptions of the Dream2B intervention?, (b) What were teachers' perceptions of the educational value of the curriculum?, and (c) What was the impact of the Dream 2B intervention on student outcomes (i.e., mathematics engagement/conceptual understanding/STEM Interest)? Below, we unpack Dream2B's core components. Then, we discuss our ongoing usability and feasibility testing of Dream2B in three fourth grade classrooms. Data collection is ongoing. Completed results will be shared in session.

Access, advancement, and power: Dream2B

Dream 2B is a narrative-based mathematics game where students play the role of "Bunny" who helps various STEM/ICT career specialists complete tasks by demonstrating their conceptual understanding of fractions. The

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game narrative describes how Bunny attends career day at school and is introduced to five different careers in STEM and ICT fields. Bunny returns home, goes to sleep, and begins to dream about the different careers discussed that day. In the dream, Bunny is introduced to different career specialists who are each encountering an issue at work and are seeking Bunny's help to fix it. Therefore, Bunny's role in the dream (or game) is to solve these challenges. Each challenge requires Bunny to engage in problem tasks (see below) that can be completed by solving fraction problems.

There are six worlds in the game, with the first five worlds corresponding to the different STEM/ICT careers: wind technician, solar engineer, fire inspector, photogrammetrist, and programmer. These five careers were chosen based on projected career increases over the next 10 years by the U.S. Bureau of Labor Statistics. Each of the first five worlds corresponds to a specific career; world six is a combination of tasks from all careers. The use of game narratives have yielded mixed findings about their effectiveness on learning outcomes (e.g., Clark et al., 2016). However, introducing a narrative has also been found to positively impact learning and motivational outcomes (Plass et al., 2015; Wouters et al., 2013). Therefore, we believe that providing a base narrative in Dream 2B will positively impact learning aligned with the mathematics curriculum we included (see below) and interest in STEM/ICT careers.

We take an innovative approach to the design and development of supplemental math interventions by integrating the following core components into Dream2B: (a) Game Tasks along a Fraction Learning Trajectory, (b) Universal Design for Learning, (c) Action Adaptive Self-Regulation Prompts, and (d) After Game Concept/Skill Connections.

Understanding dream2B's usability and feasibility

Our project is collecting and analyzing data related to the feasibility of Dream2B. This work is supported by a concurrent mixed methods design with one phase of data collection and analysis. Qualitative data will be embedded into the quantitative design. Data and analyses from this year will be used to inform a final revision to the supplemental curriculum before pilot testing.

Recruitment and training. We recruited three fourth grade teachers and their students to implement the Dream2B curriculum. Teacher and student participant selection was purposive in that inclusive math classrooms were selected that include 5-10% of students with disabilities for the feasibility testing. Participating teachers attended four one-half day training sessions on implementation of the curriculum. Day 1 of training opened with the purpose of the study, the logic model, and the target population. Teachers will become familiar with the design of the new curriculum, its features, and the overall learning trajectory that grounds the task sequence, prompts, and teacher talk moves. Over the second and third day of training, each task category and its written lessons acted as structural guides. The guides were designed to help teachers deepen their understanding of how students might think within the tasks and understand how the core components are used to bolster student learning. Teachers worked with each other to discern possible nuances in students' reasoning and prompts that are embedded into the game and curriculum. On the 4th and final day of training, teachers practiced using Dream2B through role playing. Teachers formed a small group with their peers and the research team, rotating between teaching roles and student roles, hypothetically engaging in the tasks, and implementing mocked student strategies. Teachers then engaged in discourse and used identified talk moves taught during the training to facilitate a sample student conversation.

Data collection. We are collecting five kinds of data to gauge the feasibility of the curriculum to answer the research questions (student perceptions, teacher perceptions, student outcomes). Each area is addressed below.

In terms of student and teacher perceptions, we will meet with our teachers in a 1.5 hour long semi-structured focus group to gather feedback on STEM career characters, guides, and motivational game components (i.e., resource management, narratives, character unlock). We will discuss how content is currently taught in classroom instruction, difficulties students may be experiencing with the content, and teacher familiarity with pedagogical moves used in the curriculum (e.g., worked examples, number strings; game prompts and task sequencing) and the extent to which, if at all, these design components were being used in their classroom. Finally, we will meet with 4th grade students with and without LD to conduct semi-structured interviews to gauge students' strengths (i.e., what students already know about ratio and proportion; what gestures they may already employ as they solve problems). We will also gain feedback on the preliminary list and design of STEM careers, game characters, and elements to align the game to preferences of elementary school students.

In terms of student learning outcomes, defined as engagement/conceptual understanding/STEM Interest, we will use several measures. First, the *Engagement in Science Learning Activities* survey, written for use with 10 to 14-year-old students immediately after an in-class or informal activity, will be used to measure student engagement with the curriculum. The survey measures a student's cognitive, behavioral, and affective engagement. Participants respond on a Likert-type scale ranging from 1 (*YES!*) to 4 (*NO!*). Both Cronbach's α and the polychoric coefficients yielded acceptable reliability when using all eight scale items (0.80 and 0.85, respectively). In addition to the survey, click trails will be used to determine in-game engagement. We will use 60 second game intervals without activity as the basis for engagement based on Author's prior research.

Conceptual understanding will be measured before and after the intervention using the Test of Fraction Schemes (Wilkins et al., 2013) and problem solutions generated during the games. The Fraction Schemes test is a proximal measure of the effects of the intervention on students' fraction conceptions. It consists of 12 items; 4 items for each of the following fraction concepts: unit fraction concept, partitive fraction concept, and splitting that underlies the recursive fraction and iterative fraction concepts. Internal consistency reliability for the test was reported as 0.70 for the unit fraction concept and splitting. Criterion-related validity with an associated clinical interview score was reported with coefficients of 0.52 ($p < 0.01$) for splitting and 0.58 ($p < 0.01$) for the unit fraction concept. Following Wilkins et al.[89], test scores will be supplemented by student interviews with an additional six items to assess the nature of students' pre-post fraction concepts.

Students' STEM interests will be measured with the Upper Elementary School (4-5) and Middle High School (6-12) Student Attitudes Toward STEM (S-STEM) (Friday Institute for Educational Innovation, 2016). It contains 56 items across six constructs: math attitudes (8 items), science attitudes (9 items), engineering and technology attitudes (9 items), 21st century learning attitudes (11 items), interest in STEM career areas (12 items), and 7 "About You" items that measure short-term expectations for course success and exposure to STEM careers. Responses are supported by a five-point Likert scale, with response options ranging from "strongly disagree" (1) to "strongly agree" (5). Higher scores reflect the greater perceived value of participants. Cronbach's α of the S-STEM ranged from 0.84 to 0.86 for the grade 4-5 subscales and 0.89 to 0.91 for the middle high school subscales.

Feasibility data analysis. We will take various strides to ensure the credibility, transferability, and dependability of the collected data. The prolonged engagement with teachers and students, persistent observation of problem-solving strategies, self-regulation utterances, and discourse representations, language, and observable operations), triangulation (i.e., 3 coders, 3 sources of data, 3 methods to collect data - video, student work, field notes) and member checking with teachers and students will address credibility of the data. Describing not just the behavior of students in the intervention but also the context supports transferability; we will also report examples of our coding processes and rationale for what codes were clustered together to form the basis of a theme to ensure dependability. We will also organize and analyze collected process and product data utilizing an array of tools. We will transcribe (verbatim) all video recordings that capture students' self-regulatory utterances during problem solving ("Think"), their discourse ("Pair" and "Share"), and teachers' employed talk moves ("Share"). We will also use Excel to organize students' self-reported use of checklist prompts, student and teacher self-regulation survey data, and pre- and post- test (product data) scores on the paper and pencil tests.

We will conduct 3 sets of data analysis: (1) assess teacher and students' perceptions of the curriculum, (2) assess pre-mid-post changes in self-reported engagement, conceptual understanding, and self-reported STEM and ICT interest, and (3) assess within-student fluctuations in time stamped behaviors over the learning sessions. To understand student and teacher perceptions of Dream2B, we will qualitatively analyze the focus group data. Specifically, we will transcribe and qualitatively code the data for recurring themes.

To investigate changes in students' reported engagement, their conceptual understanding, and reported STEM and ICT interest from pretest, mid-study, to posttest between conditions, we will conduct a series of repeated measures ANOVAs with time as the within-subjects factor and teacher as the between- subjects factor. We will examine the main effect of time (pre vs. mid. vs. post), the main effect of condition (teacher), and the interaction between time and condition on engagement scores, conceptual understanding scores, and STEM/ICT interest scores. We will also run linear regressions (single and multiple) to determine if engagement, conceptual understanding, and STEM and ICT interest at pretest are predictive of these measures at mid-study or posttest, or if measures at mid-study are predictive of measures at post-test.

To investigate the trace data (i.e., click trails during the game) and how they fluctuate across sessions or games, we will conduct multilevel modeling and educational data mining analyses. As the study includes a nested design (students within teachers), we can investigate the between- and within-student or teacher variance in time spent engaging in game activities or game levels, and their association with our posttest measures. The trace data will generate a stacked dataset with multiple rows of data per participant, where one row can represent a game session or game level, as opposed to aggregating all this information into a single row (i.e., mean game session duration). In addition, we will use sequential pattern mining to examine if we can detect sequences of in-game actions that are common across participants, and then determine the frequencies of those sequential patterns per student and compare those frequencies using chi-square analysis differential sequence mining. In addition to examining overall group differences between test times, we can examine processes of engaging in-game behaviors across class sessions or game levels.

Final interpretation. Results of each analysis will then be merged to compare and interrelate the feasibility of implementing Dream2B in fourth grade classrooms. Once the data are analyzed and organized, results will be used to make necessary adjustments to the curriculum. In session, we will report on the analysis and curriculum revisions.

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The Effects of Domain-specific Knowledge on (Re)reading a Literary Short Story

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Abstract: This study was designed to address the issue that student readers often struggle to generate the interpretive inferences needed for successful literary comprehension. Participants (n = 60) thought aloud as they read a short story. They were assigned to a 2(instruction: control, literary information) × 2(think-aloud: first pass, rereading) design. Providing readers with information about how to engage with a text in a literary way as well as an opportunity to reread and reexamine the story showed modest benefits for increasing interpretive inferencing. These findings have implications for how to help students to develop and use strategies that can support their understanding and enjoyment of literary works.

Introduction

Literary reading invites the construction of *interpretive inferences* about the deeper meanings of the work and reflection on the literary or aesthetic qualities of the work (e.g., McCarthy, 2015; Levine, 2019). However, students rarely make interpretive inferences as they read and often find literary foregrounding (i.e., stylistic variations) that experts appreciate to be dense and confusing (e.g., Claassen, 2012; Graves & Frederiksen, 1991; Peskin, 1998; Zeitz, 1994). In order to develop effective interventions to support the use of literary-appropriate reading strategies, there needs to be a better understanding of the domain-specific literary knowledge that supports the construction of interpretive inferences (Lee & Goldman, 2015).

McCarthy (2015) drew upon empirical studies of literature and theories of discourse comprehension to argue that literary experts possess not only knowledge that literary reading invites interpretation (e.g., a domain-appropriate reading goal), but also knowledge of relevant conventions and themes that support the construction of interpretive inferences. Rabinowitz (1987) refers to the shared knowledge between author and reader as literary rules: knowledge of conventions reflect *Rules of Notice* and knowledge of themes reflect *Rules of Signification.* Prior work has demonstrated that providing short background readings that describe relevant Rules of Notice and/or Rules of Signification prior to reading a story can improve their literary reading strategies. More specifically, these manipulations decrease student readers' reliance on close-to-text paraphrasing and encourage more interpretive inferencing (McCarthy & Goldman, 2019). Further, readers given information about the literary rules report higher ratings of enjoyment and appreciation of the story. These studies suggest that introducing novices to domain-specific literary knowledge can support more literary-appropriate interpretive processing.

The current work builds upon these studies to further examine ways to support novice literary readers in producing interpretive inferences. In the current study, we reduce the number of pre-reading conditions to include only the extremes (no information vs. information about both literary rules) and increase the sample size afford the use of inferential statistics. Critically, we also included a rereading manipulation. Rereading was assumed to support interpretive inferencing for two reasons. The first reason comes from research in discourse processing examining how readers construct mental models of what they read. Millis and colleagues (1998) demonstrated that comprehension processes during first reading are dedicated to constructing a textbase or gist representation of the text; whereas, upon rereading, resources are shifted to construction of inferences that support a more robust situation model. By the same logic, some have argued that novice readers may refrain from generating interpretive inferences during their initial readings of a text because they need to first construct literal aspects of the mental model before they are able to consider nonliteral meanings. The second reason comes from literary theory which suggests that rereading, or multiple readings, can allow readers to reexamine and appreciate literary qualities of the text (e.g., Dixon et al., 1993). In either case, the opportunity to reread should enhance readers' propensity to engage in more literary-appropriate processes, especially if they are given information that can support the generation of interpretive inferences. Thus, the current study aims to answer two research questions: (RQ1) *To what extent does providing information about literary rules change readers' processing of a literary short story?*

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Based on prior think-aloud studies (e.g., Burkett & Goldman, 2016; Claassen, 2012; Graves & Frederiksen, 1991), we predicted that students in the no information control condition would produce think-alouds dominated by paraphrasing. We predicted providing students with pre-reading information that informed them of relevant *Rules of Notice* and *Rules of Signification* would decrease the amount of paraphrases and increase the generation of interpretive inferences. We also anticipated that increased knowledge of how to make sense of the text would enhance their enjoyment and appreciation of the story. (RQ2) *Does a rereading opportunity augment the effects of providing literary information?* We hypothesized that an opportunity to read the text through once prior to thinking-aloud would allow readers to allocate more resources to complex inferences. Thus, readers may be better able to leverage the literary information on a second pass of the story. We also predicted that the opportunity to reread would increase readers' enjoyment and appreciation of the story (Kuijpers & Hakemulder, 2018).

Method

Design & Procedure

Students (n = 60, M_{age} = 27.18, *SD* = 7.18) from an urban university in the southeastern United States read and thought aloud about the short story *The Elephant* by Slowomir Mrozek. Participants completed the study one at a time in a one-hour session. Due to continued social distancing protocols, data were collected via videoconference. Participants were given a think-aloud instruction to verbalize as if they were "turning up the volume" on their thoughts as they read (e.g., Peskin, 1998). The experimenter modeled a think-aloud and then participants were given the chance to practice until they felt comfortable thinking aloud. Participants were randomly assigned to a 2(instruction: control, rules) × 2(think-aloud: first pass, rereading) between-subjects design. In the *control* condition, participants were only given the title of the story. In the *Rules* condition, participants were given information about relevant Rules of Notice (deviation from the norm, disruption, juxtaposition) used in the story and Rules of Signification (participants were told that the text was a satire and were given an explanation of what satire is). Participants in the *first pass* condition were prompted to think-aloud during their first reading of the story. Participants in the *rereading* condition were instructed to read the text silently before being prompted to think-aloud during their second reading. After reading, participants answered three appreciation items. Participants rated (1-7) the extent to which they agreed with the following statements: "Is this story an example of good literature?", "Did you enjoy reading this story?", and "Would you recommend this story to someone else to read?" (Dixon et al., 1993). Participants then completed a 20-item true/false comprehension test designed to measure readers' literal understanding of the story. Finally, the participants completed the Author Recognition Task (ART; Acheson et al., 2008) which is designed to measure print exposure.

Procedure

Think Aloud Coding

Participants' think-alouds were transcribed and parsed into idea units and coded using a simplified rubric from Whaley and McCarthy (2020). The rubric includes four categories. *Paraphrases* reflect restatements of content that is explicit in the text. *Text-based inferences* reflect a broad range of statements in which the participants are generating inferences to maintain a story-world representation of the text (e.g., "he obviously is trying to cut corners and use the money for himself or use to basically boost his ego", "So it sounds like because the director misled the kids […] seeing it disappear made them believe that elephants just aren't real"). *Interpretive inferences* are statements that go beyond the story world to identify nonliteral meaning ("it makes me think that maybe this is metaphorical for something else") and to understand the author's possible intention or meaning about the world at large ("There is some definite political statements that are being made through the subtext"). All other kinds of statements, including metacognitive monitoring statements ("Okay I'm a little confused") and personal associations ("I have rabbits at my backyard") were collapsed into an *other* category. Two researchers coded a random subset of 20% of the think-alouds, achieving good interrater reliability (weighted kappa = .75) and then independently coded the remaining think-alouds.

Results

Preliminary Analyses

ART scores (*M* = 10.46, *SD* = 9.28) reveal low print exposure relative to prior reports of undergraduate samples (Acheson et al., 2008 report *M* = 22.70 of 65), but consistent with their status as non-experts. An analysis of variance (ANOVA) test revealed no significant differences in ART score across the conditions, *F*s < 1.00,

indicating no *a priori* differences in readers' print exposure. Comprehension score was calculated as proportion correct. Participants scored highly (M = .90, SD = .07) and the ANOVA revealed no differences in comprehension score across the conditions, all Fs < 1.00.

On average, participants' think-alouds included less than 1000 words (M = 944.28, SD = 390.71). An ANOVA revealed no significant differences in think-aloud length, although the effect of rereading approached significance, $F(1,56) = 3.59$, $p = 0.06$. This pattern suggested that those who had already read the text once silently prior to thinking aloud (reread condition) generated slightly longer think-alouds (M = 1039.33, SD = 422.76) than those who were asked to think-aloud on their first pass of the text (M = 849.23, SD = 336.39).

Think-Aloud Processes

The omnibus 2(instruction: control, rules) × 2(think-aloud: first pass, reread) × 3(process: paraphrase, text-based inference, interpretive inference) mixed ANOVA revealed a significant three-way interaction, $F(2,112) = 6.45$, $p < .01$ (Figure 1). To follow up this significant effect and to address RQ1, we first examined participants who thought aloud during their first pass of the story. Consistent with prior work, there was a main effect of process type, $F(2, 56) = 46.86$, $p < .01$, such that participants generated significantly more paraphrases than text-based inferences and more text-based inferences than interpretive inferences (Tukey HSD test ps < .03, Figure 1, left). However, there was no main effect of instruction condition, $F(1, 28) = 2.24$, $p = .15$, and the process by instruction interaction failed to reach significance, $F(2,56) = 2.54$, $p = .09$.

To address RQ2, we then examined the effects of the instruction manipulation for the reread condition, who were given an opportunity read silently before thinking aloud. Consistent with the first pass participants, there was a significant main effect of process type, $F(2, 56) = 41.60$, $p < .01$, such that there were significant differences across all three types of processes (Tukey HSD tests, ps < .01). There was, again, no main effect of instruction condition, $F < 1.00$. However, these results were qualified by a significant process by instruction interaction, $F(2, 56) = 3.93$, $p = .03$. A t-test indicated significant differences in the proportion of paraphrases in the predicted direction such that participants given literary rules prior to reading and thinking aloud generated a smaller proportion paraphrases than those given no information, $t(28) = -2.13$, $p = 0.04$. There was no effect of information condition on the proportion of text-based inferences, $t(28) = 1.14$, $p = 0.26$. Finally, a t-test for the proportion of interpretive inferences as function of information condition failed to reach significance, $t(28) = 1.88$, $p = 0.08$. However, the low overall rates suggest a possible floor effect. Taken together, these results suggest that the opportunity to familiarize themselves with the text prior to thinking aloud increased the predicted effects of the literary information instructions.

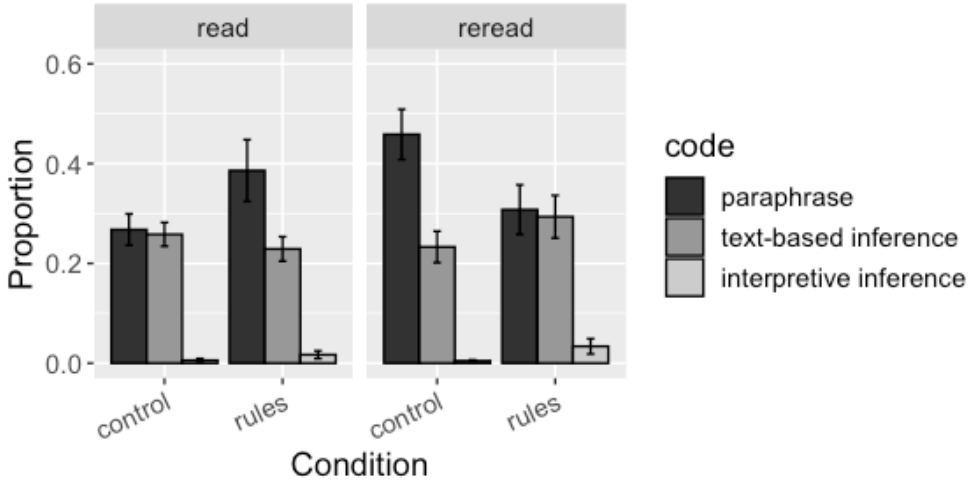

Figure 1
Think-Aloud Processes as a Function of Literary Rule Information and Rereading Condition

Appreciation Measures

The omnibus ANOVA indicated a significant three-way interaction, $F(2,110) = 4.33$, $p = .02$. Follow-ups indicated no effects for whether the story is good literature (Q2) or whether they would recommend the story to a friend (Q3; all ps > .10). By contrast, there were significant differences across conditions for ratings of enjoyment

(Q1; Table 1). More specifically, there was a significant main effect of information condition $F(1, 17.07) = 9.52$, $p < .01$, such that readers given literary rules information prior to reading found the story more enjoyable than those given no pre-reading information. These findings partially support our prediction related to the effect of literary instruction, but not rereading (e.g., Dixon et al., 1993; Kuijpers & Hakemulder, 2018).

Table 1
Appreciation Ratings as a Function of Literary Rule Information and Rereading Condition

	Did you enjoy reading this story? (Q1)		*Is this story an example of good literature? (Q2)*		*Would you recommend this story to someone else to read? (Q3)*	
	Control ***M* (*SD*)**	Rules ***M* (*SD*)**	Control ***M* (*SD*)**	Rules ***M* (*SD*)**	Control ***M* (*SD*)**	Rules ***M* (*SD*)**
First Pass	5.00 (1.41)	5.53 (1.19)	4.00 (1.31)	4.47 (1.55)	4.13 (1.64)	4.47 (1.64)
Rereading	3.93 (1.62)	5.43 (1.02)	4.00 (1.56)	4.36 (1.22)	5.07 (1.33)	4.57 (1.40)

Discussion

This study replicated previous work showing that knowledge of literary conventions and themes 1) affects how readers approach the text, such that they engage in less paraphrasing and slightly more interpretation and 2) increases enjoyment of the story. The study also extends this research by demonstrating that novice readers may be better able to leverage this domain-specific knowledge when given the opportunity to reread. These findings are consistent with the idea that rereading allows readers to focus their efforts on higher-order comprehension processes once an initial foundation has been laid and that revisiting a story gives a reader the opportunity to reexamine their understanding and gain new insights. Future research should examine reader processes in more fine-grained ways to better understand what drives these rereading effects and future development of instructional activities and interventions should consider emphasis on and opportunities to reread stories to help students to leverage their literary-specific knowledge and enact relevant comprehension processes.

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International Society of the Learning Sciences

Expanding Teacher Transformative Agency: An Activity-theoretical Formative Intervention Research in School-based Dialogue Sessions toward Future Making

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Abstract: Drawing on cultural–historical activity theory and expansive learning theory, this paper focuses on methodologically reexamining and transforming the linear interventions incorporated in traditional standardized pedagogy and educational research. To achieve this, the present study investigates strategies for generating formative interventions in teacher learning and development in an attempt to engage teachers in collaborative interventions to facilitate expansive learning. Teacher transformative agency can be generated and exercised through collaborative formative interventions. During this process, teachers become responsible activity agents who collaborate to independently reshape their activity systems. This paper presents the findings of a formative intervention study of teacher learning and development in school-based research involving teachers at a municipal elementary school in Japan. The participating teachers' school-based research can be characterized as expansive learning through which they collaboratively formed complex concepts, giving rise to a new vision of schooling.

Introduction

In the field of school reform, traditional standard intervention studies are reduced to linear causality, wherein a top-down view regards teachers as entirely passive agents of policies, while policymakers and researchers create a grand design that teachers then apply or revise, resulting in more positive change for students. Conversely, the basic principle of *formative intervention studies based on cultural–historical activity theory* is that teachers themselves gain the agency to control the intervention and take charge of the process. Thus, teachers become change agents. *Activity theory* studies how agents collaboratively redesign, change, and transform their collective activity systems, which have been culturally and historically constructed (Engeström, 1987/2015, 2008, 2016, 2018; Leont'ev, 1978, 1981; Sannino et al., 2009; Sannino & Ellis, 2013; Yamazumi, 2021). Here, the focus is on triggering and sustaining expansive transformation led and owned by teachers.

Moving beyond the limitations of linear intervention, activity–theoretical formative interventions in teacher learning and development attempt to facilitate teachers' *expansive learning*, as theorized by Yrjö Engeström (1987/2015, 2016)—that is, expanding the object of teachers' collaborative learning from below to change the broader structure of an entire school as a collective activity system. These *collaborative interventions* engage teachers in creating their own interventions to independently transform their activity systems (Yamazumi, 2021). Through such interventions, teacher *transformative agency* can be generated and exercised. In other words, collaborative formative interventions based on activity theory enable teachers to become responsible activity agents who collaborate on shared inquiry into desired objects, forms, and patterns of practice, resulting in the redesign of schools.

Drawing on the abovementioned frameworks, this paper focuses on methodologically reexamining and transforming the linear interventions incorporated in traditional standardized pedagogy and educational research. To achieve this transformation, this paper investigates strategies to generate formative interventions in teacher learning and development in an attempt to engage teachers in collaborative interventions to facilitate expansive learning. Reporting on an activity–theoretical case study, this paper presents the findings of a formative intervention study of teacher learning and development in teachers' school-based research at Jōetsu Municipal Ōmachi Elementary School, Jōetsu City, Japan, by analyzing the process involved in the teachers' expansive learning in dialogue sessions that combine classroom newsletters and activity reports.

Formative intervention methodology to expand transformative agency

Today, a form of intervention research based on activity theory geared toward people's expansive learning in social practices, work, and organizations is being promoted worldwide. This intervention research has evolved remarkably through a methodological principle called formative intervention, which is founded on the attitude embedded in concepts such as a "joint venture" (Engeström, 1987/2015, p. 22) between practitioners and researchers, premised upon practitioners becoming the collective subjects of an evolving new activity system with respect to which they collaborate, analyze, and intervene in it themselves as agents. In doing so, their joint

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intervention does not follow a predetermined course but instead seeks an expansive transition to "what is not yet there" (Engeström, 2016, p. 9).

Based on the framework of activity theory, which captures collective human creation of activity systems, expansive learning theory is a new theory of learning that considers agents' collective design of activities and practical involvement in transformations as their learning process (Engeström, 1987/2015, 2016). Expansive learning goes beyond the level of learning to solve a given problem and instead reaches the level of creating the problem or task itself, equivalent to what Gregory Bateson (1972, p. 119) calls "Learning III." Expansive learning also generates "what is not yet there"—in other words, "novel material forms of collective life, not merely construction of novel ideas in the minds of the learners" (Engeström, 2016, p. 9).

The expansive learning approach to school change through formative intervention focuses on methodologically reexamining and transforming linear perspectives of interventions that have been incorporated into traditional standardized pedagogy and educational research. The essential concern with expansive learning in and for the creation of new forms of pedagogical practices in schools is that people involved in schooling can "design and implement their own futures as their prevalent practices show symptoms of crisis" (Engeström, 1991, p. 256). In the area of school reform, the expansive learning approach is not based on the idea of "benevolent reform from above" (p. 257).

Therefore, even in its methodological principles, formative intervention differs fundamentally from the traditional top-down linear intervention that policymakers and researchers monopolize. From the viewpoint of formative intervention that facilitates participants' expansive learning, new forms of education should be reconceptualized as dialogically negotiated activities in which various agents produce new collaborative interventions while transforming their activity systems.

School-based dialogue sessions as collaborative formative interventions

Drawing on the abovementioned theoretical framework and methodology of formative interventions, this section considers school-based research at Jōetsu Municipal Ōmachi Elementary School, Jōetsu City, Japan, by analyzing teachers' expansive learning process in dialogue sessions that combined classroom newsletters and activity reports. In the 2020 academic year, 33 school-based dialogue sessions were held at the Ōmachi Elementary School and attended by all teachers. At the end of each session, the participating teachers wrote individual reflective essays, which all participants read.

It is relevant here to focus on the difference between what Mikhail Bakhtin (1975/1981, p. 342) calls "authoritative discourse" and "internally persuasive discourse" in order to gain a clear understanding of the dialogical, responsible, and reflective nature of the sessions at Ōmachi Elementary School. Bakhtin describes authoritative discourse as the "tendency to assimilate to others' discourse" (p. 342). In contrast to authoritative discourse, internally persuasive discourse evokes new ways of thinking. It allows one to acknowledge one's innermost feelings, thus bestowing the power of creative self-expression.

Having analyzed teachers' statements, the dialogue sessions at Ōmachi Elementary School can be considered a place for teachers to directly engage with internally persuasive discourse. In other words, dialogue sessions are creative and productive activities that encourage teachers to acknowledge others' internally persuasive discourse. Engaging in these interactive relationships awakens "new and independent words" within shared educational practice. This invites us to reveal "ever newer *ways to mean*" (Bakhtin, 1975/1981, p. 346).

Hence, the dialogue sessions at Ōmachi Elementary School resemble the so-called indigenous thinking that arises from below through the teachers themselves. This involves their everyday practice of educating and thorough reexamination and requestioning of the collective life of collaboration between teachers and children. In other words, this is tightly interwoven with the concept of "one's own word," as Bakhtin states. The aim is to generate a common ground and language. As one teacher stated, the dialogue sessions inspire indigenous, sensuous, and wild cognition, thoughts, and expressions rooted in the everyday lives of teachers' work with children. In connection with this, they are heading toward the creation of new common images of children and schools. Here, where school-based research is considered to be the model of a collective activity system (Engeström, 1987/2015, p. 63) for making a school, the dialogue sessions seem to act as instruments mediating internally persuasive discourse among the participants.

The emergence of teacher transformative agency through collaborative concept formation toward future making

The in-school research activity at Ōmachi Elementary School is also a form of expansive learning for teachers, ecnouraging the collaborative formation of a new concept that is "not yet there." This concept concerns the genesis of the school's future. The aim of this level of concept formation is as follows:

> The Things Considered in the Form of a Third Semester's Initiative (Issues): Constructing New Visions of the Child and the School
> It is essential we have a common concept (words) concerning views of children and education if we are to perceive, recognize, and expand the learning and growth of children as a whole school and by "everyone." The third semester will be used to inductively gather and analyze individual concrete "activity" in the first and second semester; while raising the level of abstraction, we wish to explore and assemble a shared concept (words) that expresses and directs the intended vision of the child and of the school. Into this we wish to include the school management policies of the managerial staff as well as the wishes of guardians and local communities.
> This research activity in the third semester can be considered to be linked to the creation of a grand design for the school in the new academic year, the resetting of educational and priority goals, the way school evaluations, and the organizing the curriculum. (Jōetsu Municipal Ōmachi Elementary School Research Promotion Department, "The Proposal for the 29th School-based Dialogue Session [Revised and Annotated]," January 7, 2021)

The shared concept (words) that the teachers formed through the dialogue sessions at Ōmachi Elementary School is not among those "stable, well-defined and neutral concepts" (Engeström et al., 2005, p. 48) with which only the "standard cognitive theories of concept formation" have been preoccupied. Rather, it belongs among "unstable and contradictory complex concepts" (p. 48) that teachers seek and spin out as expansive concepts that are "not yet there." In this sense, these "complex concepts" give the subject the power of creative expression by awakening "new and independent words" (Bakhtin, 1975/1981, p. 345), and they are invited to reveal "ever newer *ways to mean*" (p. 346). Engeström and his colleagues (2005) have stated that complex concepts are formed during creation. This represents the externalization and generation of culturally new concepts.

Mr. Eisuke Takahashi (2020, p. 19), head-teacher of research at Ōmachi Elementary School in 2020, understood the teachers' dialogue sessions in school-based research that combined classroom newsletters and activity reports as opportunities to collectively listen to "children's ways of living and episodes from 'activity with children.'" In other words, the dialogue session is a performance of "*anchoring down*," based on "experiential and descriptive language" or "cases, feelings, and ethnography," as referenced by Engeström (2004, pp. 98–99). In this anchoring down, teachers ask "how" questions (Engeström, 2016, pp. 95–96). Moreover, by asking "who, what, when" questions, teachers also perform "*anchoring sideways*." However, the dialogue sessions at Ōmachi Elementary School were not limited to anchoring down and anchoring sideways; they also aimed at collaborative concept formation, as described above. This means that they also strive toward "*anchoring up*." Therefore, these are dialogue sessions in which teachers asked "why" questions about the origins of the problem and contradictions in educational practice, as well as "where to" questions about the future of the entire school activity system and the network of activity systems. Engeström (2004) states that when these different types of questions act as "second stimuli" (instruments as mediating artifacts), as Lev Vygotsky (1930/1999) emphasized in his "double stimulation" principle, in workplace meetings, the following is important: "[T]he key is in complementarity, interplay, and transitions among the different types of questions" (Engeström, 2004, p. 101).

Thus, expansive learning in which practitioners themselves design and transform their own activity systems can be characterized as the "construction and use of dynamic multi-level conceptual instrumentalities" (Engeström et al., 2005, p. 59). In doing so, two-way movements, namely bottom-up and top-down, fill the gaps between situational "what" and technical "how" conceptualizations and spatial–systemic "why" and historical–visionary "where to" conceptualizations. At that point, the agent uses multi-level questions as mediating artifacts and second stimuli, whereby they themselves invent, use, and mediate, thus controlling their actions from outside and redefining the circumstances. When they actively intervene in the situation, transformative agency emerges, triggering intentional transformative actions (Engeström, 2016, pp. 224–225).

Of the 33 school-based dialogue sessions held in the 2020 academic year at Ōmachi Elementary School, the 32nd session titled "Session on School Making," in which all teachers participated, was held on February 25, 2021. The session focused on exploring ideas for shaping the school's future and legacy. Based on the school's grand design proposal for the upcoming academic year, discussions were held about the school's new image, the image of the child, the curriculum, concrete initiatives, and research directions. In other words, the "Session on School Making" was an attempt to collaborate and collectively perform epistemological work in which teachers tackle "where to" questions through the invention and use of mediating artifacts. This work explores and assembles a shared concept that expresses and directs the intended vision of the child and of the school. The "where to" concept that the teachers formed collaboratively was "making together."

Conclusions

Teachers' school-based research at the Ōmachi Elementary School can be characterized as expansive learning that fostered the collaborative formation of concepts and future making toward a new vision of the school. Such concept formation and future making does not occur in the dimension related to the method or technique of discrete teaching, but rather in the dimension of asking "why" and "where to" questions pertaining to an entire school as a collective activity system and the future of the school. School-based research helps formulate "where to" concepts such as "making together," which is a useful living instrument (mediating artifact) that teachers can use to develop a vision for their school's future activity system and redesign its present activity system.

Modeling the school's future strongly suggests the adoption of a school learning activity based on mutual aid and care as an alternative to schooling linked to the creation of a post-capitalist degrowth society. With this alternative, the use value of school learning is geared toward people living side by side and creating joy, common good, and well-being for everyone. To achieve this, the school is perceived as working on rediscovering and expanding sharing and as a place where learning is concrete, unique, and useful to each person.

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Online platforms as sites for Learning: Exploring the use of online resources in Computer and Software Engineering education

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Abstract: This study investigates how online platforms are used as sites for learning by undergraduate students in computer and software engineering (CSE). The study combined different methods and data types to explore the resource infrastructure available to 73 CSE students as they used several online platforms to learn software development over a period of three months. Our findings reveal that students combined multiple platforms in different ways, providing access to a wide variety of resources, and across learning contexts that extend beyond the boundaries of the formal curriculum. The study contributes empirical evidence about learning with platform-based resources and suggests that future research should focus on how platforms can be considered as resources for learning in undergraduate education.

Introduction

Students in undergraduate education engage increasingly with online platforms such as Google or Udemy to support their learning activities, included or not in the design of their curricular tasks (Zlatkin-Troitschanskaia et al., 2021; Henderson et al., 2017). Research shows that students use such platforms also to learn study-related content outside the context of curricular tasks (Brown et al., 2016). Online platforms can offer support for student learning in multiple ways (Manca, 2020), but research has mostly focused on examining learning in curricular contexts and through social networking platforms (e.g. Facebook or Twitter) or in instant messaging platforms (e.g. WhatsApp or WeChat). Other platforms, many of them domain-specific, have received less attention. In domains such as computer and software engineering (CSE), where professional work has become rich in online resources and practices (Storey et al., 2017), platforms are especially relevant. CSE professionals use a wide variety of platforms for their work (e.g. GitHub or Stack Overflow), and some studies have shown CSE students using those same platforms to support their learning during their studies, both formally (Tushev et al., 2020) and informally (Damşa & Nerland, 2016). Nonetheless, the understanding of how students learn using platforms in specific disciplinary domains is still limited (Zlatkin-Troitschanskaia et al., 2021), constraining teachers' efforts to support students during their studies. This study sheds light on this matter, by exploring the infrastructure of resources provided by online platforms as CSE students learn software development during their studies. To address this aim, we used a mixed methods research design, in order to answer the following research questions:
RQ1: How do CSE students combine online platforms across curricular and online, non-curricular contexts to learn software development?
RQ2: What learning resources are made available to students when online platforms are used?

Conceptual Framework

To examine students' use of online platforms, this study builds on two conceptual underlays. Firstly, the use of platforms is seen as contextual, as actions students carry out involving the use of platforms are not isolated but bound to specific situations and circumstances taking place over time (Zheng & Yano, 2007). Secondly, platforms are conceptualized as online software infrastructures that are characterized by the resources they provide access to, and which play a mediational function by linking students with different people and types of information (Bruce & Levin, 1997). Analytically, we focus on the performance of students' actions over time involving the use of platforms. These actions are represented by the access to different platforms over time, characterized by different configurations of platforms used. Configurations determine which resources are at students' disposal as they move across boundaries of curricular and online, non-curricular contexts. Configuration is a variable consisting of different combinations of platforms that are assembled in specific situations and provide access to different types of resources, shaping the infrastructure of resources students have access to as they use online platforms.

Methods

The study was conducted by inviting undergraduate students from CSE programs from four major universities in Norway to participate voluntarily in the Fall 2020 and Spring 2021 semesters through their course teachers, limited to courses related to software development. The identity of the participants was protected following national and

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GDPR regulations. In total, 73 students participated, 33 in the Fall 2020 and 40 in the Spring 2021. The dataset collected consists of students' web-browsing history and self-reports, as well as 27 individual stimulated recall interviews (Dempsey, 2010). A custom-made software was used to collect self-reports and web-browsing history, which surveyed students about actions directed at learning software development and the platforms used to carry them out. The software also retrieved information about every time those platforms were accessed during a three-month period back from the moment the survey was submitted. During the interviews, carried out using an online video conference service, students were shown the platforms they selected in the survey and the monthly frequency of access to each platform, to prompt reflections about when, how and why online platforms were used. The interviews were audio recorded and later transcribed verbatim. The dataset was analyzed, firstly, through a sessionization, in which the events in the web-browsing history were aggregated into smaller aggregated units (i.e. sessions), defined based on a maximum separation between events (Kapusta et al., 2014). A subset of sessions was selected for analysis based on the self-reports. Secondly, a descriptive mapping was carried out to identify and group the resources within each platform, in order to define distinct types of platforms. Thirdly, a latent class analysis (LCA) (Muthén, 2001) of the types of platforms used during the sessions was performed, with the best model selected based on the lowest BIC criteria. Finally, a thematic analysis of the interview transcripts (Braun & Clarke, 2012) identified learning contexts involved in the use of platforms.

Findings

The sessionization resulted in 12,799 sessions characterized by platforms accessed, of which 3,336 sessions were selected based on the actions carried out with the platforms involved. The descriptive mapping resulted in eight different types of platforms being used by the students, with search engine (SE) and video repository (VR) platforms being the most frequent in the sessions, identified in more than half of the sessions. Tutorials and courses (T&C), questions and answers (Q&A), source code repository (SCR) and communication (COMM) platforms were present in about 30-40% of the sessions, while text library (TL) and SN platforms were the least used, present in less than 30% of the sessions. The analysis of the interview data revealed that the sessions took place mainly in the context of curriculum-based tasks, although some of the students also reported using them to develop software outside their study-related work. The curriculum-based tasks were mostly recurrent software development tasks part of specific courses, and students used platforms both during these tasks as well as to prepare in advance for them. In a few cases, students used platforms also to prepare in advance for lectures. Outside the context of their studies, some of the interviewees reported using online platforms to master and implement new programming methods, either as leisure or for entrepreneurial purposes.

The LCA resulted in a five-class model being chosen after following the minimum BIC criteria, and assessing results from likelihood ratio tests and the entropy of the models, which reached 0.906, suggesting a good class assignment (See Table 1).

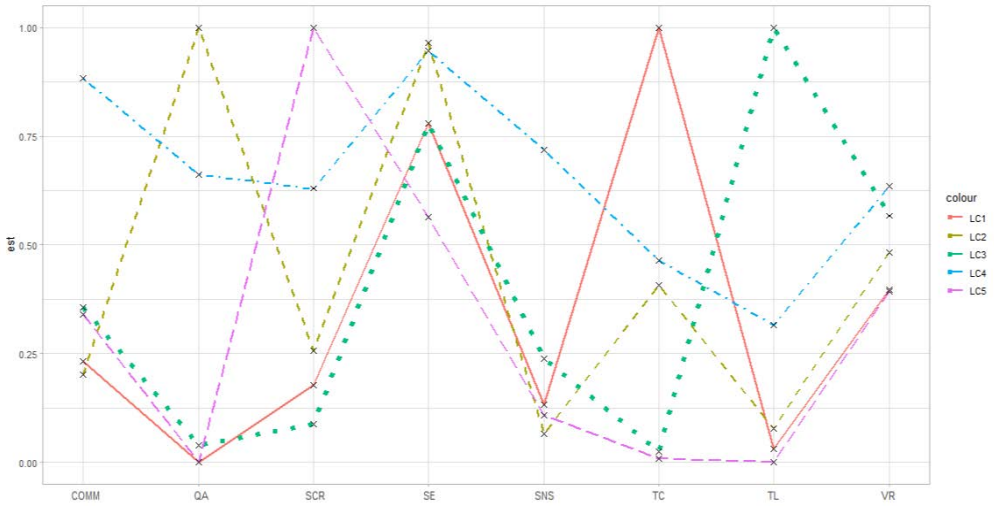
Table 1
Latent Class Analysis - Information criteria indexes

Classes	AIC	BIC	aBIC	VLMR	LMR	BLRT	Entropy
2	31263.3	31367.3	31313.2	0.000	0.000	0.000	0.888
3	30243.1	30402.0	30319.4	0.000	0.000	0.000	0.871
4	29448.5	29662.4	29551.2	0.000	0.000	0.000	0.979
5	**29222.8**	**29491.7**	**29351.9**	**0.000**	**0.000**	**0.000**	**0.906**
6	29180.7	29504.7	29336.3	0.089	0.0919	0.000	0.845

Each one of the latent classes in the selected model were found to be characterized by at least one distinctive type of platform. This is visible in Figure 1, where the x-axis lists the types of platforms involved and the y-axis the conditional probability of class membership for each type of platform. **Latent class 1** (LC1) accounted for 19% of the sessions after assigning the most likely class to the sessions, and distinguished itself from the rest due to a high conditional probability of having T&C and SE platforms. This configuration suggests that students accessed an infrastructure of resources characterized, firstly, by web-search, present in SE platforms. This enabled searching for information in other platforms based on terms introduced by the user. In addition, this infrastructure also provided access to knowledge summarizations and representations, as well as procedural models, mostly related to software development, as well as visualization software that enables running code to check its output, all present in T&C platforms. **Latent class 2** (LC2) accounted for 33.3% of the sessions once the most likely class was assigned. These sessions showed a high conditional probability of having Q&A and SE platforms present. This configuration suggests students had access to web search, like in LC1, but also to discussions directed at solving specific programming problems and functionalities for publishing text and code

components in such discussions, present in Q&A platforms. In addition, these platforms offer access to resources that enable public profiling and making connections with other users on the platforms. **Latent class 3** (LC3) accounted for 21.7% of the sessions, and distinguished itself from the rest by a high conditional probability of having TL and SE platforms in the configuration of the sessions associated with it. Similar to LC1 and LC3, this configuration suggests an infrastructure characterized by web search, but also by knowledge summarization related to a wide arrange of topics, resources that are present in TL platforms. **Latent class 4** (LC4) accounted for 6.4% of the web-browsing sessions once the most likely latent class was assigned. LC4 distinguished itself for having a high conditional probability for COMM, SN and VR platforms, as well as a moderately high probability of having Q&A, SE and SCR platforms present. This configuration suggests a large resources infrastructure involved. COMM platforms were characterized by functionalities that enable asynchronous and synchronous audio and text messaging, videoconferencing and screen sharing. SN platforms offer access to social networking resources, such as public profiling and features for making and managing connections with other people, but also resources for publishing information in different formats such as text or video. VR platforms were characterized by digital libraries of videos related to a wide variety of topics, but also by features that enable publishing text comments next to the videos, public profiling and managing connections. SCR platforms were characterized by digital libraries of source code and by functionalities that enable working with other people in source code asynchronously, by modifying and managing changes made in the code in different ways. Finally, **latent class 5** (LC5) accounted for 19.7% of the sessions, and distinguished itself from the rest by a high conditional probability of having SCR platforms present. Thus, the resource infrastructure students had access to was mainly characterized by the resources available in these platforms, which are described above, and that enable working and managing asynchronously in source with others.

Figure 1
Probability of Types of Platforms in each Latent Class



Discussion and Conclusions

With regard to *how do CSE students combine online platforms across contexts to learn software development,* the findings revealed that students' use of online platforms took place across both curricular (Manca, 2020; Henderson et al., 2017) and non-curricular contexts (Brown et al., 2016), primarily during performing software development tasks. Our findings add to previous studies by showing that, in both types of contexts, students used multiple platforms that were combined in different ways, presumably to address different aspects of the tasks they engage in. Students constantly crossed curricular boundaries to informally use resources they deemed relevant for their learning, and even used platforms to work in their own projects. Moreover, the platforms accessed by students were, in some cases, domain-specific, highlighting the importance of taking into account disciplinary contexts to understand how students learn using online platforms (Damşa & Nerland, 2016).

With regard to what *learning resources are made available for students when online platforms are used*, the findings show that, although the resources available to the students varied significantly across sessions, clear patterns emerged related to the configurations of platforms used by them to support their learning. For instance, while some of the resources infrastructures observed are similar, important differences emerged with regard to what specific resources were available across these configurations. Moreover, the infrastructures accessed not

only involved resources related to the use of information, but also those that connected students with different people and that enabled different ways of relating with them. Such differences, found as a result of the LCA and the descriptive mapping, suggest students act purposefully to address different aspects of the tasks they engaged in, suggesting that the use of platforms not only is situated in nature but also relational.

These findings are in line with previous studies that argue that students purposely shape the resource infrastructure they use to support their learning by moving across multiple contexts and that this infrastructure is domain specific (Damşa & Nerland, 2016; Tushev, 2020). Furthermore, the current study adds by providing empirical evidence of such processes, showing the specific resources and contexts shaping such infrastructure and that students use multiple platforms in combination to shape it.

This study makes an empirical contribution, by shedding light on students' learning that involves the use of online platforms. Students act purposely to assemble different resource infrastructures as a response to the learning context in which platforms are used, but also enclosed in larger learning contexts that involve both the curriculum as well as specific disciplinary domains. The current study also makes a methodological contribution, by showing how different types of data and new analytical techniques, such as the sessionization process in combination with the LCA, can provide valuable insights into students' learning practices. Future research should focus on how online platforms can respond to specific disciplinary domains, and examine in-depth how students combine multiple platforms purposefully in order to access the resources they deem as necessary for specific learning needs. This research should further explore how the resources within platforms are used by students, what relevant learning affordances these provide and what purposes drive students to use platforms. Higher education institutions should also take such considerations into account, as the informal use of platforms seems to play a determinant role in what learning resources shape student learning.

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Situating Socio-Scientific Representations in Artistic Transformations

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Abstract: The current study aims to link artistic practices with STEM learning by documenting a case study of five 6th graders who navigated multiple artistic representations to interpret an article about a social scientific issue. Analysis of interviews, observations, video clips, and students' artifacts point to a set of factors (personal, social, cultural, material, and embodied) that mediated students' construction, transformation, and communication of multiple artistic (including embodied) representations.

Conceptual framework

Research in STEM education has widely focused on the role of student-generated representations for deepening and communicating learning (Cox, 1999; diSessa, 2004; Greeno & Hall, 1997). Little research has built on these findings to expand and include explorations of how students engage in representations for Socio-Scientific Issues (SSI) explorations. SSI are controversial issues of public interest that are related to science, such as topics related to climate change. Considering that SSI interventions address controversial problems that could have multiple solutions, the study of SSI is important for grasping the complex and contested nature of science. (Tytler, 2012). The present study aims to fill this gap, including understanding how students transform representations at the intersection of SSI and arts and how they connect mental and external representations with embodied representations, which engenders new forms of learning and representing (Pande & Chandrasekharan, 2017).

The study follows an activity (1.5h duration) during a STEAM elective course in which 6th graders were framed as artists working in a museum and were asked to construct multiple artistic representations to communicate their interpretation of an SSI article. The article raised the question: "Is a person's fate a matter of nature or nurture?" with references about the influence of the environment and genes on a person's traits. Students transformed the article (sentential representation) to drawings (pictorial representations), used their bodies to collaboratively transform the drawings to "static sculptures" (embodied representations), and added sound and short movements to transform the static sculptures to "interactive sculptures" (dynamic embodied representations). The guiding research question of the study was: *How do middle school students construct, transform, and communicate various artistic representations to make meaning out of an SSI article?*

Conceptual framework

Representations as distributed and embodied

Our theoretical framework is informed by current shifts in cognitive science, namely *distributed* and *embodied* cognition theories, that stress the role of the material environment, context, motor actions, perception, embodiment, imagination, analogy, and metaphors for cognition (Barsalou, 1999; Hutchins, 2010; Johnson, 2017). Within the distributed perspective, the competences that individuals display are distributed among the tools, the environment and other people (Hutchins, 2010). Particularly for collaborative activities, participants share their representational skills and use the tools of their local environment (Cole & Engeström, 1993). From this perspective, individuals' capacities to represent need to be understood in context, that is in relation to the local setting, including the tools in use and social and cultural factors (situated perspective, Lave & Wenger, 1991). Embodied and enactive theories highlight the relation between action, perception, and experience (Barsalou, 1999; Varela et al., 2017). Embodiment is "the premise that the particular bodies we have influence how we think" (Hutchins, 2010, p. 428). Enaction is "the idea that organisms create their own experience through their actions" (Hutchins, 2010, p. 428). Hutchins (2010) applied the enactive perspective into representations by arguing that humans integrate perception, action, and imagination and "make material patterns into representations by *enacting* their meanings" (p. 434). Moving and experiencing the body affect how people perceive the represented world, a world that depends on the affordances and constrains of the bodily experiences (Hutchins, 2010; Varela et al., 2017).

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Methods

We followed a case study research design (Merriam & Tisdell, 2015), in which we developed a curriculum to foster middle school students' integrated STEM, arts, and literacy practices. Thirty-nine students participated in the elective course (18 female students and 21 male students), and 18 students consented to take part in the study and allowed for video recordings and photos. The current study focuses on a group of five students. All students of the group identified as Hispanic, and three of the students were female while the rest two were male. In the activity explored in this paper (week 4 of the curriculum; 1.5h duration), learners, in groups of 4-5, took on the role of artists who drew paintings inspired from an article about genetics and engaged in a series of representational transformations.

To ensure credibility and increase the trustworthiness of the study we collected a variety of data (Lincoln & Guba, 1986): Video records of the focus group's activities, intensive 30-min individual interviews with two of the participants, informal conversations with the group, students' artifacts (drawings, photos), and ethnographic observations (field notes and memos). We fully transcribed the interviews and the video records. For the analysis of the interviews, we conducted open coding and constant comparison (Corbin & Strauss, 2014). For the video analysis, we attended both to verbal (talk) and non-verbal (gestures, bodily postures, tone of voice, etc.) ways of communication (Goodwin, 2007). We also created matrices to examine each student-generated representational transformation (Miles & Huberman, 1994). Each matrix included a summary of observations, researchers' notes/interpretations, students' quotes from their discussions and interviews, and description of students' artifacts.

Findings

First Transformation: Article to Drawing

Students used the affordances of drawing to communicate their interpretations of the article. Their creations reveal a variety of perspectives and strategies (e.g., color, symmetry, pictorial metaphor, narrative metaphor). All students reasoned about their choices by connecting their pictorial representations with references from the text, although sometimes they distorted textual references to accommodate their choices (see Figure 1).

Students incorporated cultural norms, their preferences, and previous experiences into their drawings. For instance, Camila transformed a linguistic metaphor ("a cosmic dice rolling into one's favor") into pictorial cultural symbolism. She used a cultural inference that the best value shown in dice is six and the worst is one, as commonly agreed in boarding games. She also used the symbolism of color, dark color for representing the poor and bright color for representing the rich.

Figure 1

Photo of the Static Sculpture and Students' Drawing

Sofia created a pictorial metaphor to communicate her interpretation of success and failure. She drew a tree with some of its roots "colored all the way to show fulfilled lives" and some of the roots not "colored all the way" to show that some "lives could have been more fulfilled, but they weren't" (Sofia's interview). Sofia said in her interview that she always liked drawing trees and now she thought that "maybe, a tree could incorporate in here like a family tree." Sofia merged her preference in drawing trees with a cultural norm according to which trees symbolize "family trees." With her choice to "fill" some of the roots and not others, Sofia also created her own symbolism: the level of extension of the roots' color (not the color itself) symbolized a person's fulfillment in life. Sofia mistakenly thought that "somewhere in the article it said that some people have fulfilled lives" (Sofia's interview). Sofia was possibly referring to the article's "successful lives," but she transformed the word

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"successful" into the word "fulfilled" and this transformation aligned with her choice to "fill" with color some roots and not others. Here, she turned something abstract (i.e., "successful lives") to a concrete pictorial metaphor (i.e. tree roots filled with colors).

Second transformation: Drawing into static sculptures

The case of Sofia: From the "tree of life" to "DNA dancing"

Initially, Sofia agreed to represent a tree for the collaborative representation. When the members of the group positioned themselves in space, she tried to move like a tree and after 15 seconds, she said to her peers that she did not want to depict a tree (video records). Carlos suggested that she should represent DNA instead, and Sofia tried this option by "cross[ing] [her] arms and legs to make it look like [she] was coiled as a DNA," as she had seen in drawings of DNA (Sofia's interview). Sofia reported her "DNA dance" (our term) as fun to do during her interview, and she attributed her movements to her experience as a ballet dancer: "it's just after you start doing this sort certain dance for like months and months, then you start picking up your hands and your positions to be a bit more inclined to that position on how you are." The dynamic form of the DNA, as compared to the more static tree, aligned with how she preferred to move as a dancer. Sofia also reasoned about representing DNA, saying that "DNA is important" and that the group would not be able to relay any message to the audience without it (Sofia's interview). For Sofia, the change of the representational medium also led to different representational tools at her disposition.

Third transformation: Static sculptures into dynamic sculptures

In the initial frozen posture, Isabella put both her hands on her neck, as if she touched an imaginary necklace. Her face was frozen in an expression that showed excitement. Camila sat on Isabella's left, and her hands were positioned as if she counted money. Carlos stood next to Camila. He held his palms projecting his hands, as if he threatened someone with an imaginary gun. Next to him sat Luis. Luis sat in a curved position, holding a pencil case, pretending this was a case for people to put money in. Sofia stood in the middle, crossing her hands, as if these were the strands of DNA. When the "sculptures" became interactive, Isabella took her hands off her neck and took a red sharpener, pretending it was a mobile phone that she used to text her friends about her new necklace. Camila used her pencil case as an imaginary phone. "Hi," she said, and she froze in an expression of excitement. Carlos put his hands behind his back as if he got arrested, and he turned his face on the wall. Luis revealed a paper that wrote "needs money" from his jacket and he spoke in a weak voice: "Money, money." Sofia moved her hands and froze in a position with her right hand up and her left hand down. In the following, we present Sofia's and Luis case.

The case of Sofia: Hand down for downfall

During the group's rehearsal, Sofia moved her whole body in something that seemed like a DNA dance, and ended in a posture in which she had "one hand down on the side that Carlos and Luis were and the other hand up on the side that Camila and Isabella were" (Sofia's interview). She explained that she wanted to show "that Carlos and Luis had a bit more of a downfall than Isabella and Camila." The rehearsal video shows that Sofia "discovered" the gesture through experimenting with her body first, rather than first thinking of this idea and then applying it to her body. Sofia was using an embodied metaphor. According to Lakoff and Johnson (1980), humans understand abstract concepts using their bodily experiences and this is mirrored in the metaphors they use when they talk. Lakoff and Johnson suggest, for example, that our familiarity with the upright position produces the "up/down" conceptual metaphors; "up" is unconsciously perceived as "having control" while "down" is considered as "being subject to control" (e.g., *upper* social class, she has the *upper* hand, I am feeling *down* today, etc.). Interestingly, at this point Sofia's gesturing of some people's "downfall" and other's good fortune indexed her first metaphor (the tree with some roots colored all the way and others non-colored). Just as Sofia had transformed the article's word "successful lives" to "ful*fill*ed lives" in alignment with her choice to *fill* the roots, she now transformed the article's word "failure" into "*down*fall," in alignment with her choice to gesture *down*wards.

Discussion

Overall, participants devised and enacted creative strategies for generating, transforming, and communicating representations that supplemented the verbal-representations which dominate in traditional schooling. They created and used different kinds of metaphors to communicate their intended message, infused their previous experiences and personal preferences to their representations, considered the audience, reasoned about their decisions, and adapted their strategies to the constraints and affordances of the different

representational media. Particularly embodied collaborative representations and use of the surrounding objects in imaginative ways supported non-verbal communication and creative collaboration among the members of the group and enforced the use of embodiment that is rarely encouraged in conventional science classrooms. Therefore, students were able to construct and share meaning among themselves and their audience by using multiple rather than only propositional forms of representations, challenging a dominant schooling assumption that meaning making relies mostly on words.

The present study confirms that learners already possess rich resources for representing (Azevedo, 2000; Danish & Enyedy, 2007). Students used color to create symbolisms in the representational medium of drawing, created symmetry and contrast in space with their bodies, and communicated meaning with non-verbal ways, such as gestures. Embodied representations both facilitated students' collaborative interactions (verbal and non-verbal) and provided different possibilities of constructing meaning. This aligns with embodied cognition theories that suggest that humans express abstract concepts through movement, without the need for verbal representations (Lakoff & Johnson, 2008). Students' experiences and movements affected not only their transformations during the representations, but also their word choices when they reasoned for their decisions (Sofia's case when talking about "fulfilled" lives and "some peoples' downfall" being the most obvious example).

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Identifying Associations between Expansive Framing and Transfer through Learning Analytics in an Online Context

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Abstract: This study presents preliminary work in social learning analytics by identifying instances of expansive framing and their relationship with transfer in an online course iteratively designed using the situative principles of productive disciplinary engagement and expansive framing. This analysis occurred in two stages. First, through a discourse analysis of fifteen students who completed the course in summer 2020, a mixed-effects logistic model was constructed to understand the relationship between students' use of expansively framed speech and transfer strategies. Second, a mixed-effect linear model of students' transfer strategy use and student performance on three summative exams was constructed. While a clear link between students' expansively framed discourse and transfer strategy use was detected, no significant relationship between students' transfer strategy use and exam performance was detected. We interpret these findings in relation to the role of expansive framing, transfer in of knowledge, and the transfer out of knowledge.

This research was conducted in an online, graduate level course on educational assessment that has been iteratively refined (see Hickey et al., 2020) from the starting point of the design principles for *productive disciplinary engagement* (PDE; Engle & Conant, 2002) and *expansive framing* (Engle, Lam, Nix, & Meyer, 2012). These principles were adopted to provide multiple beneficial processes for learners to engage with the disciplinary content of the course. PDE describes a set of principles for learners to engage in authentic disciplinary problems by "problematizing" instructional content from their own perspective and publicly being held accountable for developing disciplinary norms and practices. Expansive framing is intended to increase the likelihood of transfer to subsequent contexts by extending learners' use of linguistic frames beyond the course context (i.e., outside *people*, *places, topics, and times*) to be positioned and position themselves as authors who are accountable to disciplinary norms and practices.

The principle aim of this study is understanding the relation between expansive framing and transfer as proposed by Engle et al., (2012) within an online teaching and learning context intended to promote such practices. A recent review of published research on PDE and expansive framing (Hickey et al., 2021) revealed little evidence documenting the relative impact of expansive framing on transfer in authentic teaching and learning contexts other than Engle et al. (2011). As such, this study fits within both an existing design-based research project of online teaching and learning and a larger framework for understanding the relationship between expansive framing, productive disciplinary engagement, and transfer.

An agenda for researching expansive framing within an online context

Engle et al., (2012) advanced five specific explanations of why expansive framing should lead to more generative learning and increased transfer, compared to more "bounded" curricular routines. These explanations are (a) connecting settings promotes an expectation of transfer; (b) connecting settings means prior contexts continue to be relevant in potential transfer contexts; (c) authorship and connecting to prior settings during learning leads to transfer-in of ways that support later transfer out; (d) authorship promotes accountability in particular contexts; (e) authorship as a practice generalizes practices of accountability and adaptation in transfer contexts. Engle et al. indicate that an explanation of transfer could incorporate one, a combination, or all of these hypothesized mechanisms. The current course design seeks to enable learners to expansively frame their interaction with curricular routines in terms of an actual or aspirational aim and evaluate educational assessment practices through repeated connections and revisions of these aims. This feature is intended to promote greater intercontextualities and authoritative positioning in the course context. Thus, our primary focus in the current study is to understand the relationships more fully between transfer in of knowledge introduced through expansive framing and the taking up of authoritative positions on disciplinary knowledge as introduced by the course design. This focus is chosen in part to explore whether the course mechanisms to support transfer-in actually do so, which is presumed to help explain whether transferring out knowledge also obtains. This focus further reveals if and how the establishment of intercontextuality in the form of numerous connections to outside contexts that are further expected to support transfer actually does so.

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Research question and methods

This analysis focused on the following research question: Does encouraging students to expansively frame their engagement lead to greater transfer in of prior knowledge through the use of transfer strategies of generating examples, making comparisons, and generalizations that more frequently connect to frames beyond the current course context. If so, do these transfer strategies support transfer out as estimated by exam performance?

We frame this analysis as social learning analytics (Buckingham-Shum & Ferguson, 2012) in that rather than focusing on automated, computational processes from data generated from networked systems we are attending to the social processes that are stored and represented within these systems. Specifically, we attend to the discourse stored within the course management system. As such, we approached this analysis as an initial exercise in labeling said discourse and identifying associations through a mixed method design.

Methods, participants, and data sources

A total of 15 students who took the course in Summer 2020 were eligible as participants. Only students who completed the course and did not opt out of the study were included in the analysis. These criteria did not exclude any student. Observations from these participants included student responses to wikiflolio and reflection prompts in relation to students' self-selected educational assessment problems. Wikifolio prompts asked students to evaluate their interaction with a particular element of educational assessment with their problem; whereas reflections encompassed five prompts that asked students to consider how their prior engagement in the wikifolio and their peer and instructor interactions influenced their understanding of educational assessment. Excluding missing responses, this resulted in a total of 1,597 observations. Each student's three modular exams were also used to assess the extent students' transferred out knowledge.

Our analysis incorporated quantitative methods of qualitative codes (see Chi, 1997). The analysis occurred in two stages. First, a coding of these wikifolio and reflection responses was conducted. Second, two statistical analyses were conducted. This analysis involved a mixed-effect logistic regression model constructed from coded observations to identify the relationship between expansive framing, authorship, and each transfer strategy and a linear mixed-effect model of student transfer strategy use within each module and their modular exam performance was constructed. All analysis codes, coding discussions transcripts, and R cleaning and analysis scripts are available in an Open Science Framework (OSF) repository (https://osf.io/dqfap/).

Coding procedures

Expansive framing and authorship & accountability codes were adopted from Andrews et al. (2019) and transfer strategy codes were adapted from general strategies that have been identified as effective in promoting learner transference of knowledge (see Bransford et al., 2000). All codes were binary and coding was conducted openly and transparently by the first author. Three audit sessions (see Cresswell & Miller, 2000) between the second author and two peers were held to discuss their findings and elaborate further directions in coding analysis.

Mixed-effect models

Mixed-effect models describe a family of statistical approaches that used both random and fixed parameters to deal with clustered and repeated measure data (see Raudenbush & Byrk, 2002). For the first, model each observation was used as "trial" for whether expansive framing occurred and whether corresponding use of a transfer strategy was also observed. The second model was constructed from student's modular exam scores and the frequency of transfer strategy use within the wikifolios and reflections within that module for each student.

Results

Table 1 confirms that multiple instances of expansively framed elements increased the odds that students engaged in transfer strategy use. For example, students' who framed their engagement using *time past* increased the odds that they generated examples by a factor of 5.61. However, different transfer strategies coincided with different components of expansive framing and productive disciplinary engagement. For instance, framing engagement using *time future* led to a statistically unlikely increase in the odds of making generalizations but was not significant for students' generation of examples. For comparisons, demonstrating *authorship* (making authoritative claims) and framing with *topics* (beyond educational assessment) increased the odds of making comparisons by a factor of 2.09 and 3.32, respectively (both significant). Notably whether expansive framing was specifically encouraged by the prompt did not significantly relate to the odds of using transfer strategies. Also, the type of prompt appeared to have varying influence on the extent to which a particular transfer strategy was employed. For instance, engagement in reflections indicated a reduction in the odds of students generating examples and generalizing but increased the odds of students making comparisons. This is possibly due to students

making more comparative actions on their work at different times and in relation to other participants. Taken as a whole, then, these results suggest that students were likely to use these strategies to transfer in previous knowledge as Engle et al., (2012) suggested. As such, the course appears to be functioning as intended. Of course, this raises the question on whether there was a substantive relationship of students' transfer-in and transfer out as measured by course exams.

Table 1:
Mixed-Effect Logistic Regressions of Expansive Framing and Transfer Strategies

	generates_example			generalizations			comparisons		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	0.14	0.09 – 0.21	**<0.001**	0.02	0.01 – 0.05	**<0.001**	0.00	0.00 – 0.01	**<0.001**
prompt type [Reflection]	0.25	0.17 – 0.37	**<0.001**	0.50	0.30 – 0.84	**0.008**	5.78	2.75 – 12.14	**<0.001**
encourages ef [1]	0.88	0.62 – 1.23	0.451	0.77	0.48 – 1.23	0.269	0.90	0.50 – 1.60	0.709
time past [1]	5.61	3.70 – 8.50	**<0.001**	1.66	0.97 – 2.86	0.066	0.97	0.47 – 2.03	0.943
time future [1]	1.47	0.90 – 2.39	0.122	2.34	1.35 – 4.06	**0.002**	1.41	0.71 – 2.81	0.326
participants [1]	3.44	2.11 – 5.61	**<0.001**	2.40	1.35 – 4.27	**0.003**	0.96	0.37 – 2.46	0.925
topics [1]	2.47	1.67 – 3.65	**<0.001**	1.26	0.74 – 2.16	0.390	3.32	1.61 – 6.87	**0.001**
authorship [1]	1.42	1.01 – 1.99	**0.043**	4.55	2.81 – 7.39	**<0.001**	2.09	1.17 – 3.77	**0.013**
accountability [1]	0.84	0.51 – 1.40	0.506	1.39	0.80 – 2.41	0.246	1.60	0.86 – 2.99	0.141
Random Effects									
σ^2	3.29			3.29			3.29		
τ_{00}	0.09_{student}			0.22_{student}			0.16_{student}		
	$0.15_{\text{assignment}}$			$0.56_{\text{assignment}}$			$0.78_{\text{assignment}}$		
ICC	0.07			0.19			0.22		
N	$11_{\text{assignment}}$			$11_{\text{assignment}}$			$11_{\text{assignment}}$		
	15_{student}			15_{student}			15_{student}		
Observations	1595			1596			1597		
Marginal R^2 / Conditional R^2	0.281 / 0.328			0.213 / 0.365			0.161 / 0.347		

Relation between transfer strategy and course exams

Table 2 shows that, there were no significant effects of any of the transfer strategies and exam performance. In other words, the transference out was too subtle for detection within these selected response measures and that the variation between transfer strategy did not discriminate enough to detect differences in the relatively high exam performances (the respective exam medians were 9.5, 9, and 8 out of a maximum of 10) and was not able to identify the subtle variations of transference of knowledge entailed by these strategies. Taking stock, then, we have observed that the course design facilitates and supports the transfer in of knowledge through repeated engagement routines, but we have not found a corresponding effect of students' capacity to transfer out due, in part, to the limitations of these exam measures. Namely, the exams were entirely selected response and displayed little variation.

Table 2:
Relation Between Transfer Strategy Use and Exam Scores

	exam_score		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	8.20	7.51 – 8.90	**<0.001**
generates example tot	0.04	-0.07 – 0.15	0.498
generalization tot	0.06	-0.07 – 0.18	0.390
comparison tot	0.14	-0.10 – 0.39	0.244
Random Effects			
σ^2	0.80		
$\tau_{00\ \text{student}}$	0.16		
ICC	0.16		
N_{student}	15		
Observations	44		
Marginal R^2 / Conditional R^2	0.120 / 0.263		

Discussion & conclusion

These preliminary results suggest that the course design effectively encouraged the development of students' transfer strategies through expansively framing engagement and increasing students' transfer in of previous knowledge and experience. As such, the evidence that intercontextuality was established supports Engle et al's (2012) explanation that expansive framing is likely to encourage students to transfer in prior knowledge. Similar links were observed between students taking up of authoritative positions and the transfer in of their prior knowledge. We did not observe, however, a clear indication of learners' ability to transfer out this knowledge. This may have been due to a ceiling effect in the exams as little variation in student performance scores was observed. This suggests a need for refining the exams to enable students' to more readily display their knowledge within these assessments through constructed response items. Such a revision could also assess whether there is a cost to the contextualizations produced in these courses since ongoing discussions indicate a trade-off between contextualization and likelihood of transfer (see Day et al., 2015; Goldstone & Son, 2005).

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Orchestrating the Multidisciplinary Implementation of a Narrative-Centered Learning Environment in Upper Elementary Classrooms

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Abstract: Integration of computational thinking (CT) within STEM subjects is common, although not often at the elementary school level where teachers have minimal experience with CT. We have designed and are refining INFUSECS, a narrative-centered digital learning environment to support upper elementary students' CT and science knowledge construction as they create digital stories. We used orchestration as our theoretical framework, to examine how elementary teachers planned to approach this multidisciplinary implementation. Through a series of three focus groups, we learned that teachers planned for their students to take notes or utilize other graphic organizers to align the science content with the narrative planning, to engage in collaborative sense-making, and to observe the teacher modeling use of the INFUSECS system. Ultimately, the results have informed the next phase of our research design as we collect teacher and student level data as INFUSECS is utilized in authentic classroom settings.

Introduction

Researchers and practitioners increasingly acknowledge the importance of computational thinking (CT) in supporting students' problem-solving skills across learning contexts and subject areas (Yadav et al., 2016). Although the integration of CT among other academic disciplines is both practical and effective (Voogt et al., 2015), this integration is complex at the elementary school level as US teachers have minimal experience with CT (Code.org Advocacy Coalition, 2018). The overlap between CT and STEM subjects (Basu et al., 2016) supports the integration within such subjects. Many elementary teachers incorporate reading, writing, and discussion practices into their daily teaching, making it a feasible space to integrate CT; however, there are fewer findings around how to blend CT and language arts. As such, deep multidisciplinary work, designed specifically for elementary contexts, can help us better understand how to integrate CT into these grade levels.

We have designed and are iterating upon a narrative-centered digital learning environment that utilizes a block-based programming language to foster upper elementary students' (ages 8 to 11) CT and science knowledge construction as they create digital stories. Digital storytelling permits the creation of effective and engaging learning experiences that support diverse individual needs (Smeda et al., 2014), including learning science concepts in elementary grades (Smith et al., 2020). It also helps teachers weave CT into elementary settings without requiring the need for separate courses. What is not yet known is how elementary teachers approach such multidisciplinary implementations that integrate CT, science, and language arts.

Theoretical framework

Orchestration has been proposed by educational technology researchers as a useful heuristic for understanding how teachers facilitate technology-enhanced learning environments to support student learning experiences (Dillenbourg et al., 2018). The framework supports understanding of how novel instructional technologies are implemented in the classroom by acknowledging the integral role of the teacher as they manage the complexity of these environments and their students' varied learning needs (Dillenbourg et al., 2018). We recognize that central to the technology integration process are the decisions that teachers make with regards to planning and designing for the optimal use of technology to meet intended learning objectives, and that as students use those technologies, teachers adapt and modify (Roschelle et al., 2013).

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The orchestration process for technology-enhanced learning environments often unfolds with developers initially designing curricula and resources for teacher and student use (Kollar & Fischer, 2013). Teachers then adapt the designed curriculum to fit their classroom constraints and contexts. The ways teachers intend to modify the curriculum can help researchers and developers be more efficient and practical when designing new classroom learning technologies (Wang et al., 2018).

Methods

Data collection

We conducted a series of three focus groups with elementary school teachers during the spring and summer of 2021. In the spring of 2021, two focus groups were held, each with three participating teachers. These 75-minute focus groups were conducted virtually and recorded with video conferencing software. All video sessions were transcribed verbatim. We utilized a semi-structured protocol that consisted of three parts: 1) an introduction to the learning environment; 2) teacher experimentation with the learning environment; and 3) post-experimentation focus group questions. During the experimentation phase, the participants individually joined a breakout room, shared their screens, and engaged in a think-aloud interaction with the learning environment. An example probe included, "What did you learn today that will help you teach INFUSECS curricular materials and use the learning environment?" The final focus group occurred at the conclusion of an eight-hour summer workshop on INFUSECS. The participants from this final focus group were asked questions such as, "Where do you see INFUSECS best fitting into your curriculum and what you already teach?"

The INFUSECS learning environment

The INFUSECS learning environment has two components: 1) a Science Explorer where students learn about energy sources and conversion via multimedia content and a simulation (Figure 1); 2) a Narrative Designer where students develop interactive stories using a block-based programming language (Figure 2). The goal is for students to integrate scientific understanding as they solve a problem-based learning scenario (e.g., shipwrecked scientists on a deserted island must power up their village) depicted through their narrative.

Figure 1

Screenshot from Science Explorer

Figure 2

Screenshot from Narrative Designer

Data analysis

Three researchers individually open coded the transcripts from each of the sessions. The researchers focused on thematic elements related to how teachers planned to implement INFUSECS with students. Subsequently, the researchers met collectively to determine where their identified themes converged across the sessions and reached consensus on the thematic elements of the results. The thematic findings highlight our teacher participants' perspectives on how they intend to implement and adapt INFUSECS for their students' benefit. Such orchestration efforts reflect their understanding of the complex physical and digital learning environments in their classrooms.

Findings

Strategies for connecting science to the problem scenario

Teachers were concerned with how well their students would connect and integrate the science concepts and ideas presented within the Science Explorer into their narratives. Such disciplinary literacy highlights the need to read and write well across the content areas. The teachers suggested two ways this could be supported throughout the learning experience. First, teachers commented that they would encourage their students to take notes on key

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science concepts presented to them throughout the Science Explorer. One teacher advised that, "All the vocabulary that you know [the students] are going to need [should be] accented in some manner and having them be able to take some notes… on paper and pencil or putting a little notepad on the screen."

Second, teachers noted that students would benefit from using a storyboarding process with graphic organizers for notetaking and planning of their stories. This strategy would simultaneously scaffold the integration of science concepts from the Science Explorer into their narratives. One teacher mentioned, "If you want them to write a story on a deserted island with all of the science concepts that they've just learned, you have to tell them that, and having a piece for them to pre-organize themselves, you have to do that for them."

Collaboration and discussion for sense-making

All teachers noted the potential that collaborative discussion—a CT skill—could offer for fostering successful student experiences with INFUSECS. They shared ideas of how they would embed collaborative opportunities to facilitate the sense-making process (e.g., whole-class, small group, dyads), and where in the learning process it would best occur (e.g., interactions with the Science Explorer, planning their stories). In describing the utility of peer collaboration in small groups for connecting the science concepts to the story building process, one teacher commented that small group collaboration would be beneficial for ideation, noting, "I just think they'd need to work either in pairs or in a group to come up with some ideas first and then put it in [their narratives]."

Other teachers noted that whole-group discussion would stimulate brainstorming and connecting the ideas from the Science Explorer to the problem-based scenario. One teacher suggested prompting discussion with "*If you were on an island, what could you do?,*" so all students could think through and discuss different responses before encountering the science concepts and writing their narratives. Others suggested going through the Science Explorer as a class and discussing the scientific concepts as they appeared could help to mitigate potential misconceptions and stimulate the process of scientific inquiry.

Teacher modeling and pacing

Due to the unfamiliarity of the learning environment for students, as well as the novel approach to generating science-rich narratives that it supports, teachers felt strongly that some degree of teacher modeling throughout the *entire* learning experience was necessary. This finding was somewhat in contrast to what we anticipated. We believed that teachers would primarily be interested in demonstrating the Narrative Designer portion to alleviate their stated concerns about students who would not have prior experience with a block-based programming environment. However, teachers offered ideas for teacher modeling during all the system's learning components. One commented, "I would want to go through it with my students, so they really got it. Then if there were other ones that they did later, they would get the whole process."

Further, teachers offered valuable insight into how they would pace the instruction and student exploration of the INFUSECS learning environment for optimal learning outcomes. The teachers believed that by demonstrating the learning environment first for students as a class, the time needed for students to get accustomed to the system would decrease. As such, several teachers noted the need to plan for more time at the outset of using INFUSECS. One commented, "Anytime you use something for the first time, it takes you three days to get through it. The next time, it's not going to be as much."

To create an optimal learning experience for her students, one teacher noted how she would balance and pace different instructional strategies throughout the various components of the INFUSECS system:

> "I could see teaching each of the [energy] sources, showing it in [INFUSECS], working through the slow process of how does it work, doing it in here, then playing with it, and then simultaneously, we're also starting to create that storyboard … [in] small groups … Then their final project would then be to do it themselves."

Discussion, conclusion, and future directions

Our thematic findings indicate that, even with limited background in teaching CT and block-based programming, elementary school teachers have clear and pragmatic intentions for how they propose to implement a narrative-centered digital learning environment such as INFUSECS in their classrooms. Using orchestration as a guide, we highlighted from our three teacher focus groups the ways teachers indicated they planned to modify and ultimately implement INFUSECS for the benefit of student learning outcomes.

This work foregrounds that regardless of the specific educational technology, the role of the teacher is instrumental in shaping student learning experiences. Teachers possess deep expertise about their students' needs, as well as the cultural and contextual constraints in which these learning environments will be used.

Acknowledging teachers' expertise in the classroom, we note that their desired modifications, what Kollar and Fisher (2013) call 'arranging,' in service of what is best for their students, bears out in the literature (Dillenbourg et al., 2018). Recall that teachers mentioned wanting their students to take notes or utilize other graphic organizers to align the science content with the narrative planning, to engage in collaborative sense-making, and to observe the teacher modeling use of the INFUSECS system. Listening to our teacher participants' suggested modifications will drive our research and development work moving forward.

Although INFUSECS was not explicitly designed for students to work together, teachers who create intentional opportunities for students to engage in collaborative learning throughout the scientific inquiry and narrative design process can increase student learning outcomes (Chen et al., 2018). Thus, we will document teachers' strategic use of collaborative learning with INFUSECS during implementation to determine its effectiveness. The teachers in our work noted an extensive amount of modeling they intended to utilize. Wood et al. (1976), the originators of the term *scaffolding* in education, suggest that the purpose of scaffolding is to control learners' frustration, guide learners' actions in support of their learning, and model the problem-solving process. We intend to assess teachers' varied levels of in-class scaffolding and students' learning outcomes.

Ultimately, we found orchestration, in particular documenting how teachers would "arrange" the use of INFUSECS in their classrooms, a helpful lens to plan future professional development and design support for teachers as they learn to integrate it in their classrooms. The results have also informed the next phase of our research as we collect teacher and student level data as INFUSECS is utilized in authentic classroom settings.

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Qualitative Research as the Co-construction of Knowledge: Designed and Emergent Opportunities for Equity in Data Collection

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Abstract: Power imbalances are often operationalized in traditional qualitative research when participants are seen as having "settled" thoughts or truths that a researcher can extract by objectively limiting bias. Like scholars who have advanced humanizing and dignity-sustaining approaches to research (Paris & Winn, 2020), we instead see research as an opportunity to co-construct knowledge and scholarship through building relationships and conversing as co-authorities. In this paper, we critically reflect on the methodology used in a recent study on community-based, out-of-school time (OST) youth arts programs across the United States, highlighting the ways we designed the study to subvert traditional roles and assumptions about meaning making in qualitative research.

Major issue addressed

Conducting interviews and focus groups in qualitative research through an equity lens is about much more than including participants from diverse backgrounds. It requires researchers to adapt data collection methods to meet the needs of the communities they engage with, and to approach interviewing as a process of co-constructing knowledge (Vossoughi & Zavala, 2020). Equitable methods require researchers to intentionally reflect on and mitigate power dynamics that may be present (e.g., between researcher and participant, or between multiple participants in a focus group), and interrogate the assumed roles played by all interlocutors involved. Power imbalances are often operationalized in traditional interview protocols when the participants are seen as having "settled" thoughts or understanding that a researcher can extract by objectively limiting bias (Vossoughi & Zavala, 2020). Like scholars who have advanced humanizing and dignity-sustaining approaches to research (Denzin, 2015; Paris & Winn, 2020), we instead see research as an opportunity to co-construct knowledge and scholarship through building relationships and conversing as co-authorities. With that approach, interviews and focus groups become bi-directional pedagogical encounters between agents with porous roles whose meaning making is ever-developing and mutually influenced (Vossoughi & Zavala, 2020).

In this paper, we critically reflect on a methodology used in a recent study on community-based, out-of-school time (OST) youth arts programs across the United States. Taking a Critical Qualitative Inquiry (CQI) perspective on research methodology (Cannella et al., 2015), we highlight the ways in which traditional power dynamics in qualitative research were subverted through intentional design that guided the project. Our reflection is guided by the following questions: (1) How did design features allow for participants and researchers to co-construct the research experience? (2) What meaning making opportunities emerged as a result of that co-construction?

Theoretical and methodological approaches

Critical Qualitative Inquiry

The history of racism and exclusion in the scientific community, in both the natural and social sciences, is undeniable (Gould, 1996; Bonilla-Silva & Zuberi, 2008). For instance, writers and philosophers like Zora Neal Hurston, W.E.B. Dubois, James Baldwin, and many others who put forward Black scholarship anyway they could, are rarely credited for shaping social thought. However, in an attempt to counteract centuries of discrimination, scholars have been making an effort to operationalize these philosophers' work as methodological precedents that inform decolonial perspectives in research (Grant, 2021). In other words, they are returning to writing from the past to inform scholarship today, and filling the gaps in literature left by racism and settler-colonialism.

Additionally, scholars are exploring new ways to conduct research that move away from discriminatory and paternalistic traditions. The national project we reflect on in this paper is one such example, which was developed in the paradigm of Critical Qualitative Inquiry. Denzin describes CQI as a paradigm within qualitative inquiry that attempts to interrupt dominant methodology by taking both an interpretivist and activist role in research, and by "[making] a difference in the lives of socially oppressed persons" (Denzin, 2015, p. 32). That is to say, CQI interrupts the Eurocentric lineage of academic research when scholars interrogate and expose oppressive practices and intentionally break from norms that continue to yoke the field to intellectual elitism and

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white supremacy (Cannella et al., 2015). Because repressive structures of colonialism often operate invisibly in education and educational research (Kao-mea, 2004, p. 22, as cited in Cannella et al., 2015), the project was designed to (a) subvert power imbalances that result from traditional researcher-participant relationships, and (b) create opportunities for methodological flexibility that can resist oppressive practices as they emerge and embrace a malleable meaning-making process.

Critical Indigenous Research Methodology

The specific methodology that grounded the national project in CQI comes from Critical Indigenous Research Methodology (CIRM) (Brayboy et al., 2012). CIRM is described as a reclamation of the Indigenous thought world (Brayboy et al., 2012); it moves away from the assumptions that limiting researcher voice makes it possible to objectively extract meaning from participants' responses, and that it should be the central goal of qualitative research. A CIRM framework for research is founded on relationship building, respect, and reciprocity (Brayboy et al., 2012). Intentionally fostering relationships with the goal of taking responsibility, showing respect, and enacting reciprocity was central to the design of the national project. To build relationships, the foremost priority during the research conversations was to nurture trust among all participants present. This approach was in direct contrast to positivist traditions of science that primarily seek to uncover the objective truth from participants' observed behavior and elicited responses. Here, espousing a constructionist epistemology (Denzin, 2015; Brayboy et al., 2012), researchers and interview participants are understood as generating knowledge in conversation with one another.

Project methodology

The study we reflect on in this paper consisted of a series of research conversations akin to interviews and focus groups with a variety of stakeholders in out-of-school time (OST) arts organizations. The research goal for the national project was to understand the needs, struggles, and successes of community-based youth arts programs across the United States. Arts organizations known for their work with Black youth, Indigenous youth, and youth of color (BIPOC youth), and who themselves have deep roots in the community they serve, were purposely selected to participate. Rather than follow a traditional snowball sampling method (Merriam & Tisdell, 2016), "which implies "rolling up" relevant participants into our work in a linear fashion, as one person nominates the next, we describe our approach as more like a "boat down the river"' (Halverson et al., in press, p. 13). Starting with suggestions from our research advisory board, we followed leads to stakeholders, "guiding our boat down particular river branches based on the types of communities and art forms we thought it important to collaborate with based on what we were learning along the way" (Halverson et al., in press, p. 13).

In all, 72 stakeholders participated in the study, including 9 policy makers, 8 researchers, 28 organization leaders/ directors, 17 teaching artists, and 10 youth artists. Our data set included 25 research conversations: 12 one-on-one conversations, 6 small group conversations with cultural-geographic regions, and 7 small group conversations with specific OST arts organizations. The conversations were semi-structured and mirrored a loosely organized dialogue where the interview protocol was more of a guideline than a script. Almost all conversations took place over Zoom, with the exception of one participant who preferred to speak over the phone. Analysis for the national project was an iterative process of (a) emic coding (Saldaña, 2016) that described both the topic and content of stakeholders' responses, (b) analytic memo writing (Merriam & Tisdell, 2016) to draw connections across responses and explicitly document meaning making as it occurred, and (c) regular analytic meetings to build consensus on the meaning that was emerging from responses.

Critical reflection methodology

After conducting the original study, five mini-projects were developed in which sub-groups of the research team re-analyzed the data following new inquiries. In this mini-project, we reviewed the data collection methods, the research conversation transcripts, the analytic memos, and the raw video footage in an attempt to understand how design features allowed researchers' and participants' to build relationships and co-construct knowledge and the research process together. We re-analyzed the data by coding for moments when (1) either the researcher or the participant took agency in the conversation, (2) where a researcher offered their own perspective or understanding based on what was said, or (3) where participants pushed back against a researcher's offering, against each other, or against an underlying assumption inherent in the questions being asked. Additionally, we looked for moments where interlocutors shared personal reflections or memories, erupted into laughter, and seemed hesitant or uncertain in their responses; we investigated these moments as possible examples where trust was being built or had been built.

Critical reflection

Flexible engagement

Data collection for this project took place the summer after the pandemic hit the United States in March 2020. During a time when home and work boundaries were being upended, we made it a priority to invite participants to engage in the study however they were most comfortable. Before each conversation took place, a research team member would connect with an individual expert or point person for the small groups and discuss their preferences. For instance, one participant did not feel comfortable having their video recorded, and another chose to talk over the phone instead of over Zoom. If one holds that research is meant to extract "objective" truths by controlling for discrete variables that might affect a participant's response, then this anomaly might have been thought to detract from the consistency of the research or from the reliability of the project's findings. However, centering CQI in this work meant embracing the anomaly as a feature of the collective expertise we were gathering, not a flaw. Additionally, though we did not expect that being flexible meant offering a phone interview instead of a recorded Zoom call, we quickly adjusted to suit the desires of this participant, pointing to adaptability as a necessary condition for this design feature.

We also designed flexibility around what was discussed during research conversations. As is common with semi-structured interview and focus group protocol, all conversations were not conducted identically. We wanted to remain flexible with how conversations unfolded and to prioritize whatever themes OST organization leaders thought was most important for the field to know. For example, it became clear in conversations with Indigenous experts and organization leaders who work with Indigenous youth that the separation between OST and school-based programs does not always exist, particularly in rural locations where some youth access art supplies through their schools. Instead, they chose to talk about the ways in which artmaking is both deeply embedded in some tribal culture and difficult to access through formal educational environments. Designing for flexibility allowed participants to share information that was most relevant to the work they do and take ownership over their participation in the study. Moreover, the flexibility in design also highlighted the importance of adaptability on the part of researchers, which emerged as a critical feature alongside flexible engagement.

Honoring expertise

Participants' expertise is not always valued in research, but we perceived all stakeholders as experts in the field of OST youth arts and experts of their own lived experiences as artists, youth workers, and members of the community they served. In other words, the role of "authority," which is usually reserved for scholars, became porous as everyone who participated in a conversation was considered an authority. We honored participants' expertise when we invited organization leaders to direct the program-centered, small group conversations after sharing with them the general themes the research team was interested in. Additionally, organization leaders were encouraged to tailor the conversation questions for the group depending on what would be most salient to the group based on their insider knowledge.

This design feature was included as a way to subvert traditional roles between researcher and participant, and empower participants to guide the study. Ultimately, we realized this feature also allowed us to highlight and tap into the trust, rapport, and shared knowledge that was already established between organization leaders, teaching artists, and youth artists. Some of the most powerful moments occurred when the OST organization leaders guided the conversations themselves. Moreover, because everyone was an authority in their own right, the conversations were not one-sided in favor of either the researcher or the participant. Approaching meaning-making in research as a collective process transformed the research conversations into bi-directional pedagogical encounters whereby all interlocutors could learn from another. Framing research as an opportunity for both researchers and participants to learn and evolve subverts the expectation that interlocutors' thoughts and understanding is settled and static.

Nurturing relationships

Building trust was a key component of fostering meaningful relationships with participants over the span of 40-90 minute conversations. As we mentioned above, one way we built trust was to tap into relationships where it already existed and allow those bonds to guide the research. Another way we built trust, particularly in the small group conversations, was through the inclusion of a theatre improvisation game. At the beginning of each small group conversation, the researchers led everyone through an activity known as Gift Giving (though it probably has many names), in which one person pantomimes handing another person a gift (in our case, through the Zoom screen). Then the person receiving the gift replies something to the effect of, "Thank you for the gift! How did you know that I needed this [fill in the blank] in order to get through the rest of my day?" The person receiving

the gift then pantomimes using whatever they improvised. This type of warm up game or icebreaker is a common ritual among theatre ensembles. By dedicating 10 minutes to this activity, it was our intention to begin building a connection that would be the foundation of the group conversation. We hoped the activity would provide everyone a point of joyful, silly, and meaningful connection through a common experience (if they did not already have one), and a chance to learn a little about each other prior to opening up in conversation. Ultimately, the activity invited participants and researchers to acknowledge and reflect on their current state of mind in a fun, whimsical manner that seemed to create space for vulnerability and more candid conversation.

Conclusion

Although more research is necessary to understand how the design features impacted participants' experiences, we believe these features allowed participants to co-construct the research experience and play an integral role in directing the outcomes of the study. Participants were encouraged to take agency over the study and their participation in it. Their expertise was honored, allowing the roles of "researcher" and "researched" to be porous and in flux (Vossoughi & Zavala, 2020) and encouraging everyone in conversation to learn from one another. They were met with flexibility, respect, and a genuine opportunity to foster relationships through trust. Opportunities for joy and silliness were specifically designed into this study in a way that invited participants to speak candidly during conversations. In watching the video recordings, we noticed an air of familiarity and uncertainty among the interlocutors, an atmosphere where they are simultaneously commingling, building relationships, and co-constructing knowledge. Analyzing and understanding the relationship between researcher and participant is not usually a core component of qualitative research even today. Although taking such an approach to research is complex and somewhat nebulous, it is an important step to developing new visions of qualitative research as we endeavor to honor and gain insight from communities in equitable ways.

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Facilitating productive struggle in science education: The possible benefits of managing scientific uncertainty during sensemaking

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Abstract: Utilizing students' scientific uncertainty as a resource for deep learning opportunities has been introduced for productive sensemaking in science education. However, productively managing the emerging uncertainty is challenging for teachers and students in that they are often frustrated by or ignore the uncertainty during sensemaking. It also remains unclear what drives or obstructs sensemaking when students are learning science concepts, and when the process advances or recedes. This paper aims to suggest a conceptual framework to understand how uncertainty management can facilitate students' sensemaking so that they can experience productive struggle. To develop the framework, this theoretical paper explores sources and types of scientific uncertainty, and how the management of these uncertainties does or does not promote the productiveness of students' struggle during sensemaking. Lastly, a framework is proposed to translate the theoretical constructs into classroom practices.

Introduction

An extensive research strand emphasizes the importance of struggling experiences in developing a deep understanding of science concepts, phenomena, or solutions. Among them, to name a few, are impasse-driven learning (VanLehn et al., 2003), productive failure (Kapur, 2008), and productive struggle (Warshauer, 2015). The underlying ideas across these theoretical approaches to confronting impasse are consistent regarding its prerequisite: the recognition or identification of the impasse, gap or inconsistency in the current knowledge structure offers opportunities to move one step forward, and then, the subsequent intentional and effortful struggling to overcome the challenges yields productive learning outcomes.

In a similar vein, utilizing students' scientific uncertainty as resources for deep learning opportunities has been explored in science education (Beghetto, 2017; Manz, 2018). Practices of science (e.g., Next Generation Science Standards [NGSS], 2013) inherently involve dealing with uncertainty. When students are required to engage in scientific practices to make sense of scientific phenomena, identifying and exploring what they are uncertain about can drive their process of sensemaking (Odden & Russ, 2019). However, recognizing and maintaining emerging uncertainty is challenging for students; they are often cognitively overwhelmed or even emotionally frustrated, and thus tend to ignore the uncertainty (Chen, 2022; Jordan & McDaniel, 2014). Instructional supports are thus needed to gear students' struggling toward productive management of their scientific uncertainty when engaged in sensemaking during science learning.

Researchers have explored the process of sensemaking in order to identify when and with what students may struggle and offered frameworks for how teachers can support the sensemaking process. They have identified a series of non-linear phases of sensemaking (e.g., inconsistency or gap recognition, generation of explanation, and resolution; Odden & Russ, 2019). However, it remains unclear what drives, obstructs, or resumes the process of sensemaking and when the process advances and recedes. To uncover this issue, this theoretical paper aims to suggest a conceptual framework to understand how uncertainty management can facilitate students' sensemaking process so that they can experience productive struggle.

Sensemaking and scientific uncertainty

Odden and Russ (2019) defined sensemaking as "the process of building an explanation to resolve a perceived gap or conflict knowledge" (p. 187) and identified what elicits and sustains the process of sensemaking (e.g., perceived gap as an entry condition, lack of discussion as constraints, or satisfactorily resolved gap as an exit condition). Building on this previous research, this paper suggests four phases of sensemaking: *phenomena representation, knowledge gap recognition, exploration*, and *application and evaluation* of potential resolution.

Along with the four phases of sensemaking shown in Table 1, this paper highlights iterative and effortful uncertainty management with which students are engaged during sensemaking and explains the (meta-)cognitive engagement involved in uncertainty management during each phase. In this manner, this paper advances an understanding of the role of students' uncertainty management in driving or impeding sensemaking related to scientific phenomena, and of when and how instructional strategies can be implemented during sensemaking.

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Table 1
The Four Phases of Sensemaking and the Students' Uncertainty Management

Phases	Sensemaking features	Students' uncertainty management
Phenomena representation	• Interpreting and representing situations • Prioritizing parameters • Generating initial thoughts	• Students raise uncertainty when they recognize and acknowledge uncertainty of interpreting and representing situations, otherwise it is ignored or vanishes
Knowledge gap recognition	• Prior knowledge alignment • Recognizing the gap between initial (naïve) thoughts and target knowledge • Specifying the knowledge gap	• Students reflect on uncertainty and recognize, acknowledge, and/or specify inconsistency between prior knowledge and the target knowledge
Exploration	• Observing and gathering data, information and ideas • Analyzing and interpreting data, information and ideas • Generating explanation and reasoning	• Students maintain uncertainty during the exploration of new data, information and ideas • New uncertainty may emerge in the exploration (i.e., situated uncertainty) while the old uncertainty is being managed
Application and evaluation	• Applying a new understanding to the represented phenomena to fill the gap • Evaluating the potential solution • Revising the initial thoughts and retaining the revised ones	• Students reduce uncertainty when the recognized gap appears to be filled, otherwise uncertainty may remain or be ignored • New uncertainty may emerge in the process of applying or evaluating the suggested solution

Uncertainty management for productive struggle

As suggested so far, it is not the uncertainty itself but the *management* of uncertainty that drives the sensemaking process in either productive or unproductive ways during science learning. To unpack the relationship between uncertainty management and productive struggle, this theoretical paper distinguishes desirable uncertainty from undesirable uncertainty and posits how managing the two types of uncertainty can cause either curiosity or frustration through productive or unproductive struggle as illustrated in Figure 1. In addition to the discussion on desirability of uncertainty for productive struggle, two major sources of scientific uncertainty, *content knowledge* and *epistemic knowledge*, are introduced.

Sources of scientific uncertainty

Uncertainty in learning is defined as a subjective experience of being aware that one has insufficient or incoherent knowledge, or ability to make sense of phenomena, situations, or solutions (Chen, 2022; Jordan & McDaniel, 2014). The feeling of uncertainty is subjective because it is experienced differently between individuals depending on the degree to which individuals react to novelty, complexity, unfamiliarity, ambiguity, and lack of clarity. Individuals' ability to understand the given topic also interacts with these causes of uncertainty to spark students' subjective uncertainty (Silvia, 2010).

In science classrooms, there are two major sources of scientific uncertainty against which students experience novelty, complexity, etc. during science learning: Content and epistemic knowledge. In other words, content and epistemic uncertainty can be distinguished in terms of what is known and how it is known. *Content uncertainty* can be defined as individual's subjective feeling that they are unaware of or unconfident about the terminology, principles, or theories being discussed (e.g., "What theory can explain why the small ball fall faster than the big one with the same weight?"), while *epistemic uncertainty* refers to individual's subjective feeling that they are unsure about "how we know what I know and why we believe it" (Duschl, 2008, p.269; e.g., "How can I know that the air makes the difference in the speed of falling balls?").

Types of scientific uncertainty

Additionally, content and epistemic uncertainty can both fall into additional categories determined by their desirability: Desirable and undesirable uncertainty. Regarding the types of uncertainty in this vein, researchers used different but similar terms, such as *good and bad uncertainty* (Beghetto, 2017) and *productive uncertainty* (Manz, 2018). The authors concur with these distinctions of uncertainty in that they address that not all uncertainty is detrimental or beneficial. Nevertheless, this paper prefers to frame uncertainty based on its desirability. This is in part because this paper distinguishes uncertainty from uncertainty management which Beghetto (2017) and Manz (2018) did not. It is the productive uncertainty management that can make even "bad" uncertainty desirable at some points. The desirable uncertainty is desirable because it concerns the knowledge which is crucial to

sensemaking of the topic and it emerges at an appropriate time (e.g., emerging during the phenomena representation rather than interrupting the process of reducing other crucial uncertainties).

Engaging in productive struggle through uncertainty management

While it is individual differences that makes uncertainty desirable or undesirable at the beginning of sensemaking during science learning as stated above, the productive management of both types of uncertainties can encourage students to engage in productive struggle and spark curiosity for learners to yield productive learning outcomes. *Productive struggle* involves the process where students grapple with their understanding of the presented information and actively work through the struggle to make sense of the problematized phenomenon and advance their own understanding (Warshauer, 2015). In this theoretical paper, we adapted the Fredricks's et al. (2004) framework of examining school engagement to represent student engagement at the level of a learning event. With this framework, this paper distinguishes productive struggle from unproductive struggle regarding three dimensions of engagement: *behavioral, emotional, and cognitive engagement* (See Figure 1). This framework not only helps construct a multifaceted understanding of individual differences during uncertainty management but also suggests instructional strategies for productive uncertainty management in multifaceted ways.

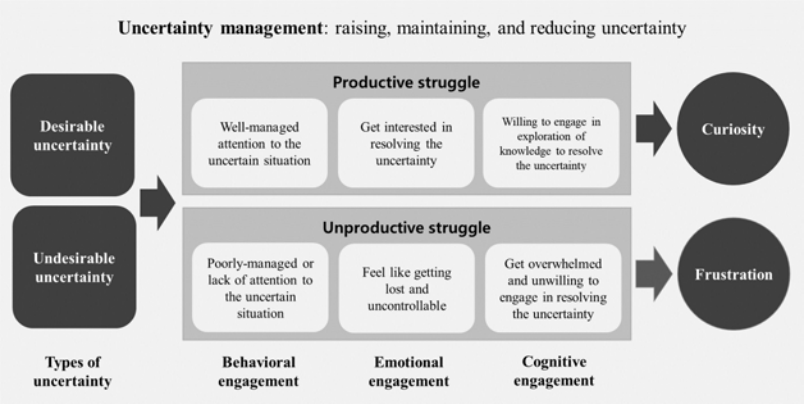
Gee (2017) emphasized that the combined effects of behavioral, emotional, and cognitive engagement facilitate the process of resolving the recognized uncertainty. For example, Gee identified a) well-managed attention to what students fail to make sense and b) interests to what they are paying attention to and c) intentional caring for the uncertainty as crucial factors of meaningful learning experiences (i.e., productive struggle). On the other hand, students may disengage in their learning when they lose their attention, feel uncontrollable, or get cognitively overwhelmed partially due to their perceived inability to understand or due to persistent failure (D'Mello & Graesser, 2012; Silvia, 2010).

Outcomes of uncertainty management

Desirable uncertainty can spark curiosity when it is productively managed, but it can also frustrate learners when it unnecessarily persists unresolved (D'Mello & Grasser, 2012). Similarly, undesirable uncertainty can also frustrate learners when it is, for example, too complex to resolve, but it can also lead to students' curiosity when it is strategically managed (See Figure 1). It should be noted that productive uncertainty management is not easily achieved and thus needs the combined effort of a strategic approach utilizing student, peer, and teacher support (Chen, 2022; Jordan & McDaniel, 2014). A strategic approach will include, for example, (collaboratively or individually) raising, maintaining, and reducing uncertainty through questioning, comparing, or generating explanations about issues of uncertainty at an appropriate time. One means of translating this approach into practice is discussed in the following section.

Figure 1

Productive and Unproductive Struggle through Uncertainty Management



Facilitating productive struggle in sensemaking

How students manage their uncertainty determines the processes and outcomes of sensemaking. Therefore, instructional supports are needed to help students productively manage their uncertainty for productive struggle in sensemaking. Understanding how (un)desirable uncertainty associated with epistemic or content knowledge can lead to (un)productive struggle sheds practical light on how teachers can support students' uncertainty management in each sensemaking phase. Table 2 shows some examples of instructional strategies that teacher can use based on the phase of sensemaking and knowledge type associated with students' scientific uncertainty.

Table 2
Managing Scientific Uncertainty During Sensemaking to Facilitate Productive Struggle

Sensemaking phases	Source of scientific uncertainty		Uncertainty management
	Epistemic knowledge	Content knowledge	Teachers' strategies for using desirable uncertainty to manage uncertainty
Phase 1: Phenomena representation	Knowledge used for representing and interpreting phenomena	Knowledge about scientific concepts associated with the phenomena	- Raising desirable uncertainty by problematizing, challenging initial ideas or opening up the problem space in ways that elicit curiosity
Phase 2: Knowledge gap recognition	Knowledge used for recognizing inconsistency between initial thoughts and the represented phenomena		- Reflecting on uncertainty to trigger prior knowledge and identify what knowledge needs to be explored - Expanding desirable uncertainty to other relevant uncertainties targeting the hypothesis, variables, and methods that students plan to explore
Phase 3: Exploration	Knowledge used for finding, collecting, and interpreting data to use as evidence and elaborate the potential solution		- Maintaining uncertainty by comparing conflicting ideas or data, or introducing alternative claims - Maintaining uncertainty by seeking variations of potential solutions while staying curious about options - Raising a new uncertainty when necessary
Phase 4: Application and evaluation	Knowledge used for applying the potential solution and evaluate the soundness of it		- Reducing uncertainty by helping to construct and determine the best solution - Reducing uncertainty by helping to reconstruct a new knowledge system that is not the same as Phase 1

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Young children's use of spatial sensemaking practices as mediators of spatial skills during informal STEM programs

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Abstract: While considerable research has examined when young children develop spatial skills and how these predict their success in STEM engagement, this study adds to the limited research on the processes through which young children learn to reason spatially during everyday learning environments. Through investigations of science and engineering programs for 3–5-year-old children, we provide evidence for how these programs engage children in a diverse range of spatial sensemaking practices, such as gestures, sketching, and object manipulation, which in turn engage their use of multiple forms of spatial skills. Our findings suggest children used spatial sensemaking to solve engineering problems and make sense of science phenomena, setting the stage for future STEM learning.

Introduction

Spatial thinking—the use of spatial concepts, spatial tools, and application of spatial reasoning— is fundamental to everyday life as well as advancing access to science, technology, engineering, and mathematics (STEM) pursuits (National Research Council, 2006). We apply the skills of spatial thinking when we use a map to navigate to a new location or use instructions to assemble furniture. Yet early differences in how children reason spatially have implications for their near-term and long-term opportunities in pursuing STEM interests. Research demonstrates that preschool-age children's spatial skills predict early success in mathematics (e.g., Gunderson et al., 2012) and has thus provides the link to later persistence in science (Wai et al., 2009). Spatial skills–application of cognitive processes to reason about spatial information—can be improved through a wide-variety of interventions, even among very young children (Uttal et al., 2013; Yang et al., 2020). However, what is needed is more information on how children's everyday learning contexts, such as museum settings and preschools, can provide *spatialized* experiences for children that embed training for spatial thinking alongside play-based STEM engagement (Newcombe, 2013). This study considers how STEM programs in a science center provide an opportunity for a spatialized experience where children enact spatial practices in order to engage in spatial skills.

Spatial Skills and Distributed Spatial Sensemaking

Literature on how people engage in spatial thinking often frames the process as a set of cognitive spatial skills (e.g., Uttal et al., 2013). One benefit of categorizing spatial skills is the identification of correlations between specific spatial skills and performance in STEM fields (Hegarty, 2014). Such findings suggest that supporting flexible use of a broad range of spatial skills might benefit children in their early learning experiences. We drew on a taxonomy which classifies spatial skills along two orthogonal dimensions: *intrinsic* to *extrinsic* and *static* to *dynamic* (Uttal et al., 2013). For example, the spatial skill mental rotation (the ability to rotate 2D or 3D objects in one's mind) is classified as *intrinsic* (within the object) and *dynamic* (active mental manipulation).

We also use a distributed spatial sensemaking framework to better examine how the learning environment support children's use of spatial skills. Distributed spatial sensemaking frames children's use of spatial reasoning as practices situated in context and drawing on social and material resources (Ramey, Stevens, & Uttal, 2020). This framework helps us better understand children's learning by situating spatial thinking in their everyday learning opportunities. Young children's spatial thinking is malleable (e.g., Yang et al., 2020) so it is important for research to identify the range of conditions that improve children's spatial thinking. The distributed spatial sensemaking framework was used to identify how and when the children used spatial sensemaking practices – defined as "strategies for making sense of spatial information that relied on communication with other individuals (learners or instructors) or interactions with external objects and representations" (Ramey & Uttal, 2017, p. 12). While this framework has been used to uncover the ways middle school students use spatial sensemaking (e.g., Ramey & Uttal, 2017), our research demonstrates the utility of this framework to understand the processes through which spatial thinking is learned, enacted, and leads to constructing explanations and solving problems in everyday learning contexts for preschool-age children. Drawing on these frameworks, we conducted a qualitative study of three preschool STEM programs, guided by the following research question: *In what ways do spatial sensemaking practices engage children's use of spatial skills during STEM programs?*

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Methodology

Our methodological approach drew on interaction analysis because it is grounded in a belief that "knowledge and action are fundamentally social in origin, organization, and use, and are situated in particular social and material ecologies" (Jordan & Henderson, 1995, p. 41). Gathering video-data is well-suited to interaction analysis because it allowed us to generate patterns from multiple sets of observations. Further, video analysis allowed us to consider the embodied nature of children's meaning-making with their hands, bodies, and material manipulations.

To investigate children's spatial sensemaking, we chose three preschool STEM programs at a science center located in a town in the North Eastern United States. The programs selected for their potential for prompting children's spatial thinking: a 5-day engineering camp, a 30-min program about lunar craters, and a 30-min program about shadows. Participants included the preschool-age (age 3-5 years) children attending each program: n=8, n=10, and n=6, respectively, and the early childhood educators who led each program. Each program was video recorded using multiple camera angles. We selected only the video sections from the engineering camp showing children working towards solving each day's main engineering challenge as our pre-coding suggested these would provide a rich source of data on young children's spatial thinking (~1.5 hrs / day) for analysis. We analyzed the full data sets from the other two programs (~30 min each).

Using *Vosiac* for video coding, we first broadly coded to identify events in which children and educators engaged in spatial sensemaking practices. Within these events, we applied three coding schemes. (1) We began with coding children's spatial sensemaking practices (SSPs) (Ramey & Uttal, 2017): spatial talk, gestures, object manipulation, body movement, and sketching. (2) We coded clusters of SSPs for spatial skills using Uttal et al. (2013)'s typology, with sub-codes defined in Ramey et al. (2020). The four spatial skills are: *intrinsic-static*: "Perceiving objects, paths or spatial configurations amid distracting background information," *intrinsic-dynamic*: "Piecing together objects into more complex configurations, visualizing and mentally transforming objects," *extrinsic-static*: "Understanding abstract spatial principles, such as horizontal invariance or verticality," and *extrinsic-dynamic* "Visualizing an environment in its entirety from a different position" (Uttal et al., 2013, p. 4). (3) We coded each event for social and material resources mediating their production: educators, other children, physical materials, sketches, and tools (Ramey et al., 2020). (4) We coded for preschool-age children's evidence-based explanations (e.g., Plummer & Ricketts, 2018) and engineering problem-solving (e.g., NRC, 2013).

To improve the validity of our coding, we used existing frameworks from the literature (e.g., Ramey & Uttal, 2017; Uttal et al., 2013; NRC, 2013). The first author coded the video data and then reviewed all coding with the second author to improve reliability. All codes were agreed upon after discussion. Working across our coded videos, we defined themes from patterns observed across the code groups (Braun & Clarke, 2006).

Findings

Our analyses resulted in three major themes. First, we demonstrated how the preschool-age children engaged in a range of spatial skills, during science and engineering activities, using multiple spatial sensemaking practices. Second, we identified the important role played by educators and the material resources provided to the children in how they engaged with spatial thinking. Third, the children used spatial sensemaking practices as an essential component of constructing evidence-based explanations in science and solving problems in engineering. Below, we provide excerpts from the programs illustrating these themes. Each science program and each day of the engineering camp engaged children in a few spatial sensemaking practices, which in turn supported one or two spatial skills. However, across all three programs, we found children engaged in a broad range of practices and three of the four spatial skill quadrants. And, individual spatial sensemaking practices (e.g., sketching, gesturing) engaged children in diverse spatial skills, depending on the program. Figure 1 shows the relationship we observed between the spatial skills and the range of spatial sensemaking practices children were using.

We include two excerpts to illustrate the relationship between spatial sensemaking practices and spatial skills in children's STEM learning as well as the important role played by the educators and materials. These practices, people, and resources came together to engage children in designing solutions to problems and constructing explanations for science phenomena. The first excerpt took place during Day 1 of the engineering camp. Initially, each child drew a design for their fort. Mia (5 years) drew a square base with a triangular roof and a chimney then worked with Sean (4 years), Adam (5 years) to build the fort's base using cardboard and tape. Just before the transcript below, Laura (Educator) placed a large flat piece of cardboard on as a roof for their fort.

Mia: (to Laura) Look at this. This is the chimney [points to her drawing] and this is the (unintelligible).

Laura: This isn't what you guys were drawing. My roof is flat [Laura rubs her hand across flat roof].

Mia: This is OK. [She rubs her hand across a spot on the edge of the roof.]

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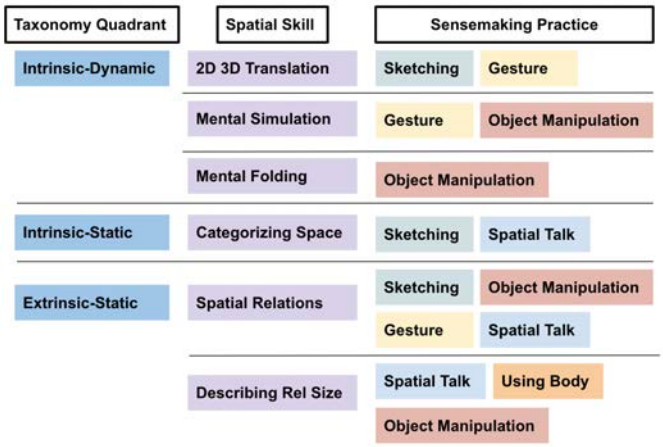
Laura: You're OK with it flat?
Mia: Yeah, [she returns to point at her drawing] it's just that, we can make this the chimney [indicates chimney] -
Laura: Make the, so we're going to use [gestures with both hands a rough chimney shape] –
Mia: [Places hand back on the same spot on the roof] The chimney can be right here, I know – [spins back to grab her pencil and starts drawing on the roof] –
Laura: So how can we make a pretend chimney –
Mia: [Brings Laura back to her drawing] We'll make a hole in the roof. OK, [unintelligible but she is gesturing to her drawing for Laura to see].

After this, the group works to construct a cardboard chimney attached to the spot Mia indicated on the roof. Mia used spatial sensemaking practices of *gesturing* and *sketching* to support her use of the Intrinsic-Dynamic spatial skill of *2D to 3D translation*. This spatial skill involves moving between 2D representations (Mia's sketch) to 3D representations (locating and then creating the chimney on the fort). Mia used the spatial sensemaking practices––gesturing and sketching—to facilitate her engagement with *designing solutions* (NRC, 2013) – an important engineering practice – as she worked to communicate her ideas about the design (e.g., the location of the chimney) and negotiate the nature of the fort (flat versus peaked roof) with Laura.

Figure 1
Relationship between the spatial skills observed and children's use of spatial sensemaking practices



The second example is from the end of the shadow program. Earlier in the program, the children used flashlights and small bear figures to investigate ways to create shadows of different lengths and directions. At the end of the program, the educators, Nora and Tina, work with Mark (5 years) and the other children to draw a picture of the location of the Sun, Bear, and his shadow.

Mark: This is Bear's shadow [taps on his drawing of the shadow to get Nora's attention].
Nora: OK, so here is the Sun and here is Bear's shadow. Why did you draw it there?
Mark: (short, unclear comment)
Tina: Tell us what you figured out before.
Mark: So, when I holded it right here [points pen towards Bear drawing to indicate how he held his flashlight during the investigation] then his shadow when this way [gestures towards his drawing of the shadow on the opposite side of the Bear figure].
Nora: OK, that was your observation.

In the excerpt, Mark used the spatial sensemaking practices of *gesturing, sketching, object manipulation*, and *spatial talk* to support his use of the Extrinsic-Static spatial skill, *spatial relations*. This spatial skill involves visualizing or describing relations between objects, such as how Mark described the relationship between the light source, object, and shadow location using his sketch, pen, and gestures. In doing so, Mark used evidence he gathered (earlier in the program) while engaged in *object manipulation* to initially determine the relationship using a flashlight and a bear figurine. He referenced this ("*when I holded it right there*") as evidence for the *explanation* he constructed for the shadow phenomenon (Plummer & Ricketts, 2018).

We have described how the children used spatial sensemaking practices to facilitate their use of spatial skills when designing solutions or constructing explanations. But these episodes were also facilitated by children's access to the material resources provided in the learning environment (e.g., cardboard boxes, flashlights, sketch

paper and pens) and the supporting prompts and questions by the educators. Both Mia and Mark used the materials resources to facilitate their spatial reasoning; Mia used the cardboard fort to help her communicate spatial elements of the design to Laura while Mark reflected on embodied knowledge of the use of his flashlight when recounting spatial relations in his explanation. These, and the majority of episodes of spatial sensemaking we observed, were facilitated by educators' questions and guidance. In the engineering camp, Laura engages with Mia to negotiate a design solution for the chimney. In the shadow program, Nora prompts Mark to explain his shadow drawing which provides an opportunity for him to offer the evidence for how his reasoning supports his claim.

Discussion

Our analysis demonstrates the diverse set of practices preschool-age children used to apply spatial skills while engaging in solving problems and investigating science phenomena. Across a selection of STEM programs, we identified children's use of spatial skills within three quadrants of Uttal et al. (2013)'s taxonomy. Further, our analysis reveals that young children draw on both personal resources (spatial sensemaking practices) and external resources (educators and the materials provided in the workshop) to facilitate their application of those spatial skills to solve spatial problems. Thus, we make the following contributions to the literature on young children's spatial thinking. First, this study address gaps in the literature about how STEM education may engage young children's early spatial skills through participation in distributed spatial sensemaking, though more research on the efficacy of such programs is still needed. Second, our study provides insight into methods that may improve young children's spatial skills using alternatives to traditional models of spatial training or decontextualized instruction (e.g., Yang et al., 2020). While spatialized instruction is largely absent from formal early education curricula (Pritulsky et al., 2020), our findings suggest that play-based, STEM activities may engage children in distributed spatial sensemaking providing opportunities to develop spatial skills.

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How Research-practice Partnerships Learn to Develop Goals for Math and Identify Local Problems of Practice

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Abstract: Research-practice partnerships (RPPs) are an efficacious and increasingly common organizational approach for educational improvement. However, as RPPs learn to effectively engage in instructional improvement, they go through various stages. Several factors can influence the development of organizational learning across these stages. We describe how RPPs at their earliest stages in two school districts in the United States learned to develop goals for improving math teaching and learning, and identify local problems of practice with respect to these goals. We also highlight how district history, the engagement of "boundary spanners," and other key factors influence this process.

Introduction

RPPs are an efficacious and increasingly common organizational approach for educational improvement. They engage researchers and practitioners in joint work around local problems of practice and promote evidence-based inquiry into how such problems might be addressed (Penuel et al., 2011). RPPs can also be a productive approach for developing the capacities of its participants and respective organizations if they are deliberately designed with this goal in mind (Fishman et al. 2013). However, RPPs are different; they develop over time, across various stages, and require different types of organizational learning. Preliminary or initial developmental stages, in particular, have a significant impact on the life of RPPs (e.g., Law & Liang, 2019).

In this paper, we describe how RPPs at their earliest stages in two school districts in the United States learned to develop goals for improving math teaching and learning, and identify local problems of practice in relation to these goals. We also examine factors that potentially influenced such goal development and problem identification. As part of the CASPIR (Collaborating around Structures, Processes, and Instructional Routines) Math Project (referred to hereinafter as CASPIR), university researchers and professional developers formed an RPP with each school district. The goals of CASPIR are to co-develop and co-implement a multi-component professional development intervention designed to improve teachers', teacher leaders', and administrators' understanding of effective math teaching and learning, and to enhance the organizational capacities of schools and districts to support such instructional improvements in math. CASPIR employs a design-based implementation research (DBIR) process involving collaboration between researchers, professional developers, and district and school personnel. In the cases of both districts, district math leadership teams (DMLTs), in collaboration with the university team, constitute the organizational unit responsible for identifying the problems of practice and where CASPIR's efforts at developing structures for ongoing RPP work were focused.

The CASPIR Math Project Model

The CASPIR model is aimed at using a DBIR process to enhance organizational and stakeholder capacities to identify local problems of practice related to math teaching and learning and develop and implement strategies to address these problems. The model includes three components enacted across teacher, school, and district levels. First, DMLTs are formed with teachers, district/school administrators, and the university team. DMLTs then regularly meet and collaborate to co-develop a robust vision for math teaching and learning at the district level, which contributes to a "coherent instructional system" (Cobb et al., 2018, p. 11-12). Once the vision is articulated, the DMLT analyzes the district's strengths and needs, and develops district math goals and strategies to support math improvement in relation to local problems of practice. Second, professional development is co-designed and co-implemented by the DMLTs, and aimed at teachers, school leaders, and district leaders. This PD can attend to a range of issues, depending on the vision for math teaching and learning initially developed, and on the specific local problem of practice chosen by the DMLT. Third, iterative cycles of design and redesign are implemented annually—whereby data is collected, goals are set, strategies are implemented, strategies are assessed, and the cycle begins anew. This paper describes the initial stages of CASPIR.

Theoretical and Empirical Background

The key features of a DBIR approach include: (1) focusing on user-centric problems of practice; (2) iterative, collaborative design; (3) developing a theory of improvement through systematic inquiry; and (4) developing

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capacity for sustaining change in systems (Penuel et al., 2011). Such an approach recognizes that "achieving successful change in complex work systems means recognizing that one cannot predict ahead of time all of the details that need to be worked through nor the negative consequences that might ensue" (Bryk et al., 2015, p. 7). Meanwhile, RPPs are directly aimed at learning to do such work not simply from an individual perspective but also organizationally. Routines and processes, shared insights and understandings, and information processing abilities, are foundational elements for building organizations that can effectively engage in DBIR (Basten & Haamann, 2018). However, RPPs do not simply work "out of the box." Rather, they develop over time and through various stages. For example, it can be efficacious for RPPs learning to engage in DBIR to begin their work by focusing a central team of researchers and practitioners on a discrete and user-centric problem of practice, like student skills and knowledge in a particular content domain (Fishman et al., 2003). Emphasizing the importance of shared understandings, Henrick et al. (2015) highlight the utility of specifying explicit, high-quality visions or goals for teaching and learning at the outset of DBIR work to serve as a target for learning. Grounded in this vision, a theory of action about supports for teacher learning in relation to this goal can be articulated and ultimately implemented. As RPPs participating in such a process mature, they engage in design, analysis, and feedback cycles, potentially guided by tools, routines, and procedures that are instituted to develop capacities to engage in such work sustainably. These early moves are key steps for organizations learning to engage in DBIR.

A key element of organizations developing such capacities at their earliest stages and learning to conduct such work are evaluators/researchers. Indeed, they can leverage practitioners' experiences to better understand local problems of practice (Dozios et al., 2010) by framing key issues and problems, introducing frameworks to guide meaning-making, identifying key indicators to guide data collection, and building stakeholder consensus. Conversely, several interrelated factors can influence how RPPs develop and learn to engage in DBIR over time. For instance, local district context and history constitute key factors, as they can drive the emergence of different problems of practice and make scaling up challenging across different contexts (e.g., Bryk et al., 2015). Certain elements of the RPP itself are also key factors influencing RPP development. Notably, boundary spanners (or brokers) are individuals that can help bridge differences across researchers and practitioners, such as goals, expectations and routines (Hopkins et al., 2019). Boundary objects (i.e. shared resources and ideas that facilitate coordination of activities) can promote productive researcher-practitioner communication (Hopkins et al., 2019).

Methods

Drawn from a larger multiple-embedded case study involving several school districts (Yin, 2013), data for this study come from DMLTs in two districts—Washington and Hamilton (pseudonyms). Washington has four primary schools, and Hamilton has three. During the 2020-21 school year, we collected two data sources across both DMLTs: semi-structured interviews with all DMLT members (N = 64), and observations of all DMLT meetings to-date (N = 53). All data sources were recorded and transcribed.

We developed a different analytic procedure for interviews and observations, followed by triangularization across both data sources. Beforehand, training and interrater reliability (IRR) were conducted. For the semi-structured interviews, we first developed an inductive coding scheme based on extant research that captured perceptions about instructional improvement, role of the DMLT, and data-driven decision making. After achieving a Cohen's Kappa of 0.80 or higher, a group of eight researchers from the university team live coded all interviews. DMLT meetings were scored using a graded rubric across various elements including membership, roles/responsibilities, mission/vision, and data-driven decision making to track DMLT progress towards goal development for math improvement/learning.

Findings

Washington DMLT

Washington had a history with the university team prior to the start of CASPIR. For the five years prior, the district participated in extensive teacher and administrator professional development activities, and received regular instructional coaching support. With the exception of one of these years, the district had a DMLT that met between 2-3 times during the school year, generally discussed teacher professional development efforts, and had ongoing discussions about how to support peer classroom observations among teachers in the district. However, the DMLT did not engage in any systematic data collection or iterative cycles of instructional improvement.

CASPIR began its collaboration with Washington in AY20-21. At the first meeting, the CASPIR team introduced CASPIR as well as its goals related to supporting the district in learning how to engage in data-driven improvement cycles. To prepare the DMLT for defining a problem, CASPIR personnel facilitated DMLT discussions on articulating a vision of math teaching and learning in the district. They started with a vision board and then generated descriptive statements. DMLT members generated descriptions of their idealized visions of

what teachers and students should be doing in schools and classrooms. They categorized and connected these statements into a web depicting a draft of the Washington vision for math teaching and learning. The district vision includes statements about students engaging in productive struggle and using tools such as manipulatives and high-quality tasks, and teachers creating learning environments in which students are respected. The DMLT's analysis of the vision determined that the least well-developed category included "tools"—i.e., written materials and tasks that support high-quality instruction. Using interview data collected from DMLT members, there was significant consensus around how to describe a high-quality task that aligned well with what research says.

After identifying tasks that support high-quality instruction as a potential focus for a first improvement cycle, the DMLT designed and implemented an exploration of the problem space related to such tasks. This exploration resulted in a list of potential problems presented as questions. At the same time, several DMLT members had concerns about how the district would determine and agree to which tasks would be deemed as supporting high-quality instruction. This led to the DMLT's use of various research sources (e.g., math standards, educational research articles) to build from DMLT members' interview comments and develop a draft framework for analyzing tasks. This process occurred over the last four DMLT meetings. At the end of Year 1, the DMLT was developing a plan to collect data on the types of math tasks present in the math curricula, and a plan to improve teachers' and administrators' understanding of different types of tasks. Overall, in Year 1, the Washington DMLT developed a robust, research-based vision for math teaching and learning. The team then used this vision to identify a potential focus are for a first improvement cycle.

Hamilton DMLT

Hamilton had an uneven history with the university team prior to the start of CASPIR. In the two years prior to CASPIR, the district initiated a DMLT that met between 2-3 times during the school year that generally discussed a vision for math teaching and learning, reviewed math curriculum materials, set a teacher professional development plan for the year, and explored curriculum analysis tools. The DMLT meetings were facilitated by district representatives, with some support provided by the university, and consisted of only math teachers. The DMLT did not engage in any systematic data collection or improvement cycles.

CASPIR began its collaboration with Hamilton in AY20-21. At the first meeting, the CASPIR team introduced CASPIR and its goals related to supporting the district in learning how to engage in data-driven improvement cycles. The team also discussed the need to build a collaborative vision for high-quality math teaching and learning across the districts, and possible areas of focus to inform the math improvement cycles. However, the district math lead on the DMLT pushed back on the need to develop a vision for math teaching and learning beyond the current version, citing "We already have a vision." At subsequent DMLT meetings, the district math lead proposed a possible focus area for math instructional improvement, namely number sense. As she stated, "We can be pretty confident in saying our students have struggled with number sense." While this decision was not based on any systematic data collection, there was general agreement from other district representatives on the team, and the DMLT agreed on this focus area for a first improvement cycle. As another member reiterated, "I am one hundred percent behind [number sense]. I have felt there is a huge deficit in our district."

For the remainder of the DMLT meetings in Year 1, the team drew from various research-based documents related to students developing number sense (e.g., math standards, research articles from practitioner journals). As part of these discussions, the CASPIR math coach presented a framework for the multiple dimensions of students' number sense that ultimately served as the guiding framework for how the DMLT defined number sense. The focus of the last four DMLT meetings of Year 1 involved developing a shared understanding of number sense according to this framework and discussing the development of a common assessment system for number sense that could be used across schools and grade levels. At the end of Year 1, the DMLT developed a plan to revise existing assessments for the common assessment system over the summer, with the goal of administering the revised assessments in the next school year. So, in contrast to Washington's DMLT, Hamilton's DMLT quickly narrowed its focus to a problem of practice without devoting significant attention to goal development and understanding associated evaluative frameworks.

Discussion

Although the Washington and Hamilton DMLTs were both RPPs at their earliest stages engaging in similar work, their learning about goal development and problem identification took very different trajectories. Where Washington's problem was grounded in strongly articulated goals for teaching and learning and primed for systematic data collection, Hamilton's problem was not and mainly anecdotal. Looking across both cases, our initial analyses highlight key factors influencing the trajectory of both DMLTs (see Table 2).

Table 2
District Trajectories in Early RPP Stages

District	History	Visioning Process	Vision	Identified Problem and Approach
Washington	Long history with professional developers, no specific perceived area of teaching and learning need	Long and focused	Strongly articulated, robust focus on teaching and learning, operationalized by framework	Improvement of math tasks using vision and systematic data collection supported by framework
Hamilton	Uneven history with professional developers, perceived need to focus on number sense	Short and superficial	Vague and not directly tied to teaching and learning	Improvement of students' number sense without vision or systematic data collection

There are likely several factors that influenced how Washington and Hamilton learned to engage in goal identification and problem identification in their RPPs. Our early analyses highlight the importance of district history. Washington had a long history with professional developers who focused on math teaching and learning in ways reflected by the visioning process. These professional developers served as key boundary spanners who were core members of the university team. In contrast, Hamilton had an uneven history with these professional developers, and their boundary spanning was not as effective at focusing the RPP on learning to develop high-quality goals for math teaching and learning. Moreover, members of the Hamilton DMLT came into the RPP with a belief that number sense was a key area for instructional improvement.

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AI-Supported Scaffolding for Writing Academic Arguments

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Abstract: Despite the importance of writing academic arguments, instructors often lack enough time and knowledge to provide prompt support adaptive to individual students' discipline-specific arguments. AI techniques can enable automated and adaptive educational scaffolding. In this study, we created a test version of the Artificial Intelligent-Supported Scaffolding (AISS) system that provides scaffolds in the form of alternative writing examples that human experts would write. Our mix-methods data gathered from 14 students enrolled in two sections of the same graduate-level online course revealed that the students leveraged AI-generated scaffolds to build a more substantial claim with elaborated ideas in a cohesive text structure. The current study's findings demonstrated the potential of AI to provide personalized scaffolding for writing academic arguments.

Introduction

Competent writing capabilities are required for tertiary students because they are often tasked with communicating in a scientific manner through written arguments (Pelger & Nilsson, 2016). Students must utilize discipline-specific knowledge, integrate various information from multiple sources, and construct compelling arguments (Goldman et al., 2019). Despite the importance of academic argumentation, due to the complexity of writing arguments, writing arguments often remains as a demanding task even for proficient learners. However, students rarely receive formative and prompt support due to instructors' lack of time and skills to teach individuals' discipline-specific argumentation topics (McNamara et al., 2019; Passonneau et al., 2017).

Scholars have explored the use of AI that may assist or substitute for expert human tutors (Puri & Mishra, 2020; Yang, 2021). For example, Yang (2021) demonstrated that an AI system as a teaching agent guided students to deploy good processes and strategies in writing. However, the current AI's ability tends to focus on well-structured domains (e.g., algebra) and therefore is not enough to understand ill-defined and complex problems such as individual students' domain-specific written arguments (Koedinger & Corbett, 2006; Goel & Joyner, 2016).

Admitting that the use of AI in education is in its infancy, we attempted to leverage AI techniques to help students to write academic arguments. To this end, we developed a pilot application named the Artificial Intelligent-Supported Scaffolding (AISS) system. In this initial investigation, we deployed a mixed-methods approach to examine how AI-provided scaffolding drove students to revise their arguments. Specifically, the following questions guided this study.

- To what extent did the AI-enhanced scaffolding help students to improve the quality of their arguments?
- How did students draw on the AI-based scaffolding to revise their arguments?

Background

Academic argumentation and AI-Enabled Scaffolding

A skilled writer leverages domain knowledge and the source of ideas they have learned to support a claim and articulate a process of argumentation in cohesive and coherent ways to persuade others. One effective way that helps students improve argumentation skills may provide them with good examples pertaining to individuals' argumentation topics and use examples as scaffolds to articulate their arguments (Westby et al., 2010). Given scaffolds, students may learn about more appropriate languages, ideas, and professional tones and manners to write a strong argument.

We focused on the role of AI to provide automated scaffolds adaptive to individuals' arguments. Scaffolds– is a broad range of instructional support that enables students to perform beyond their current capacity can take various formats, including prompts, feedback, guidance, hints, and expert models (Wood et al., 1976). In this study, we regarded expert modeling as the most effective way to support students' argument development because expert models can serve as a conduit through which students consider better ideas and sound evidence (i.e., conceptual scaffolding), learn about writing strategies (i.e., strategic scaffolding), and evaluate the quality of their arguments against given experts' examples (i.e., metacognitive scaffolding (Anderson et al., 1997).

We drew on the current Natural Language Processing (NLP) AI techniques that can make sense of the complex disciplinary textual data (Goel, 2019) and provides individualized and prompt scaffolds in the forms of computer-generated written examples that human experts would write. Therefore, augmented by AI, personalized

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support for individuals' argument development can be scalable to many students from diverse disciplines and backgrounds.

Lexical features, text cohesion, and argument quality

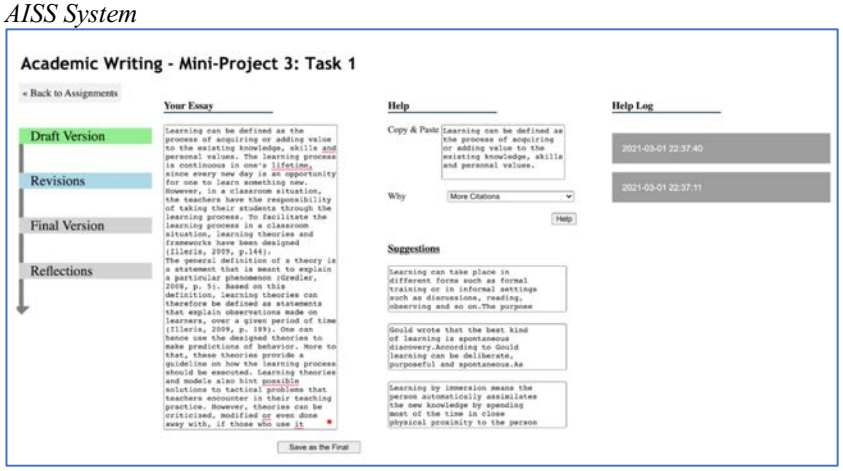
Academic writing consists of developments at various interconnected competencies across different levels of words, phrases, clauses, intra-sentential, inter-sentential, paragraph, and textual levels of analysis. Accordingly, an argument is structured with lexical items—typically nouns, verbs, adjectives, adverbs, etc.—that build their syntactic expressions and semantic relations together (Williams, 2015). Therefore, understanding an argument's lexical elements and syntactic structure is critical to determining the quality of arguments. Scholars have agreed that lexical features contribute to both construction and comprehension of semantics of a text and therefore relate to the quality of arguments (Morris & Cobb, 2004; Vogelin et al., 2019). In this study, we focus on four aspects of text cohesion, as follows:

- Lexical diversity indicates the extent to which unique words are used in the text.
- Lexical density describes the extent of using content words (i.e., nouns, verbs, adjectives, and adverbs) in text.
- Sentence overlap indicates the number of text items repeated across sentences.
- Semantic overlap indicates the extent of underlying semantic relations in the text.

AI-supported scaffolding system (AISS)

We developed a prototype of the AISS system that supports students to practice argument writing skills. As depicted in Figure 1, AISS's NLP AI algorithms generate examples as expert models (suggestions) for the part students like to improve (Help). Referring to expert models, students can learn new/correct vocabulary and citations for their arguments (i.e., conceptual scaffolding) and improve the ways to write cohesive and coherent paragraphs (i.e., strategic scaffolding). A process of revisions is stimulated by students' self-evaluation of what they have written against given examples (i.e., metacognitive scaffolding). On AISS, such an argument development is guided by the process of planning, drafting, and revising (i.e., procedural scaffolding),

Figure 1
AISS System



Methods

Research context and participants

Participants were 14 students enrolled in two sections of the same graduate-level online course, which allowed us to have more cases and compare two cohorts. Cohort 1 included 6 students who consented to the study participation out of 13 students enrolled in a spring semester section. Cohort 2 consisted of 8 students out of 12 enrolled in the following summer semester. During Week 9 of the course, as part of the assignment, on AISS, students developed their arguments for the question: "Is the constructivist learning approach better? Choose your position. If YES, what is a constructivist learning environment, and what effects are intended? If NO, are there downfalls in using the constructivist teaching approach?"

Data collection and analysis

We analyzed draft and final versions of the students' arguments, using the Tool for the Automatic Analysis of Cohesion (TAACO; Crossley et al., 2016) that provides hundreds of indices at the word, sentence, and document level leveraged to evaluate linguistic features of students' written arguments. Scholars have used TAACO to evaluate discourse-level cohesion–the degree to which information is connected across the text (Skalicky, 2019). In this study, we selected 17 indices corresponding to the four text cohesion categories (see Table 1). Also, we conducted visual inspections of the written arguments to examine how students used the feedback to revise their arguments.

Findings and Discussion

As described in Table 1, in both cohorts, final versions showed a decrease in the values of lexical diversity indices. Results indicate that the students tended to use selected words (i.e., concepts), including their synonyms, rather than bringing in more new languages in their revisions. It seems that students became aware of and focused on key ideas supported by the AI scaffolding. Contrarily, indices of lexical density increased from drafts to final versions, meaning that the students more frequently used content words in their final arguments that contribute to the meaning of the text. Taken together with lexical diversity, it appears that students developed their arguments containing more words possessing semantic content while centering on key ideas.

Table 1

Average Differences between the Final and Draft Arguments

Category	Index (Final – Draft)	Cohort 1 (N = 6)	Cohort 2 (N = 8)	Total (N = 14)
Lexical Diversity	Lemma_ttr	(0.052)	(0.047)	(0.049)
	Noun_ttr	(0.035)	(0.036)	(0.035)
	Verb_ttr	(0.095)	(0.018)	(0.051)
Lexical Density	lexical_density_tokens	0.003	0.002	0.002
	lexical_density_types	0.032	0.023	0.027
Sentence Overlap	adjacent_overlap_all_sent	(0.001)	(0.000)	(0.001)
	adjacent_overlap_2_all_sent	(0.039)	(0.017)	(0.026)
	adjacent_overlap_binary_all_sent	0.002	0.001	0.001
	adjacent_overlap_binary_2_all_sent	0.000	0.000	0.000
	adjacent_overlap_CW_sent	0.004	(0.003)	(0.000)
	adjacent_overlap_2_CW_sent	(0.036)	(0.024)	(0.029)
	adjacent_overlap_binary_CW_sent	0.031	0.012	0.021
	adjacent_overlap_binary_2_CW_sent	0.036	(0.016)	0.006
Semantic Overlap	lda_1_all_sent	0.004	(0.000)	0.002
	lda_2_all_sent	0.003	0.002	0.003
	word2vec_1_all_sent	0.011	0.014	0.012
	word2vec_2_all_sent	0.018	0.016	0.017

Note. A number contained within parenthesis is a negative number. Content words (CW) include nouns, lexical verbs, adjectives, and adverbs derived from adjectives. Lexical diversity indices: Measure of lexical diversity of the ratio of unique (type-lemmas, nouns, and verbs, respective) to all words (tokens-lemmas, nouns, and verbs, respectively). Lexical density indices: the proportion of the text that consists of content words (tokens or types). Sentence overlap: The amount of text items that repeated in text. Adjacent overlap 1 and 2 sent indicate the number of lemma types (or any CW lemmas) that occur at least once in the next sentence and the next two sentences divided by the number of words considered, respectively. Adjacent overlap _binary 1 and 2 sent indicate the number of any lemma types (or any CW lemmas) that occur at least once in the next sentence and the next two sentences divided by the number of sentences considered, respectively. Semantic overlap: Underlying semantic relations in texts through computational models. Ida_1 and_2 indicate average latent Dirichlet allocation divergence score between all adjacent sentences with one and two-sentence span, respectively. Word2vec_1

and_2 indicate average word2vec similarity score between all adjacent sentences with one and two-sentence span, respectively.

As to sentence overlap, both one sentence and two sentences adjacent overlap indices for all lemma types and content words lemma types tended to decrease while their overlap binary values increased, indicating that the students attempted to avoid a redundant use of the same languages (overlap indices) but tried to properly use main ideas across adjacent sentences (overlap binary indices), resulting in a more cohesive argument. In the same vein, semantic overlap indices showed an increased overlap in the students' arguments, indicating that the students used languages within similar topics (i.e., LDA indices) and contexts (i.e., Word2vec indices).

Besides, visual inspection of students' arguments showed that students used examples to add new ideas and paraphrase AI-generated texts. Such additional activities entailed restructuring the logical flow of the arguments (examples of visual inspections will be presented at the conference).

The findings of this exploratory study demonstrated the potential of AI to provide personalized scaffolding for writing academic arguments. The AISS scaffolding appeared to help students to locate relevant and most current literature. Students leveraged AI-generated scaffolds to build a stronger claim with elaborated ideas in a cohesive text structure. However, the current study revealed several limitations. NLP AI techniques need be fine-tuned to are still at the infancy stage, requiring further articulation. The original AI algorithms in AISS have not been tuned to educational use, especially for scientific argumentation. For example, the AI sometimes generated thematically irrelevant suggestions. Also, we need to detect whether students just copy and paste the suggestions without learning how to formulate their own responses to improve text.

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Teachers' use of augmented reality in the classroom: reasons, practices, and needs

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Abstract: Research on augmented reality (AR) in education shows various advantages and challenges for learners while research on teachers is scarce. In practice, teachers drive the implementation of AR in classes, and it is important to examine current practices and requirements to be able to effectively support their efforts. $N = 16$ teachers who had used AR in their classes took part in a survey with open-ended questions focusing on reasons for, current practice of, and needs when using AR in education. The answers were classified into different (sub-)categories. As reasons for usage, different instructional and non-instructional purposes are mentioned. In the current practices various technologies, design-platforms and educational materials are described, and needs include content availability, pedagogical integration, and technical infrastructure. The results are discussed with a focus on unexpected outcomes and the potentials of collaboration between researchers, practitioners, and other stakeholders to support teachers AR classroom integration.

Introduction

In this study, we examine teachers' use of augmented reality (AR) in the classroom. AR is an emerging visualization technology defined by the simultaneous presence of real and virtual objects that are geometrically aligned and enable real-time interactions (Azuma et al., 2001). Previous research identified several opportunities of AR for the purpose of teaching and learning. For example, AR can support the understanding of complex science concepts by visualizing the invisible (Yoon & Wang, 2014), scaffolds inquiry-based learning (Kyza & Georgiou, 2019), and reduces cognitive load leading to increased performance (Buchner et al., 2022). Krüger et al. (2019) describe three major characteristics that distinguish AR learning environments from other technology-enhanced learning scenarios and entail advantages when purposefully implementing AR for appropriate learning goals: *contextuality*, i.e. placing virtual elements in a real-world context; *interactivity*, i.e. combined physical and virtual manipulation; and *spatiality*, i.e. spatial positioning and dimensionality of virtual objects. In addition to promoting learning and comprehension, researchers mention motivational and affective factors as central outcomes when using AR in education (Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018). However, along with the opportunities, research shows that implementing AR in the classroom is challenging. Most often, technical issues are reported in the literature, like the lack of devices, weak internet connection or problems during the representation of the AR visualization (Akçayır & Akçayır, 2017). Another matter concerns instructional design, including the identification of learning objectives that can be effectively achieved using AR or the prerequisites for learners to successfully engage with the AR learning environment. In their review, Buchner et al. (2022) distinguished between declarative and procedural knowledge acquisition and found that AR is better suited to promote procedural knowledge.

As the research presented shows, scholars have so far focused their investigations on learning and the role of the learners. Research that focuses on teachers is scarce. However, as for any other technology, teachers have a key role here as they are responsible for an effective and efficient use of the technology, like AR, in class. Alalwan et al. (2020) provide in their study a developing country perspective of AR usage in science education. The authors interviewed 29 primary school teachers revealing that lack of competency and resources (among others) were common challenges. In da Silva et al. (2018), results from Brazilian teachers and their use and experience with AR are reported. The authors conclude that AR is still something new for the teachers and a major limitation for further use of AR in school is the lack of content creation tools. Other studies exploring the AR experience of teachers under real classroom conditions are lacking. Hence, several questions regarding the use of AR in schooling remain open. For example, do teachers use AR in their lesson for the same reasons found in the research literature, which specific implementations do they use, and is the lack of resources also true for the European context? In this study, we aim to address these questions and contribute to the limited research base regarding teachers' use in educational practice. Therefore, we investigate teachers' reasons for and current practice of using AR in their classes. Furthermore, we examine what teachers require to overcome challenges linked to the usage of AR in education and to make the use of AR in practice more effective and efficient.

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Methods

A semi-structured survey was addressed to German-speaking teachers who had used AR in education. A convenience sampling approach was used and $N = 16$ teachers, age 26 to 56 ($M = 37.80$, $SD = 8.74$), from different school forms and course areas took part. Six were male, nine female, and one did not disclose.

Five open-ended questions should trigger word-based, open responses in three categories, inquiring about teachers' reasons to use AR, their current practice of implementation, and their requirements to overcome challenges they come across. We added different sub-questions to elicit elaborate, detailed answers, for example specifying the question on how AR was used by asking for the specific methods and technologies and triggering a description of requirements by asking for what went wrong in the implementation. The specific questions in their original German and translated English form can be found here: https://osf.io/yqux4/.

The teachers were contacted especially through posts and messages on Twitter directed towards relevant audiences. A link to the online questionnaire was provided and participants gave their consent for data collection at the beginning. They then answered general questions about the context of their AR use. On the next page, the open-ended questions were given. At the end, the demographics were inquired, and a short debriefing was given.

Because the goal of the survey was to learn more about teachers' reasons to use AR, their current practice of implementation, and their requirements to overcome challenges they come across, these categories were also focused during data analysis when classifying the participants' answers. The authors classified answers and individual text-snippets into the three question-categories: (1) "Why do teachers use AR in instruction?"; (2) "How do teachers use AR in instruction?"; (3) "What do teachers need to overcome challenges of using AR in instruction?". Further, in a joint negotiation of two authors, answer-categories and -subcategories were developed.

Results and Discussion

The structure of the established categories will be described in more detail in this section. For example quotes per (sub-)category, see https://osf.io/yqux4/.

Why do teachers use AR in instruction?

Regarding the question why teachers use AR in their lessons, we found that most of the statements address a kind of instructional purpose with the sub-categories learning from AR, learning with AR, and learning about AR. Most of the teachers stated that they use AR to visualize content and invisible phenomena. As a result, the teachers expect the visualization to more effectively support comprehension of the content compared to other illustrations, e.g., 2D pictures (learning from AR). The use of AR to visualize the invisible is also reflected in the research literature on AR in education and the opportunity to illustrate complex and abstract content and information is described as a main benefit of AR usage. The possible advantage of 3D (like used in AR applications) over 2D is also reported by teachers in da Silva et al. (2018). The next most frequently mentioned instructional purpose represents a learning with AR perspective. Here, teachers used AR technology to involve the learners in a design process. For example, teachers reported that the students created videos to orally practice a foreign language. As shown in the literature, involving learners in a design process can be an effective learning approach. In the Brazilian context (da Silva et al., 2018) teachers also described AR content creation by students. In the developing countries perspective reflected in Alalwan et al. (2020) this purpose is missing because of lacking authoring tools. AR was also mentioned as a purpose on its own, representing a learning about AR perspective. For example, one teacher used AR in computer science education showing the learners how the technology works. Interestingly, this aspect is novel for our study. However, researchers point out the importance of learning about new digital technologies like AR due to an increasing demand for people with skills in this area (Fominykh et al., 2020).

We identified three categories not fitting into the instructional purpose category. Teachers implemented AR in the classroom because they themselves were interested in the technology and wanted to test it. Others mentioned that they wanted to design a learning experience beyond the curriculum to create memorable events for the learners. Another aspect concerned sustainability. One teacher stated that AR helps to provide further information without printing masses of paper sheets. While personal interest and providing experience beyond the curriculum is mentioned similarly in da Silva et al. (2018) and Alalwan et al. (2020), using AR for sustainable reasons is an aspect not reported in the literature so far. Another interesting result of our study is that none of the teachers quoted motivational aspects as a reason for AR use. This is contrary to the literature as authors indicate motivation as an important advantage of using AR in educational settings (Akçayır & Akçayır, 2017).

How do teachers use AR in instruction?

The questions of how teachers used AR in their lessons including which technologies and materials they implemented were answered very differently. The answers could be classified into three categories, namely

instructional approaches, technologies, and educational materials used. The instructional approaches mentioned in or implied from the description of the procedures include teacher-led approaches like demonstration and augmentation of available physical curricular materials. This is supported by the often-mentioned instructional purposes of illustration or concrete visualization of material in the previous section (Yoon & Wang, 2014). Further, student-centered instructional approaches were described, including inquiry, project-based and problem-based learning, and collaborative experimentation. Inquiry, project-based and collaborative learning were described as important approaches that can be achieved with AR (Garzón et al., 2020), which may be a reason the teachers used them. The implementation of the student-centered approach of design-based learning is furthermore connected to the above-mentioned instructional purpose of learning with AR instead of from AR.

Concerning the different technologies used, a distinction can be made between hardware and software, or more specifically design-platforms used. Most teachers stated that they used mobile devices like tablets and smartphones, which are ubiquitous and less expensive than the less-mentioned AR-glasses. One teacher described projecting the screen of a tablet onto a beamer, probably to enable every student to see the material. This shows that creative approaches can be born if, for example, there are not enough devices available. Many different design-platforms were mentioned, including Areeka Studio, Blippar and HP Reveal, which was also mentioned in da Silva et al. (2018). While this diversity in available and used software may be enriching because different use cases can be addressed, the incompatibility between different platforms might be a problem for sharing materials. Many of the teachers mentioned more than one platform, which shows that they either had to switch due to different use cases, or that they switched because they have not found the perfect platform, yet. Either way, there seems to be some effort involved in choosing the appropriate application.

Concerning educational materials, some of the participants describe materials that they developed themselves, while other participants described having used available materials. Own materials were often developed with easily usable authoring tools like HP Reveal or Blippar, although more elaborate content-creation including the design of a booklet and a specific application were also mentioned by a participant. The educational material that was already available could be split into the marker-based, marker-less, and location-based AR technologies, where marker-based materials were described more often, e.g., in the form of Areeka animal cards or the MergeCube. A few marker-less materials, like GeoGebra, were mentioned. Location-based material was described only in one case, namely with the platform Actionbound. This prevalence towards marker-based materials may be based on their higher availability due to less technological requirements for devices. While marker-less applications require a device that can scan surfaces which is, for example, possible through ARkit and ARcore technologies in most new IOS and Android mobile devices, marker-based applications mostly only need a functioning camera for target detection.

What do teachers need to overcome challenges of using AR in instruction?

Regarding the perceived challenges and needs to overcome them, we found three main categories. The first category concerns content - self-created and existing. For content creation, teachers complain about the lack of easy-to-use and cost-free authoring tools. For example, some teachers mentioned that they used the HP Reveal AR studio, which is now no longer available. Additionally, the teachers call for training on how to create AR objects, especially 3D models, and more time to prepare AR-enriched lessons. For existing AR materials, teachers report that these do not align with curriculum goals and lack of interactivity. Furthermore, the applications are not inclusive (e.g., usable on different devices) and not freely available. In sum, more high-quality AR educational materials are needed. The results in the content category are like those found in da Silva et al. (2018) and Alalwan et al. (2020), indicating that the problem of content is independent of the country. A detail stressed by the teachers in our study is that they request more materials in German.

Second, teachers experienced pedagogical issues during the AR classroom integration. These can be summarized as a lack of ideas for purposeful usage and perceived pitfalls that should be avoided. For example, teachers observed a so-called *wow-effect* that did not translate into more effective learning. To overcome this issue, training on how to purposefully use AR in class was suggested. This might also help to avoid the observed pitfalls like a distracting effect in terms of technical problems during the use. This issue is also reflected in the literature (Akçayır & Akçayır, 2017).

Third, technical issues like poor internet or the complete lack of devices that can easily display AR were also listed as problems by the teachers in our study. It is particularly interesting that one teacher pointed out that the use of students' smartphones can also cause problems. Some devices would simply no longer meet the requirements and have too little computing power for AR. The small display of smartphones was also mentioned as a limiting factor. Thus, teachers in the European, German-speaking context are struggling with the same technical shortcomings as the teachers in da Silva et al. (2018) and Alalwan et al. (2020).

Conclusion and implications

In summary, European (here: German-speaking) teachers face similar challenges when using AR as, for example, teachers in developing countries. To facilitate teachers' use of AR, different recommendations can be made.

School authorities, such as policy makers, need to provide a technical infrastructure so that the use of AR can take place smoothly and teachers can focus on instructional design considerations. Here, there is a need for trainings from teacher education institutes and continuing education providers that convey both the technical and pedagogical fundamentals for the use of AR in class. One concern of the teachers surveyed was that they would like to exchange ideas with others. Hence, it would be desirable to establish a networking platform that allows the exchange of AR materials, instructional designs, and experiences. It also became apparent that previous research has not yet been sufficiently successful in sustainably anchoring developed AR applications in practice. Future educational AR research should therefore integrate experimentally gained knowledge and technological approaches even more closely within practice. By directly involving teachers in these research and development processes, this can result in applicable, freely available, and reusable AR materials. Moreover, research can develop free and user-friendly AR design platforms to help harness the potential of teachers as a significant resource for content creation. Companies developing or willing to develop AR learning materials should also collaborate with both practitioners and researchers. As shown, the quality of many existing materials is considered poor. Collaboration among AR developers, educational technology researchers, and practitioners would certainly be able to contribute to more effective, efficient, and high-quality AR educational media in this regard.

To conclude, it was found that some teachers are in general willing to employ AR in the classroom for several reasons and with different instructional approaches, although these teachers still have to endure various challenges. To overcome these challenges, collaboration with research and other stakeholders is necessary to make AR an integral part of teachers' instructional toolbox.

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International Society of the Learning Sciences

Designing STEM Classes for Hawaiian Youth's Rightful Presence

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Abstract: This paper shares the process of designing a summer school science and technology class focused on youth advocacy and the development of youth *rightful presence* (Calabrese Barton & Tan, 2019) for students in Hawaii. We examine students' changing perspectives and connections to STEM through their engagement in projects that center their own geography and life experiences. Findings indicate that youth sense of agency and autonomy were greatly improved by engaging in a space where science and technology were tools serving their own goals of protecting the island from further development and tourist abuse.

Introduction

Students entering the STEM workforce must be both trained and motivated to do so. However, the ability of school instruction to impart the necessary knowledge is largely dependent upon a solid foundation of motivation and prerequisite skills developed earlier (Akerson et al., 2011). Low levels of participation in STEM have been traced back to a lack of effective preparation and a lack of interest from students; without prior exposure and interest, students are unlikely to choose STEM as a focus of future pursuits (Hall et al., 2011). As such, it is essential that youths' skills and interest be developed prior to the secondary level. Minoritized communities and individuals have long found themselves excluded from legitimated access to STEM classrooms, careers, and communities. In order to support student STEM interest within the context of rural Hawaii, this research explores the development and design of a culturally responsive computing and making class specifically designed to support youth *rightful presence* in STEM (Calabrese-Barton & Tan, 2019).

Background

Making and specifically targeted inclusive maker activities offer a context that can support the development of *rightful presence* (Calabrese Barton & Tan, 2019). The tools, materials and processes of making can disrupt stereotypes around who can and does engage in STEM by affording youth the opportunity to engage in projects and activities of their own design (Fields & King, 2014). The duality of low and high tech materials used in making can provide a novel entry point for youth into STEM as often young people already see themselves as capable in using crafting supplies (Kafai et al., 2014). This is especially true for individuals who already craft or have family members who craft (Tofel-Grehl et al, 2017). Many making activities, such as electronic textiles (e-textiles) have been shown to integrate handcrafts and cultural funds of knowledge not often engaged in school classrooms (González, Moll, & Amanti, 2005). This has shown some promise in bringing historically marginalized groups into STEM (Kafai et al., 2014). Further, e-textiles are highly personalizable, providing opportunities to express oneself and connect with others through STEM. For instance, youth may use e-textiles materials to tell a story about a meaningful moment in their life or to build something to address an issue in their community (Greenberg & Calabrese Barton, 2017). Research in culturally responsive computing has also shown that narrative and place-based approaches to making are especially promising for bringing historically marginalized or excluded groups into STEM (Searle et al., 2020). Therefore, by engaging youth in STEM activities through making rooted in a particular place and support the sustained development of interest and personal belonging in STEM, further inroads may be made into how youth perceive who does STEM.

Theoretical Framework and Research Questions

Our goal for this work was to support the development of better STEM identity and youth agency among Hawaiian youth. To that end, we engage Calabrese-Barton & Tan's *rightful presence* framework to guide this work. Rightful presence is "legitimate membership in a classroom community because of who one is (not who one should be), in which the practices of that community work toward and support restructuring power dynamics toward more just ends through making injustice and social change visible" (Calabrese Barton & Tan, 2019, p. 618). Rightfullness of presence requires youth to fully occupy the disciplinary space within their classroom in such a way that they are able to restructure and reimagine their learning space for themselves. Rightful presence calls for a deconstruction of the power structures fundamental to schools in three core ways. First, the notion of a choice to extend rights to all parties inherently requires a brokering of power wherein those with power choose to extend rights to those without it. This structure makes the rights of some contingent upon

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the benevolence of others—something that inherently undercuts rightful presence. Secondly, rightful presence requires the acknowledgement that science cannot be divorced from the political. Rightfully present spaces recognize and make visible the political struggle of minoritized individuals central to their history as related to science. Third, rightful presence requires the active deconstruction and disruption of normative power processes that marginalize students. This disruption of structural oppressions creates visibility, and recenters the responsibility on the beneficiaries of power. For youth in Hawaii a rightfully present STEM class centers around issues and questions of great importance to communities on the island, such as the impact of tourism.

With this framework and a design-based research approach in mind, we ask the following research questions:

1) How can educators design opportunities to support youth's sense of rightful presence?
2) Does youth's rightful presence manifest into action or agency within a classroom setting?

Methods

We engaged a phenomenographic lens for qualitative data collection and analysis during the course design and planning, the teacher professional development, and the ten day class sessions. Data collected include audio recordings of the class, curriculum design notes, fieldnotes, interviews, and photographs of artifacts.

Context & participants

Ten youth from around the local town enrolled in the middle school participated in the maker class, which met four hours a day for two-weeks. Youth were from various cultural and social backgrounds. The participating teacher is national board certified in science and social studies and has been teaching for over 20 years. She has been teaching at this public charter school for the past 8 years since moving from the mainland to Hawaii.

Description of the class

The class was co-designed in collaboration with the participating teacher. Her focus was on finding ways to engage science and technology to support youth awareness and activism with indigenous issues on the island. The class included two place-based field trips to sacred sites on the island. Youth engaged in three Hawaii focused maker projects. The first project tasked youth with engaging in making a paper circuit plaque that shared information about themselves and their passions (see figure 1). In the top left corner, they were asked to share an area of science that was of interest to them. In the top right corner, they were asked to share a place they want to visit. In the bottom right corner, they were asked to share a hobby or interest and in the bottom left corner they were asked to share a social or community issue they were passionate about.

Figure 1. Example of Name Placard, 3D Printed Volcano Map, and Advocacy App

The second project (figure 1) saw youth using 3d printed topographical maps to build computational circuits that explored the geology and history of the island's volcanos. This project let students engage with both the geography and geology of their island. Students investigated topics such as volcanic age, activity, or height. With this information in hand, students picked three volcanoes and determined how to visually represent the data they had on a single aspect of the geologic information gathered about their island's volcanoes.
The final project engaged youth in the design and coding of "advocacy apps." During the place-based fieldtrips, youth were tasked with interviewing land caretakers about the behaviors and actions of tourists as they visited important places around the island. These interviews were used to generate class derived codes of conduct for sacred spaces. Youth then built apps to support tourists engaging in appropriate behaviors (see figure 1).

Data

A member of the research team took fieldnotes and kept daily reflections during and after class. In addition to the collection of qualitative fieldnotes, table microphones were used to collect audio recordings of the groups. A

total of 40 hours of class time were recorded and transcribed. At times youth were interviewed to follow up on conversations that emerged organically at tables. Daily photographs were taken to capture the process of making and youth engagement with designing projects that engaged their identities. Of specific interest in tracking shifts in youth identity were localized projects focused on various places on the island.

Findings

In seeking to develop youth's sense of agency and rightful presence the class needed to support youth in finding contexts and content that was both meaningful and applicable in their daily lives. With the rising resentment across the island towards tourist vandalism, the collaborating teacher felt that engaging youth in learning and thinking about how they could affect behavioral change on their island was essential to students on Hawaii.

The first project was designed as both an ice breaker and key point of contact for us to be able to collect information about what was of value to the youth in the class. Designed by the collaborating teacher, the activity asked youth to share their names, pronouns, and four facts. Students were asked to share a passion, a place they love, a hobby, and a science interest. As she conceptualized the activity, the teacher noted:

> I like this name card activity because it lets us learn about the kids and what is important to them… If we combine it with the paper circuit, the kids can learn that part of the science while we learn what matters to them. When the kids can tell us what matters to them, they get a lot more into it.

By allowing youth to share their interests and passions, we were able to open up dialogues in the class with the specific goal of creating greater rightful presence for youth. For example, when one student, Leilani, shared her passion for protecting the Maunakea volcano from further development and destruction by scientists who were seeking to put up another large telescope, we pivoted the conversation to talk about why this conflict between Indigenous Hawaiians and scientists was important for all citizens of the island.

Figure 3. Leilani's name card showcasing her care for the Maunakea and disinterest in science.

With the conflict on the island having been the source of great angst for some students like Leilani, who spent her weekends with her family camped on the mountain seeking to stop impending bulldozers, other students made clear their lack of knowledge about the conflict. When Leilani explained the importance of the site, classmates began to discuss why it was important for everyone to help solve the problem. Marcus commented "Yesterday I did not even know about this. But now I can understand why Leilani is upset. I would be mad too if someone bulldozed my church. So, like, helping stop this is really important."

In Marcus we see the beginnings of an awareness at the injustices around him and the urge to help his friend make better a problem that was important. This marks the beginnings of a more rightfully present classroom as students uncover and address injustices, one of the core tenets of rightful presence. This dialogue continued as students engaged in their second project, the 3D printed volcano. After learning about the ages, activity, and relative heights of all the volcanos on the island, they selected three to create a computational circuit with actuators to model features of the volcanoes. Students programmed microprocessors to help tell the geologic story of their island. Tying the scientific information about the volcano into her display, Leilani shared some of her knowledge about how its great height was explained in Hawaiian culture because it was the child of the sun and earth. This bridging of scientific understanding with her Hawaiian epistemology brought Leilani to the idea that "geology isn't so bad." Her softening towards science was noteworthy because of her belief that science was at war with her people.

During the class students took two field trips to Hawaiian sacred sites. The first field trip took youth to the Wai'pio valley to interview and learn from the land's caretakers. The second field trip brought youth to the

Pu'ukohola Heiau, a national historic site and holy site to Indigenous Hawaiians. Through their conversations with the land caretakers students learned about the many problematic behaviors of the visitors to these sites. After these two field trips, the class began to brainstorm ways they could help people learn about the rules and regulations they needed to follow to have a respectful visit to these spaces. Youth engaged in a design and coding project entitled Advocacy Apps. Using MIT's App Inventor, a visual programming environment designed to facilitate app building for novice programmers, youth designed and built apps that explained the importance of respecting Hawaiian spaces and appropriate codes of conduct.

Students were eager participants in the design and coding processes for their apps. As one youth commented "These apps are good because I think people could really use them. They might work." The project marked a turning point for several youth in the class. Rather than observing and worrying about the injustices they discussed as a class, participants were able to engage with a problem and work to bring attention to the issue. In doing so, several youth commented on how they could see the value and applicability of the project. As Manzina said "I really like this because I feel like I can do something. In school I can't do anything with what I learn." Manzina's comment highlights precisely why designing for rightful presence in STEM is so important.

Conclusion and Discussion

Designing projects in support of youth rightful presence can be challenging but offers unique links between youth home identity and school identity. Making can provide youth a meaningful, culturally relevant way to engage with science learning around issues important to them. We see in this class experience that teachers are able to bring together content knowledge they need to teach with projects that engage student interest on a personal level. This integration of science into their daily lives and concerns creates a space in which science is personally and politically meaningful. Rightfully present science teaching not only makes science more accessible, but it also works to dismantle historic notions of what science is and who does the work of science. Culturally relevant making and rightfully present science go hand in hand to redefine what science is, who does science, and what science can bring to the lives and experiences of communities across the globe.

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Innovate to Mitigate: Analysis of student design and rationale in a crowdsourcing competition to mitigate global warming

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Abstract: The Innovate to Mitigate project adapts crowdsourcing to support project-based STEM education, posing design challenges for secondary-school students to design feasible innovative strategies to mitigate CO_2 emissions and thus global warming. The paper presents evidence that the web-mediated communities of practice support learning of STEM concepts and practices and provides an account of how student and scientist discourse support that learning. Productive talk deployed by community members elicited greater levels of reasoning than was originally manifest in student work and resulted in improved student products.

Introduction

Global warming is increasingly seen to affect everyone's lives and many young people are eager to respond (e.g., Thunberg et al. 2020). Engaging the issue constructively ("active hope") can counteract the anxiety and depression such an overwhelming problem elicits (Hayes et al., 2018). The Innovate to Mitigate (I2M) project poses design challenges in climate change mitigation for middle- and high-school students. Our initial research (Puttick & Drayton 2017; Drayton & Puttick, 2018) suggests that an open but well-structured challenge to develop mitigation strategies can galvanize creativity and engagement among young people, and support "3-D learning" (NRC, 2012).

Crowdsourcing for STEM learning

Crowdsourcing and social media are increasingly common media for participation in society (Hossain & Kourainen, 2015; Arelas & Ladrón-de-Guevara, 2011). The crowdsourcing communities in Innovate to Mitigate (I2M) (students, teachers, scientists) are designed as learning environments in which students can collaborate to iteratively improve design ideas and STEM knowledge. Such heterogeneous communities of practice offer a diversity of inputs, including insights about practice from more experienced participants (Wenger, 1998). Dialogic knowledge- construction and design, facilitated by the division of labor within the team (Puttick & Drayton 2017; Drayton &Puttick, 2018), is strengthened by collaboration among competitors in the challenge. This open integrative process is central in our adaptation of crowdsourcing. Students' discourse can provide insight into students' reasoning and understanding of STEM concepts and practices, and evaluation of each other's comments (Ketonen et al., 2020; Samarasekara et al., 2020; Cheng & Tsai, 2012). Other impacts may include growth in quality and depth of student argumentation, and in metacognitive effects such as students' capacity to evaluate their own reasoning and evidence (Anker-Hansen & Andrée, 2019).

Dialectical learning in science education

"Discourse" in science classrooms has taken on great importance under the influence of research in the sociology of science. The Frameworks argue that the true aim of science is to create and critique evidence-based causal accounts of natural phenomena (NRC, 2012). On this view, science moves forward in important measure by its discourse within a community of practitioners. One genre or mode of discourse is “narrative” (Kvernbekk, 2003). A second, strongly advocated approach is “argumentation,” structured around making and defending claims that propose explanations for phenomena (Allchin & Zemplén, 2020; Boğar, 2019).

A further refinement, "productive talk," developed and characterized by learning scientists in recent decades, places a key emphasis on collaborative knowledge building and on the ways that teachers can facilitate (but not direct) the use of "talk moves" that help students make theory- or data-based claims, seek or evaluate evidence for or against the claims, and elaborate the implications of their work. A further intent is the adoption of "talk moves" by students into their dialogue with each other within teams, in large-group critique and collaborative sense-making (Michaels & O'Connor 2021; Resnick et al. 2015).

We conjecture that a collaborative/competitive design challenge such as I2M will not only offer an

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opportunity for students to engage in STEM practices, but also to engage in sense-making and knowledge-building discourse related to their designs, which will shape how resulting products are reshaped. In this paper we ask: (i) What evidence is there that crowd sourcing led to changes in students' design artifacts and rationales, generated during an I2M challenge? (ii) How are these changes related to students' science discourse with each other and with scientists giving feedback on the project designs?

Methods

Student teams propose a design abstract, based on a mitigation strategy such as energy conservation, alternative energy generation, or social/behavioral change. Since abstracts scaffold the whole investigation, students are asked to describe their idea, how they consider it an innovation, and how feasible it might be to implement. Teams post their abstract to the project's online page. All students and TERC scientists post questions and comments. After two weeks of discussion, teams post revised abstracts, using comments received. The teams conduct their project over the next 3 months and produce a final paper and a short video presentation.

Participants

For this paper, we analyze the data generated by five I2M teams during the abstract phase of the 2021-2022 competition: Eco Warriors (5 students in 10th grade), Team Imoto (2 in 12th grade), Wolf Pack (2 in 9th grade), Dream Team (2 in 9th and 2 in 11th grade), Carbon Cancelling Cougars (2 in 10th grade).

Data sources and Analysis

The data in this case study include: (i) The teams' initial abstracts, (ii) All discussion posts from students and scientists, and (iii) The revised abstracts.

Data were coded by three researchers to identify technical/science content, proposed design elements, categories of rationale, evidence adduced, and talk moves (Table 1).

Table 1 *Coding Scheme*

Code	Description
Say more	Asks for clarification of a statement or claim
Rephrasing	Restatement of what commenter thinks they read Ask for evidence
	Asks for evidence in support of a statement/claim Ask for reasoning/rationale
	Asks for description of thinking about a claim
Rationale: Authority	Explicitly cites an authority, (e.g., teacher, article) Rationale: Causal
	Relies upon an explanatory theory or concept
Rationale: Empirical	Based on empirical data, or absence thereof Rationale: Factual
	Asserts a claim as fact
Rhetorical	Aims to persuade, engage Challenge/counterexample
	Describes an exception to an idea Agree/disagree (and why)
	Asks others to agree/disagree with their point Add on
	Asks others to provide more information
New idea	Provides an additional new idea
Affect	Expresses approval, liking

Coded data were discussed by researchers. After coding was stable, a researcher wrote an interpretive research narrative about each team. Narratives were discussed by the research team to test inferences, identify issues requiring further analysis, and maximize the value of the data. Finally, cases were compared to identify differences and similarities of interest in relation to the research questions.

Results

Three of the five initial abstracts that the teams posted provided a rationale for their proposed designs that relied on statements of fact and unsubstantiated claims. For example, Team Imoto, proposing an innovation related to renewable energy generation, wrote, “Renewable energy can be produced from a multitude of ways, wind, solar, or even something as grand as nuclear. But something overlooked is the use of gravity in generating electricity. Using the force of the Earth’s gravitational pull, we want to create some device that will generate electricity by a turbine that is pushed by a flow of water from a rain gutter.”

In the discussion of abstracts, coding of statements from competition **participants** yielded (a) “Affect,” (b) “Add on,” or “Say More," and (c) “Ask for Evidence” as the most frequent codes. For example, Pranav

commented on Team Imoto's abstract, "Very unique idea. (Affect) 1. What materials will have to go into building this device? How accessible is it for people to obtain said materials?" (Add on, Say more). Ned, commenting on the same abstract, asked, "How would gravity be used to generate electricity? How much would the device cost? Would it be relatively simple? […] How would this collect drinkable water?" (Add on, Ask for Evidence). Commenting on Dream Team's abstract proposing to innovate on textile dyeing, Micah Red asked, "Some of your words are a little hard to understand. Could you please explain what a super-degrading microorganism is? Or give an example?" (Say more).

Scientists, on the other hand, tended to suggest new but related ideas, and to ask for reasoning. For example, Gina commented on Team Imoto's abstract as follows, "I wonder how you're thinking about its possible impact on reducing emissions. Will you measure the current produced, then do a calculation […] to come up with an overall guesstimate of greenhouse gas reduction?" (Add on, New Idea, Ask for Evidence and Reasoning). Commenting on the textile dyeing abstract, Benny asked, "Does it make a difference whether the dyes being used are plant- or mineral-based, as opposed to synthetics? I know weavers and spinners in my area […] believe these dyes are better for the environment. I am not sure it's true, though." (Add on, Ask for Evidence, New Idea, Ask for Reasoning).

Regardless of how probing the comments and questions were, the conversational exchanges between teams and commenters uniformly revealed productive reasoning and development of science practices. For example, the following exchange occurred in discussion of the Carbon Cancelling Cougars design, which was to find, and test overlooked hydrocarbons, e.g., household waste, as biofuels:

Brody: Great idea! Do you have any specific materials in mind for initial testing?

Ned: one of our chief areas of interest was the "reuse" part of the classic "reduce, reuse, recycle" mantra. This means that instead of disposing of things like cooking grease (often a waste product), one could use that to produce a fuel to use to cut down on gasoline usage. Not only does this reduce carbon emissions, it also cuts down on waste.

Benny: do you have a combustion system […] to test the different fuels with, or will you use a calorimeter and other sensors to evaluate heat output and emissions, or what?

Ned: the calorimeter would be a great tool for testing the output. We'll also be actually testing the different fuels in an engine (not sure of exactly what yet) to test efficiency, as that is also a priority (if the alternative is less efficient than the status quo, it's unlikely to be implemented).

Gina: I'm curious how you plan to do this critical piece of research [ID'ing wasted fuels] before you get to testing the candidates you've chosen. What criteria do you think you will use to make the decision?

Ned: To find such materials, we could ask around and take a survey (perhaps students/teachers/parents of our school?) to find what kinds of products are commonly wasted in everyday life. We would then compare what we know from the EPA of the chemical composition of these products to the goal of what is necessary for a biofuel.

Parag: Do you have an estimate (in pounds/tons) of the amount of greenhouse gas emissions that can be reduced with your idea? Moreover, how will you measure efficiency with regards to biofuels?

Ned: The estimate would be extremely variable based on how large implementation could be, as well as what metric we are going on, e.g., "how much does a gallon of biofuels reduce emissions?" As far as efficiency, what I'm talking about there is how useful the biofuel is compared to conventional sources.

In these exchanges we notice commenters asking for clarification, additional information, evidence, and elaboration of reasoning. Comments in turn elicited a series of elaborated statements that were empirical, causal, rhetorical and authoritative rationales that would contribute to a reshaped design.

The revised abstracts showed quite extensive elaboration of detail and reasoning. For example, the revised abstract from Team Imoto included the same idea of generating "hydro-power" from generators positioned in household gutters but the team elaborated the proposed mechanism thus, "The water will then be stored in a tank and with the help of a small pump, like the one used at UNITEC, will help to generate the electricity. The water can then be used, alongside a pump, to turn a microturbine and generate electricity. The type of generator so far that we are looking at is a cylindrical power generator which we thought about thanks to the idea from Benny." The rationale for their design was buttressed by citing an authority, and an explanatory concept. The team also provided a causal rationale, in connecting their device to mitigation, "Bringing it to a wide scale […] will help people in the fight against climate change because it will bring people energy independence from major fossil fuel companies and in turn reduce greenhouse gas emissions."

Likewise, the revised abstract from the Dream Team remained focused on innovations in textile dyeing but included more depth in detail and reasoning. For example, describing how untreated wastewaters are often dumped into nearby water bodies, the team explained that "Leftover dye water hinders penetration of light into affected bodies of water, impairing photosynthesis rates." Prompted by one commenter, they

provided a causal rationale for their design in linking impaired rates of photosynthesis to climate mitigation, "...carbon is sequestered in the world's bodies of water and the lifeforms that live in them such as fish and marine plants. Therefore, the overall health of these ecosystems is critical to combat climate change."

Discussion and significance

This paper provides preliminary evidence that a crowd-sourced challenge, situated in a heterogeneous community whose conversations are scaffolded by a shared purpose, can enable substantive STEM learning. As the exchanges between commenters and responders show, the abstracts gained empirical and theoretical strength as participants practiced "productive science talk." Research has shown that student uptake of productive talk moves generally only increases after the moves have been modeled in the classroom by a teacher (e.g., Murphy et al., 2018; Sedova et al., 2016), yet this type of discourse emerged without coaching in the I2M community. Furthermore, our findings show that this productivity – in discourse, in reshaped abstracts - was made possible by the diversity in expertise central to learning in a community of practice. Future research will focus on the impact of including additional crowdsourcing opportunities in the course of future competitions and on the microgenesis of concepts and practices in an extended, discourse-mediated design project.

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Promoting shifts in teachers' understanding and use of phenomena in instruction and assessment

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Abstract: This paper examines an online professional learning intervention to develop teachers' pedagogical design capacity to develop five-dimensional (5D) learning and assessment opportunities, which involve integrated use of science and engineering practices, disciplinary core ideas, and crosscutting concepts in science to make sense of phenomena and problems that are interesting to students and support students as knowers, doers, and users of science. We present findings from our design study, which suggest both the promise of such an approach and some of the challenges and tensions experienced by teachers as they chose and used phenomena to support 5D learning opportunities for students.

Introduction

An important focus of professional learning is to support teachers' development of pedagogical design capacity (PDC), that is, their capacity to create and adapt materials that can deepen their practice and improve student learning (Brown, 2002). Supporting this development is an intensive, iterative process that requires preparing teachers to choose, adapt, and create materials to align with instructional goals (Brown, 2009). This approach to professional learning acknowledges that teachers are in fact *designers* of learning opportunities for students, not just implementers of others' designs (DeBarger et al., 2013).

The purpose of this design study was to develop and test an online professional learning intervention for teachers to support them in designing and using assessments that are aligned to the vision of science teaching and learning articulated in *A Framework for K-12 Science Education* (National Research Council, 2012). Assessments that align with this vision are quite different from those typically used in science classrooms: they demand tasks that are compelling to students and require them to use science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) in science to make sense of phenomena and problems (NASEM, 2019; National Research Council, 2014). Bell et al. (2016) argued that the *Framework* presents a five-dimensional (5D) vision of instruction and assessment that not only includes a three-dimensional (3D) vision of science, involving the integration of DCIs, SEPs, and CCCs, but also two additional dimensions: engaging student interest and supporting students' identity development as knowers, doers, and users of science.

A particularly vexing challenge for science curriculum and assessment designers and teachers alike is choosing phenomena for instruction and assessment. Phenomena are observable events that students can explain using science knowledge and practices and are key to realizing the vision of the *Framework*, because they provide contexts for students to use the dimensions together to engage in science (NASEM, 2019). It is challenging to choose phenomena for instruction and assessment, because it is possible to choose phenomena that are interesting to students but that do not provide opportunities for students to develop and demonstrate understanding of 3D standards. Similarly, it may be possible to choose phenomena whose explanations address 3D standards, but do not connect with students' interests, experiences, and identities. What designers in any role need is a type of "design know-how" (van den Akker, 1999) for choosing and using phenomena that support students' 3D understanding, while also accounting for their interests and identity development. This paper explores how we supported the development of this "design know-how" or PDC with rural teachers in the context of an online professional learning intervention.

Description of our intervention

Our intervention is an online adaptation of a two-day, face-to-face workshop series to help teachers design assessment tasks aligned with the NRC (2012) *Framework*. Penuel et al. (2019) found that teachers who participated in these workshops improved the quality of their designed tasks. Building on this work, we identified five PDC areas that teachers need to develop 5D instruction and assessments, namely their capacity to 1) "unpack"

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the targeted 3D understandings found in the standards, 2) learn about their students' interests and prior experiences with science, 3) understand what phenomena are and how they can be used to frame instruction and assessment, 4) choose phenomenon contexts that are engaging and productive for students to develop and demonstrate targeted understandings, and 5) develop assessments that prompt students' integrated use of the 3Ds to explain phenomena. These areas are interconnected, as teachers' unpacking of standards and understanding of their students' interests influence how they choose phenomena and design prompts that support student sensemaking and identity development. In this paper, we explore how our intervention supported teachers in understanding the purpose and value of using phenomena and the challenges involved when choosing appropriate phenomena to frame instruction and assessment opportunities.

We used a storyline approach (Reiser et al., 2021) to design three sets of lessons and tools to support the development of teachers' PDC. Teachers engaged in 25 hours of synchronous, online learning over nine afterschool sessions during Fall 2021, with additional asynchronous work and opportunities for feedback between sessions. In Lesson Set 1, we co-developed with teachers a 5D, *Framework*-aligned vision of instruction and assessment. We introduced teachers to tools designed to help them elicit information about their students' interests and science-linked identities and unpack the targeted 3D understandings from the standards. In Lesson Set 2, we co-developed with teachers characteristics of phenomena that would help students achieve the targeted 3D learning goals, engage student interest, and support students' science identity development. Using these characteristics and tools, teachers identified and evaluated candidate phenomena and developed assessment scenarios that included data to present these phenomena to students. In Lesson Set 3, teachers collaboratively analyzed examples of phenomenon-driven assessments from different grade bands and content areas and developed and administered their assessments to their students. Using evidence from student work and surveys, teachers developed rubrics to make claims about students' 3D understanding and provide feedback.

Methods

This design study involved three middle and eight high school science teachers from two rural districts and two facilitators. All teachers were beginning to implement their state's 3D standards. To analyze how our intervention supported teachers in understanding, choosing, and using phenomena, we analyzed data sources from the second lesson set (Sessions 4-6, 7.5 hours), when teachers began integrating the PDC areas named above: (1) field notes, which synthesized detailed descriptions of the facilitation and teachers' engagement with the ideas and tools, (2) virtual artifacts that documented shared thinking, and (3) exit tickets, where teachers shared how each activity met the session's learning goals. Analysis of data sources involved identifying each instance where teachers discussed or wrote about phenomena. In the context of the intervention's designed learning trajectory, we characterized teachers' ideas about phenomena and the "rules of thumb" they developed for choosing phenomena. Since teachers were new to 5D instruction and assessment design, we identified challenges that teachers named or encountered when designing with phenomena. We created and discussed analytic memos and identified themes about how teachers understood and began to use phenomena and the 5Ds in design.

Findings

Our paper focuses on the shifts and tensions observed in teachers' considerations when choosing phenomena.

Teachers deepened their understanding of the role of phenomena

The intervention's planned trajectory was designed to deepen teachers' understanding of the considerations that they needed to think about when choosing and using phenomena. Teachers posted their initial definitions and characteristics of phenomena on a digital interactive whiteboard (i.e., Jamboard). Teachers focused initially on two aspects of phenomena: (1) they should be "observable" and involve "real world" situations and (2) they should be "engaging" and prompt students to wonder or ask questions. These aspects of phenomena aligned with two dimensions: engaging student interest and creating authentic situations that could support the development of practice-linked identities. However, only two of the initial 29 characteristics connected the use of phenomena to the development of scientific understanding. Leveraging these initial ideas, facilitators engaged teachers in an activity to use these characteristics to evaluate candidate examples of phenomena. These examples varied in intentional ways to allow teachers to distinguish between phenomena, which foregrounded observations for student sensemaking, from non-examples, which included concepts or "big ideas" (e.g., evolution) or components of an explanation that could be used to explain a phenomenon. Through this activity, teachers clarified and iterated upon their ideas to develop "rules of thumb" for identifying phenomena and lenses for making examples more "phenomenon-like". For example, teachers clarified that phenomena were not "scientific facts" for explaining a phenomenon. One teacher shared that a card that read, "Chlorophyll causes plants to appear green" was a "scientific fact" that could be used as part of "a good explanation of a phenomenon," but was not a phenomenon

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(Session 4 Field Notes, 9/21/21). Upon reflection, a teacher shared why it made sense for phenomena to focus on what was observable rather than components of an explanation, "when you explain it in detail, it's just spitting out facts - not leaving space for the students themselves to question and figure it out. It needs to not be fact, but something that leaves room for learning" (Session 4 Field Notes, 9/21/21). Thus, this teacher connected her understanding of what phenomena are to the role that phenomena play in inviting students to wonder and support student sensemaking in service of the desired learning goals.

Although teachers could articulate what phenomena were *not*, teachers continued to encounter challenges with describing phenomena as observations to be explained. After discussing our rules of thumb for identifying phenomena, one teacher desired to apply what they had to learned to describe what the phenomenon was from that session, where teachers watched a time-lapse video showing a badger decomposing on the side of the road. When describing what the phenomenon was in the video, the teacher described the explanatory processes involved ("the multiple stages of decomposition the badger include"), while another focused on the medium used to present the phenomenon ("the time lapse video of a dead badger") (Jamboard, 9/21/21). In response, the facilitator pressed teachers to think about what the students observed, which helped teachers to describe the phenomenon as the disappearance of the dead badger over three days. Thus, deliberating on our description of the phenomenon helped teachers refine their rules of thumb for describing phenomena, which was an important stepping-stone for designing 5D learning opportunities for students to make sense of phenomena.

Teachers experienced design tensions when choosing phenomena

The intervention used three key tools to support teachers in developing 5D, phenomenon-driven learning opportunities for students: 1) the *Student and Community Interest Inventory* to elicit understanding of students' interests and science-linked identities, 2) the *Unpacking Tool* to analyze the targeted 3D understandings at grade band, and 3) the *Choosing Candidate Phenomena Tool*, which used findings from the first two tools to evaluate the appropriateness of phenomena and choose data sources that invited student sensemaking using the targeted 3Ds. While teachers made progress with considering how phenomena could frame 5D leaning opportunities, teacher required additional support, even with the support of tools, when developing their own assessments. We describe some of these challenges and tensions below.

Weighing student interest with 3Ds when choosing phenomena

In the course, teachers considered how students' explanations of phenomena could support students in developing and demonstrating an understanding of the target DCIs. At the same time, teachers were expected to consider student interest and identity as well. Several teachers came to appreciate the design challenge of designing for all 5Ds and not just the 3Ds foregrounded in standards documents. For instance, one teacher wrote, "It is actually harder than it seems to come up with compelling phenomena that can be used to both grab students' attention and get at a deeper understanding!" (Session 6 Exit Ticket, 10/5/21). Facilitating conversations around these tensions helped to develop teachers' lenses for evaluating and enhancing phenomena. In one task, teachers chose between two phenomena to help students demonstrate a high school chemistry standard (HS-PS3-4), "Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system". One teacher in a small group discussion argued for using hot springs as the phenomenon, since she felt it was *better aligned with the target DCIs*. In contrast, another teacher argued for melting polar ice caps, because she thought it would be *more compelling and relevant to students*. She contended, "That's going to get the interest of the kids! […] If my aunt is affected because she lives in Key West, they're going to say, 'The scientists need to monitor it!'" (Session 5 Fieldnotes, 9/28/21). In response, the first teacher offered ideas for enhancing the DCI alignment of the melting polar ice phenomenon by foregrounding the contact between warmer ocean water and the polar ice to show how "the transfer of thermal energy when two components of different temperature are combined" (HS-PS3-4) could explain the phenomenon (Session 5 Fieldnotes, 9/28/21). In this small group discussion, we observed tensions when considering a phenomenon's 3D alignment and its interest to students. However, the group found a way to consider both lenses to enhance the 5D-alignment of phenomena and the importance of content expertise when choosing and enhancing phenomena.

Weighing authenticity of data sources for assessment scenarios with 3D learning goals

Facilitators intended to focus on the use of scientific data as one of several ways to present a phenomenon to students when designing assessment scenarios. Some teachers became overwhelmed by the search for data. For example, one teacher shared, "I had to stop halfway through and do some deep breathing, because it overwhelms me. Do you know how long I spent searching for data, local data - searching, searching, searching for an entire day. It's just a lot of time" (Session 6 Fieldnotes, 10/5/21). Teachers analyzed an example assessment that used

modified scientific journal data to support student sensemaking, which may have contributed to feelings that the inclusion of scientific data was essential to scenario development. In conversations with teachers, facilitators recognized that some teachers lost sight of the purpose for using the data, which was to present the observations or information needed to support student sensemaking of the phenomenon. To alleviate this tension, facilitators attempted to broaden teachers' vision for the type of data that would be needed to meet their targeted 3D goals and pointed them to resources for finding data or phenomena that could be adapted.

Conclusion

Phenomena are key to realizing the vision of the *Framework;* but, choosing phenomena that align with targeted 3D learning goals, engage student interest, and support students as knowers, doers, and users of science is an ambitious and complex design task. The lack of examples of high quality, phenomenon-driven assessments highlights the need for interventions to develop teachers' capacity to design 5D assessments. Our intervention has designed tools to help mediate this work, and our initial findings suggest that teachers improved in key PDC areas that can support them as designers and adaptors of existing materials. Although our research surfaced challenges and tensions that teachers face when engaging in this work, our intervention created time and space for teachers to process and apply what they learned with support. All instructional and assessment examples used in the intervention came from freely available materials, so that teachers could have a model from which to base their designs and consider ways to implement what they have learned in instruction. To summarize, our initial findings suggest that when used in a collaborative context, the intervention tools can foster the development of teachers' capacities to act as designers of 5D learning opportunities for students.

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Balancing Agency and Accountability to Support Learning in Playful, Embodied Science Activities

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Abstract: Student agency is important to support in learning environments, as it enables students to control their learning and can lead to new understandings of content. Yet, there are many questions about when and how to hold students accountable for content learning while still fostering their agency. This paper examines data from a first-grade classroom, in which students embodied bees in the STEP (Danish et al., 2020) mixed-reality environment in order to learn about nectar collection and pollination. We analyze the ways in which student agency and accountability interacted in the embodied learning space and led to engagement with science content. We describe patterns in how student agency can support sensemaking as students navigate different sources of accountability and we discuss productive ways to balance agency and accountability in embodied learning environments.

Introduction and framing

Student agency has long been seen as an important part of science learning. It provides new roles and voice to students (Barton et al., 2010), and enables students to actively generate disciplinary knowledge (Cavagnetto et al., 2020). While agency has been defined in several ways across education and psychology, we find it productive to view agency from a sociocultural perspective. We build on sociocultural theories of learning, which highlight how cultural ideas and artifacts mediate learning (Engeström, 1987; Vygotsky, 1978) to view student activity as individuals-operating-with-mediational-means (Wertsch, 1993). Agency, then, is not something that students possess or do not, but instead can be conceptualized as the mediated actions that students have opportunities to, and choose to, enact within a classroom activity system. In this view, it is important to consider what features of the classroom environment support or limit students' ability to exercise agency and how they do so. In our work on embodiment, we have found that activities where students use gestures, body positions, and movement to represent and explore their ideas can provide new opportunities for, and constraints on, student agency (Danish et al., 2020). Students often have the freedom to move however they want, yet their peers' motion or the software environment also constrain the impact that their movement has on the system being explored.

The goal of this paper is to examine the ways in which particular features of an embodied learning activity influenced student agency and supported student learning. We focus specifically on understanding the role of *accountability.* Agency and accountability are often dichotomized as opposites, in which agency is good and accountability, structure, or teacher authority should be minimized. However, in an academic setting, students often need to be held accountable to disciplinary practices and content, and so the question shifts to how agency and accountability should be balanced in the classroom in order to foster learning (e.g. Danish & Enyedy, 2006). In embodied environments in particular, students act and interact in ways that are different from many science classrooms (Danish et al., 2020; Lindgren & Johnson-Glenberg, 2013), which necessitates new understandings of how agency and accountability function. Therefore, we ask the following research questions:

1) How do students take up agentic roles in embodied learning experiences?
2) How do interactions between agency and accountability in embodied activities influence the learning of scientific content?

Methods

Participants and data sources

This work examines data from the Science through Technology Enhanced Play (STEP) project (Danish et al., 2020). In this project, 11 students from a small public school in the midwestern United States participated in collective embodied activities in a mixed-reality environment, in which motion tracking software captured student movement and depicted students on a screen as bees in a field (see Figure 1). This analysis focuses on the group of students participating in a series of eight lesson plans focused on understanding honeybees, nectar collection, and pollination (see Danish et al., 2020 for similar studies). The classroom teacher and several researchers served as instructors of the unit.

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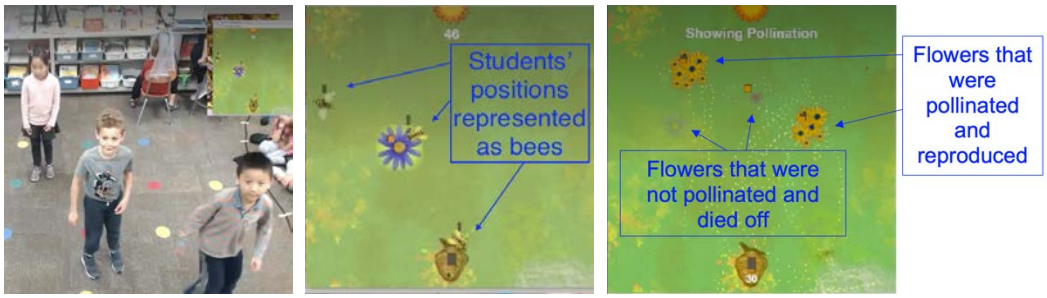

Figure 1. Students tracked by STEP (Image 1) and the projected STEP simulation (Images 2, 3)

Analysis

We began by reviewing video footage including screen recordings of the STEP simulation of the whole lesson sequence, and logged moments where agency or accountability were salient. Based upon this first pass, we selected moments for further analysis in which interactions between accountability and agency seemed to be productive for the learning of scientific content. We iteratively reviewed these moments by articulating and refining conjectures about the role of agency and accountability in supporting learning. In the present analysis, we present patterns that we observed across the lessons, and then focus on one activity that occurred on the sixth day of the sequence where students learned about pollination. We selected this illustrative example, in which student agency seemed to positively impact learning, because we were interested in highlighting the potential value of student agency in this kind of embodied design. Note that while episodes had varying levels of student agency, many had similar moments and we selected this particular episode because of the many interactions between agency and accountability that were concentrated in one sequence. We use interaction analysis (Jordan & Henderson, 1995) to consider how students interacted with each other, the instructors, and the simulation, and the ways that the activity oriented students to behave in agentic ways or notice different sources of accountability.

Findings and discussion

Patterns across the lesson sequence

Our first research question asked how students take up agentic roles in embodied learning experiences. Across activities and days, we noticed a stark contrast between the limited agency that students were afforded in teacher-led discussions about content (where students could choose to answer a question or not), and the more flexible agency that they were afforded in the embodied activities (where students had agency to act, speak, and model in ways that they decided). In the embodied activities, one way that students acted agentically was by making decisions about where and how to move in the space. In some cases, students' movement choices were influenced by the way that the system responded to their behaviors. For example, some students chose to crouch down, but when they did so, they lost the nectar that they had collected because the system could no longer see them. As a result, students stopped choosing to behave in this way and stood up tall. In addition to the ways in which students decided to move, they also had agency to call out and direct other students' actions. That is, as students watched others engaging in movement, they often took it upon themselves to hold their peers accountable to the content, particularly through comments like "get the nectar to the hive!" Students that were directed by other students had agency to listen or not, prompting them to navigate sources of accountability in relation to their own goals.

Our second research question asked how interactions between agency and accountability influenced the learning of scientific content. In this designed space, we found that there were several competing sources that students needed to be accountable to, including the instructors' suggestions, other students' suggestions, and the software. The presence of these competing accountabilities gave students the agency to determine which ones to follow, and why. We argue that in exercising this agency, students explored and made sense of the underlying rules that are a part of accountability, leading to learning of the target content.

Illustrative case: Agency, accountability, and learning about pollination

In this case, we focus on the agency on one particular student, Tom (though other students also acted in agentic ways), and how that agency enabled the class to learn more about the process of pollination. Prior to this episode, students had just finished a round of embodied activity in which they acted as bees to visit flowers, and then saw that the next spring, most of the flowers died, but one was replaced with many other flowers because it had been pollinated. Students held many diverse ideas about the ways that bees pollinate flowers, including that the one flower grew back the next spring because it had more nectar left, because it got the least pollinated, because visiting multiple flowers pollinates them, and because flowers get pollinated when bees go to the same type of

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flower (to which another student disagreed). The current episode began after Tom exercised agency by suggesting that to pollinate the flowers, the bees needed to visit the big yellow flower on the right and then the big yellow flower on the left. An instructor took up Tom's suggestion and engaged the class in testing that hypothesis. Tom was the first student to enter the field as a bee and he went straight to the yellow flower to collect its nectar:

(1) Instructor 1: Okay, so now go to the other one.
(2) Instructor 2: You can go to the other one, Tom.
(3) Tom: Wait, I'm full though, so I can't go anywhere. *(walks backwards towards the hive)*
(4) Caleb: Yeah you can.
(5) Instructor 2: Okay, come back quick.

In this interaction, Tom encountered competing sources of accountability: being accountable to the instructor for the pollination plan that he created, and being accountable to the software for the behavior of bees (when the bee is holding the maximum amount of nectar that it can, it needs to drop it off at the hive). In line 3, Tom exercised agency by deciding to behave as a bee would by moving back towards the hive, instead of adhering to his pollination plan. Another student argued that Tom could actually move wherever he wanted (line 4), while an instructor gave him permission to enact agency by following his choice of accountability source. In doing so, Tom was able to engage in sensemaking around the behavior of bees.

After Tom returned to the hive, an instructor sent Jade into the embodied space. While instructors served as one source of accountability for students, reminding them of Tom's idea throughout the embodied experience, Tom also had agency in holding his peers accountable to his idea, who also had agency in how they followed up:

(1) *(Jade walks out to a purple flower)*
(2) Instructor 2: We're going to the yellow ones, Jade.
(3) Jade: Oh. *(moves to a yellow flower)*
(4) Instructor 2: The two big yellow ones are the ones we're going to. That was what Tom had suggested.
(5) Instructor 2: Drop it off, you've got to pay attention.
{33 seconds pass with other students entering and leaving the space}
(6) Tom: Try the other yellow one, I'm the only one who's went there.
(7) Instructor 1: Yeah, make sure you go from one to the next. You could fill up a little bit on one.
(8) Caleb: You're filling up all on just one. They're just filling up on one!

Accountability played a positive role in this exchange in that reminders to follow the rules ensured that students would be able to see the results of Tom's plan. In line 4, an instructor held Jade accountable to the original plan, and specifically positioned Tom's ideas as a valuable contribution. In addition to instructors enforcing accountability, Tom and Caleb made suggestions to the embodied participants. The instructor's comment on line 7 reinforced the norm that students have agency to make suggestions by ratifying Tom's comment from line 6.

There were several components of students' agency in relation to accountability that led to engagement with the scientific concepts. Tom's agency to suggest an idea, to choose to be accountable to the rules of the simulation rather than to the teacher, and to hold students accountable to trying his idea all helped students to learn about how pollination works. When the embodied experience ended, students were successful in pollinating the yellow flowers and were able to articulate what bees needed to do for pollination to occur:

(1) Instructor 1: Okay, so let's see what happens the next spring. *(Figure 1 Image 3 is displayed)*
(2) Students (overlapping): Ooohhhh! That's awesome!
(3) Instructor 1: So what'd you notice?
(4) Tom: That you have to go to the same flower.
(5) Diana: No!
(6) Tom: No, that you have to go to the same type of flower.
(7) Instructor 3: So Diana, what do you think?
(8) Diana: It helped going to different flowers. But it would help if we would go to the purple flowers. If there was like two purple flowers, you could go to both of them, and two yellow ones.

Not only did students articulate that their method, going from one yellow flower to another, was successful in pollinating the yellow flowers, but in line 8, they extended their explanation to say that if they had also visited two purple flowers (a different kind of flower), those flowers also could have been pollinated, suggesting that they

had begun to recognize the importance of visiting flowers of the same species as indicated by color. Students continued to discuss what happened and their theories of pollination. The episode concluded:

(1) Instructor 1: So do bees plan like that, you think, or it just happens?
(2) Students (overlapping): It happens.
(3) Instructor 1: Yeah, but what about flowers makes bees want to go to them to make that happen?
(4) Tom: Cause they want to get nectar, but they accidentally pick up pollen and they go to different flowers, the same bees.
(5) Instructor 1: Good, so lots of good nectar is what will draw bees to the flowers.

Tom articulated that bees' primary goal is nectar collection, and that pollination is a byproduct of that process. Perhaps his desire to drop off his nectar rather than visit the next flower during the embodied activity helped to prompt this realization for the class. A multiple-choice assessment provided additional evidence that students learned about how pollination works. Students participated in a pre and post test before and after the series of eight lessons, in which four questions about pollination were posed. Students scored significantly better on this set of questions on the post-test as compared to the pre-test, $t(9)= -2.058$, $p < 0.05$, one-tailed. Note that one student declined to participate in the multiple-choice assessment.

Implications and conclusion

In our analysis, we found that embodied activities broadened the types of agency available to students as compared to traditional teacher-led discussions. That is, students enacted agency through choosing where and how to move, holding their peers accountable to ideas and content, and navigating competing sources of accountability. This work suggests that accountability does not necessarily have to limit student agency. Having multiple sources to be accountable *to* (instructor(s), the other students, and the rules of the software/technology) and being accountable *for* multiple ideas (in this case, for enacting a pollination plan and for collecting nectar) enables students to understand that rules are not just for following, but for making sense of. When students had agency to make sense of competing sources of accountability, they gained nuanced understandings of content. Therefore, designers of learning activities should consider how to create an environment where multiple, competing sources of accountability are present, and where students are given agency to both act as and to navigate these sources.

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Constructing a Mathematical Identity as an Adolescent Black Girl

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Abstract: Recent literature within mathematics education has begun to focus on identity and its effect on students' self-perception as mathematical learners and doers, as it shapes every part of a students' life, including their relation to mathematics. This study investigates the construction of mathematical identity for a middle school Black female mathematics student, Crystal, over the course of her sixth grade year. The student was observed in her online and in-person classroom and interviewed after school to gain insight into her mathematical identity. Selected interview data centered on discussions of identity were analyzed to generate an understanding of how her mathematical identity was crafted, and how this influenced her as a mathematician. This study emphasizes the importance of voice scholarship (Ladson-Billings, 1995) in spotlighting an oft-forgotten group to broaden research about their mathematics education experiences.

This case study considers the following research question: *What are the factors associated with Black girls' mathematical experiences, and how do they inform the construction of their mathematical identities?* I ground my research on McGee's (2015) construct of fragile and robust identities, a framework the author used to survey the intersection of mathematical and racial identities relative to the mathematical experiences of Black undergraduates. Mathematical identity construction involves the intersection of a plethora of factors including students' personal experiences, and McGee (2015) argued that for Black students in particular, mathematics education researchers should also consider race as a dominant factor. Black students arrive at school with their own knowledge (Freire, 1968), and for them, this includes knowledge of racialized experiences and events they encounter, all of which contribute to their mathematical identity.

For Black girls like Crystal, mathematical identity research is critical because their self-perceptions about their mathematical competence are highly related to their social identity as members of two minoritized identity groups. Evans et al. (2011) emphasized the importance of examining multiple identities jointly, as one's identity is a conglomeration. They claimed that even if identities may be hierarchically ordered, intersectionality, rather than additivity, must be the focus. In comprehending how Black girls craft their mathematical identities, it is crucial to understand what it means to learn mathematics while being both Black (Martin 2012) and a girl (Kurtz et al., 2008).

Methods

I engaged in a year-long study of Crystal in her mathematics classroom at a public suburban middle school in the Northeastern United States. This school was composed of approximately 71% White, 13% Black, 6% Asian, 5% Hispanic, 4% multiracial and non-Hispanic, 0.2% Native American, and 0.1% Native Hawaiian and Pacific Islander students. Nearly 11% of students are economically disadvantaged. Potential participation was limited to all Black girls who volunteered and whose parents consented across three sixth grade mathematics classes. Due to difficulties in recruiting during the first full academic year during the COVID-19 pandemic, as well as having to withdraw a student for inconsistent participation, Crystal was the single study participant. She identified as a Black girl with parents who immigrated from Nigeria, and she attended sixth grade through the full remote model up until mid April 2021, when she switched to being fully in person, per State and District orders for all students to return to K-12 schools.

There were three rounds of observations and interviews from February to June 2021, and following each one of these rounds of observations were interviews after school that lasted up to 30 minutes. In total, there were 10 interviews conducted. In these interviews, Crystal was asked follow-up questions related to classroom lessons, as well as questions about her identity more broadly. Due to limitations of online class observations (e.g., Crystal's choice regarding camera and microphone usage) to examine Crystal's interactions with her peers or teachers, there was nominal data relevant to her identity in the classroom data. Conversely, much of the interview data related specifically to identity, the focal point of this study. As a result, only the interview data were selected for analysis. For one of the 10 interviews, I used a guided protocol, the Multidimensional Model of Black Identity (MMBI; Sellers, 2013) which included statements related to identity. This interview was not selected for analysis as the questions' central focus on identity influenced Crystal's answers, providing less spontaneous responses on her part.

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I then transcribed each of the nine remaining interviews. In order to further pare down my dataset, I used a grounded approach (Glaser & Strauss, 1967) using ideas in formation (Charmaz, 2006) to identify emerging themes in the transcripts, highlighting those themes which repeated throughout all transcripts (see Data Analysis section). Identity was an obvious theme, but others emerged throughout my analysis. Thus, I decided to select only the interviews in which Crystal conveyed or explicitly suggested identity in our conversations at least once. In total, there were nine interviews selected.

Along with two other coders, we developed a coding scheme through a line-by-line review of the interview transcripts. We noted themes that were referenced in the transcript lines, which were the following: (1) affect, (2) expectations, and (3) identity. Using Merriam-Webster Dictionary's definitions, affect is defined as: "the conscious emotion that occurs in reaction to a thought or experience." Expectations are social norms around what others consider "reasonable, due, necessary" or expected of someone. I define identity by extending McCarthey and Moje's (2002) definition: it is comprised of social and/or personal constructions about self that can vary over time and contexts that shape or are aspects of how humans understand the world around them and how they too are understood.

I coded every line of the transcripts to identify these themes, and used an utterance as my unit of analysis, focusing only on Crystal's utterances. I define an utterance to be a single line of verbal discourse by a speaker, bound on each side (i.e., beginning and end of an utterance) by utterances from another speaker. Utterances could be coded for multiple themes and sub-themes (see below). To ensure the reliability of my coding, a second training coder with a PhD in mathematics education and I each independently coded 20% of the transcript data (i.e., two interview transcripts) for the three themes; this also accounted for 20% of the total interview time (1). The second coder and I had an 84.71% agreement.

I then returned to the nine interview transcripts to identify sub-themes (Saldaña, 2013) to gain a deeper understanding of how all of the themes materialized and shifted over time. The respective sub-themes, which all fall under the expectations theme, shown in Table 1, are: (a) personal expectations, (b) parental expectations, and (c) societal expectations.

Table 1.
Sub-themes used in coding of data.

Sub-themes	Definition	Example
Personal expectations	Personal beliefs about what is considered "reasonable, due, necessary" or expected (using Merriam-Webster Dictionary definition of "expect").	*"Math is one of those things that you just have to do."* ***February 4, 2021, Line 71***
Parental expectations	Messages parents/guardians convey to children relative to their beliefs regarding what is considered proper and necessary (Parsons et al., 1982).	*"And my parents kept-, kept on telling me, 'make math your friend'."* ***April 30, 2021, line 179***
Societal expectations	Normative beliefs fostered by others in the social environment (Joseph et al., 2020).	*"They just portray [school] as a horrible place that you should never wanna go to."* ***February 4, 2021, line 139***

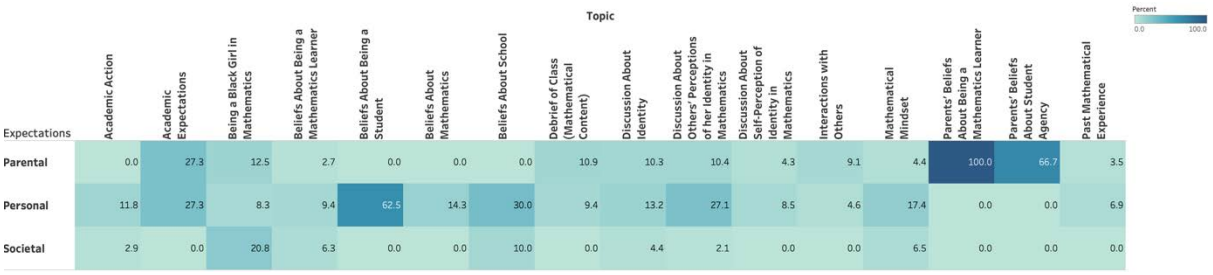
After refining the sub-themes, I shifted my attention towards identifying what may have prompted Crystal to answer my questions in particular ways, to learn more about Crystal's relationship to mathematics. For example, were there types of questions associated with specific sub-themes, and could any shifts identified be explained? I considered each coded utterance in context to explore this, looking at how these themes shifted across the three rounds of data collection. I did this by first identifying the topics covered during our discussion, and calculating the percentages of each sub-theme in her discourse about the topics. These shifts were used to then construct my study's claims.

Findings

Figure 1 displays a heat map of all nine interviews in which Crystal participated over the course of her 6th grade year that had utterances coded for expectations. On the top of the heat maps are the different topics discussed across all interviews, which were identified from examining the questions from the interview protocol. These

topics are alphabetically ordered. Gaps in the heat maps are a result of the lack of topic and sub-theme overlap. Cell shading corresponds to the intersection of sub-themes and topics. The lightest shade denotes lower percentages of these occurrences, while the darkest shade denotes higher percentages. For example, 62.5% in the personal expectations row means that 62.5% of the utterances across the nine interviews had an overlap between personal expectations mentioned by Crystal and a question from her about her beliefs about being a student. The column width of the topics do not denote the length of interview time spent on them.

Figure 1 *Heat map comparing Crystal's utterances coded for expectations for all the three rounds of data collection.*



Of her utterances about beliefs about being a student, 62.5% of them were coded as her personal expectations. For instance, Crystal leans into perfectionism, believing that mistakes are a negative mark on one's competence. She reflected on her negative 5th grade mathematical experience:

> 98 Crystal: All I know that, is that in 5th grade, I kinda varied. But most of the time, what I [inaudible]. I didn't really like 5th grade [inaudible] is that oftentimes I would, I would get in this habit of pouting during math class.
>
> 101 Crystal: Uh, most of it because of a bad score, or I felt as though I was, you know, low self-esteem. I thought I was dumb, I was getting things wrong. I thought everyone knows this but I don't. So, what's wrong with me? (*April 30, 2021 Interview*)

She continues this thinking in sixth grade:

> 134 Crystal: Like, some people accept their mistakes, except I'm just one of those people that don't like them.
>
> 135 Sophia: Mhm. What-, what do you think-, what don't you like about your mistakes?
>
> 136 Crystal: Well, I don't know. I just-, I just hate, uh. [inaudible]. OK, so bottom line, I'm the kind of person that likes to be right.

Though initially this understanding may seem to be isolated as her own expectation, it was in fact connected to her familiarity and interpretation of societal and parental expectations. Joseph et al. (2019) claimed this is true for all students, as their academic identities are a mix of how they, their families, and others see them. Crystal's parents wield momentous power in her understanding of what it means to be Black and learning mathematics. She acknowledged that despite her parents informing her that "Black people are really, really smart" (February 23, 2021 interview, line 204), "[Black people] have to work twice as hard as a White person might work" (June 8, 2021 interview, line 49). Crystal had a keen awareness of societal expectations about mathematics which implies that mathematics learners are not typically perceived to be Black or female. In speaking about the lack of Black women in the mathematics field, Crystal said this:

> 237 Crystal: Maybe they-, maybe th-, they want to get into the math field, except-, e-, e-, except all the-, all these White people th-, th-, that-, all these White people th-, th-, that are part of the math field are like, "you can't do this. You can't be in the math field. Get out of here!" (*February 23, 2021 Interview*)

Crystal's parents' expectations themselves are rooted in societal expectations for Black students and subsequently, a desire for Crystal to achieve well. This undoubtedly affected her own personal expectations. As evidenced by the heat map above, in addition to her beliefs about being a student, Crystal's utterances related to her personal expectations were centered on topics related to ideas she had conceived about school (30%), academic expectations (27.3%), and discussion about others' perceptions of her identity in mathematics (27.1%). And yet, 100% of her utterances across the interviews about her parents' beliefs about being a mathematics learner were coded as her parents' expectations. Contrastingly, 0% of her utterances about the same were coded as her own personal expectations. I contend that this is because Crystal's own expectations were actually rooted in her interpretation of her parents' expectations for her.

Conclusion

In McGee's (2015) three-component framework, a fragile mathematical identity is based on the "delicate" (McGee, 2015, p. 604) relationship between a Black student's mathematical achievement and their constant racialization sustained in doing mathematics. Contrastingly, a robust identity centers on the resilience and fortitude these students develop and exhibit in spite of racialized mathematics experiences to maintain the necessary motivation for mathematical achievement. Crystal was extrinsically motivated to achieve highly in mathematics due to her parents' expectations, which were based on societal expectations for Black students. According to McGee (2015), this means her mathematics identity is fragile.

There are several limitations to this study, one of which is the fact that this is a single case study, which is not generalizable. Nonetheless, for students like Crystal, their attitudes about mathematics cannot be examined as existing in a silo, but in combination with external factors, especially race, which is often a dominant factor for identity. Next, Crystal's identity as a child of immigrants adds a different dimension to identity construction that my study does not address. This would certainly be a unique experience that cannot necessarily be extended to other Black girls.

Endnotes

(1) The total interview time was 3 hours, 53 minutes, and 20 seconds, and 20% of this time was 37 minutes and 47 seconds.

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Organizing Outreach for Cultural Transformation: The Design of a STEM Education Learning Pathway

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Abstract: This case study leverages the Nasir et al. (2020) *learning pathways* framework to examine the relationship between learning environments, activities, roles and responsibilities, as well as social interactions taking place in a collegiate STEM outreach program. Using observational, survey, and interview data collected from three groups of instructors and learners in both university and high school settings, we identify how the course participant structure and distributed system of activities helped to engender university students' participation, identification, and transformation. We highlight how students embarked on a transformative identification process with STEM fields and broader intellectual identities as they undertook multiple roles and responsibilities in different learning sites and timescales. Our study suggests an innovative model to enhance the design and enactment of university-based outreach efforts to support alternative, culturally transformative pathways in STEM.

Overview and significance

Like many STEM fields, engineering seeks to attract a diverse population into the field. But becoming an engineer is complicated and dehumanizing endeavor for many identity groups, who experience being marginalized and pushed out (Adams et al., 2011; Stevens et al., 2008). Cultural change is needed to create more just, equitable, and humane learning environments. In this paper we examine two linked environments—one in higher education and STEM education settings in rural high schools. Rural US settings are under-resourced and under-researched (Lavalley, 2018), and have challenges in recruiting teaching staff (DeFeo & Tran, 2019), and in preparing students for engineering (DeUrquidi, 2019). We describe the organization of a university outreach program based in a college of engineering, who partners with high school STEM teachers. This program has tools and cultural practices to support learning pathways (Nasir et al., 2020) for two groups: (1) higher education graduate and undergraduate engineering students (whom we call "mentors") interested in educational outreach; (2) high school students taking STEM education courses (whom we call "students"). This paper focuses on the university mentors.

Literature review and conceptual framing

The program utilizes a *project-based learning (PBL)* approach that seeks to promote students learning by doing as they collaboratively pursue endeavors that are authentic to them and to disciplinary practices, while teachers facilitate students' investigations (Boardman et al., 2021; Miller & Krajcik, 2019).

We employed Nasir et al.'s (2020) *learning pathways* conceptual framework to guide our analysis. Learning pathways are culturally organized trajectories of positioning, participation, and identification. The framework advances two key ideas: a) how access, resources, and experiences of learning, while multidimensional and intersectional, are socially and institutionally driven and b) how learning as a process of navigating and interacting with cultural practices and values always evolves in relation to identities. The framework takes as a unit of analysis *cultural activities*, encompassing practices, interaction, artifacts, and objects that support how an individual is "socialized into navigating and understanding" their learning and development (p. 205). We applied three characteristics of learning from the framework: (1) how *identification* is based on relationality, affect, and motivation, (2) how *learning* is accomplished through cultural practices and routines distributed across persons, time, and space, and (3) how *privilege and marginalization* are enacted within structures.

To understand how *learning* is accomplished through cultural practices and routines distributed across persons, materials, time, and space, we utilize the concepts of participant structures, activity structures, and hybridization. Philip (1972) described *participant structure* as the organization of roles and responsibilities in a learning environment, which is one aspect of division of labor (Engeström, 2001) widely taken up in learning sciences (Sandoval, 2014). Within a participant structure, *role assignment* influences learners' social, linguistic, and cognitive development (Herrenkohl & Guerra, 1998). *Distributed activity structures* delineate sequences of activities, milestones, and artifacts, all tying to disciplinary goals (Polman, 2004); this perspective describes how students appropriate the tools they use during activities as their own, thus learning and developing new identities, under the guidance of teachers (Polman, 2004). In *hybridized learning,* people carry out hybrid cultural (Gutiérrez et al., 2019) and boundary-spanning (Buxton et al., 2005) practices. Examples of successful hybridized learning

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space include the Fifth Dimension (Cole & The Distributed Literacy Consortium, 2006) and related efforts (DiGiacomo & Gutiérrez, 2017) which have bridged university teacher education and learning sciences coursework, and many more in museums, libraries, and communities.

Context and Methods

This analysis is drawn from a university-based science and engineering outreach program, AirProject (all proper names are pseudonyms), in a mountain west US state. The collegiate course is in an engineering department at a large US public university which serves almost 33,000 students in its graduate and undergraduate programs; 70% identify as white, 13% receive federal Pell grants, and 30% take out loans (NCES, 2020). The high school students served by this program are in 9 rural schools and are 71% white and 52% economically disadvantaged; 40% would be first generation college students (Colorado Department of Education, 2020).

Mentors' learning is structured into a yearlong course, offered to both undergraduates and graduates. The fall focuses on (1) technical objectives around air quality science and engineering, (2) scientific communication, and (3) mentoring skills. Specifically, mentors conduct a small research project of their choice, in which they pursue air quality questions in their local environment; collect data with a monitoring device (yPod); analyze the data and communicate results. They also practice teaching. In the spring, with support from university instructors and partner teachers, mentors guide HS students through a three-month air quality monitoring project. They meet once a week with instructors and classmates to reflect, discuss, and strategize teaching tips and problem solving.

Study participants include 12 mentors enrolled in the AirProject course, 3 university course instructors, and 3 high school teachers. 7 mentors identified as female and 5 male; 10 mentors identified as white, 1 Hispanic or Latinx, and 1 white and Asian American. High school classroom activities involved 86 students. Our data is drawn from three sources: 1) classroom observation notes; 2) mentor surveys; and 3) a focus group interview with 12 mentors at the end of the spring. We coded these data using the conceptual framework described above, along with axial emergent sub-themes within each category (Corbin & Strauss, 2019).

Findings

The AirProject *participant* and *distributed activity structure* prompted mentors to conduct air quality research throughout the fall and then teach these content and skills to their high school students during the spring. Thus, mentors have opportunities to rotate among different conventional and unconventional roles within a familiar curriculum. We identified two key themes: a) how the AirProject learning ecology shaped mentors' culturally transformational learning pathways and b) how mentors enacted learning as identification and becoming.

The learning ecology shapes culturally transformational learning pathways

Learning with multiple, responsive instructors and supportive high school teachers. In this small-size, learner-focused university course, the instructors worked together and supported one another in facilitating the lessons as well as responding to student inquiries. Ava appreciated "different angles that each instructor brought to the table." Ava's impression was concurred by all mentors. Participant structures incorporating multiple instructors are not novel, but it was notable how the three instructors, each with unique expertise, worked together to facilitate a multi-level scientific and engineering learning environment. In addition to appreciating the learning experiences in their university-based class, mentors reflected on their interactions with the high school teacher. Due to COVID-19, mentors had to call in for remote teaching while their partner teachers were in the room with students. Teachers skillfully helped mentors to stimulate students' learning through compliments, encouragement, and lighthearted jokes. Lucas said: "Our teacher was phenomenal… knowing the students, he would say … 'This person is probably going to have good work, we can volunteer them to go as an example." In between lessons, teachers were the main source of immediate assistance for students. They coordinated a schedule to lend out yPods and helped answer questions and troubleshoot. While leaving mentors autonomy to execute their lesson plans, teachers modeled productive, engaging communication.

Learning with multiple purposes. What was unique in the design of AirProject was that as mentors participated in the course, they had just-in-time learning to facilitate teaching HS students. Mia noted, "I didn't know very much about [air quality engineering] going into the course, so a lot of what we ended up teaching to the students I'd learned like a month or so beforehand … [I] immediately transferred that knowledge to someone else." Positioned as a mentor, Mia not only noted information relevant for lesson plans, but also handpicked materials that she believed to be engaging for students, drawing from her personal experience with those materials. Ben, Lucas, and Sophie recognized how they took on *facilitating, scaffolding, and mentoring* roles the ways that mirrored what their instructors did in the fall. In our observations, we frequently corroborated the synergy between the university-based instructors' guidance and how mentors positioned themselves as facilitators in high school

classrooms. Mentors carried themselves more like "knowledgeable partners" as opposed to merely claiming a position as authoritative sources of knowledge (Tabak & Baumgartner, 2004).

Mentors' participation in the AirProject reflected how they motivationally, relationally, and affectively (Nasir et al., 2020) operated in a system of learning pathways generative to their identity development. Like many of her peers who came to the course without much familiarity with air quality, Amelia pushed herself to study unfamiliar concepts and terminologies. Similarly, Noah was motivated to further his curiosity; he explained how he appropriated previous knowledge of scientific reasoning and sensemaking to his AirProject experience. Mentors also noticed generative relational patterns in their participation. Noah described how the collaborative mindset and the "peer community" learning experience rippled into the HS classrooms; he detailed how mentors rotated responsibilities, so they had one person focusing on the main curriculum and the other more "focused on managing time and interactions" and served as "the backup on curriculum topics and content." As Ava taught, she related more to her professors' work, and found herself willing to pay more attention in class to reciprocate the professor's effort. Mentors were transitioning from positions of novice learners to more knowledgeable peers; they appropriated relevant skills to advance disciplinary proficiency and at the same time actively moderated their own participation. Finally, at the end of the year mentors discussed *emotion and affect*. Emma described her overwhelming "imposter syndrome" and "lack of confidence" had made her feel the experience was at first "terrifying." Emma then noted improvements in how she handled questions and facilitated learning each time she came back to visit her students, which was "affirming," as was seeing her students skillfully presenting their projects. Other mentors concurred with "joy" and "pride" in seeing students present their research.

Learning as identification and becoming

Eleven of 12 mentors self-identify and are socially positioned as white, but the focus group interview revealed their non-monolithic identity positions. Working alongside peers and mentees prompted mentors to revisit their personal and social awareness. Liam recalled that as a "first-generation student, … without my middle school and high school teachers finding me to be excelling in math and science, I probably would never [have] become interested in engineering." Emma noted that "as a high school student I didn't think engineering was an option due to [my] lack of confidence." A student from a rural part of the state and a student whose pathway was through the community college system shared similar sentiments. These examples characterize how mentors' learning pathways included enactment of both privileges, for having racially privileged backgrounds and enrolling in a predominantly white institution and discipline—ones that persistently favored their racial identity—and marginalization, ones defined by their first-generation status, gender, geographic location, and age.

Mentors' self-identifications situated how they identified with *mentoring and role modeling*. Mia was adamant, "I do see myself as a role model because I came from a similar background as many of these kids, and now as a college student, I feel like I could be an example of where hard work can get you." Meanwhile, Emma saw *mentoring and role modeling* in her students connecting with her through the experience of "someone who doesn't have all the answers, because I think that feeling of not knowing all the answers is relatable," and referred to her interactions with students as a way to together disrupt stereotyping in their STEM pathways. Mia's identification reveals how notions of relationality can be blended in the dominant discourse of meritocracy. Emma's identification reflects a more holistic and reflexive imagination, emphasizing that mentoring is as much about building relationships and connection with students as sharing domain-specific knowledge.

Mentors' transition of roles, engendered by the AirProject activity structure, contributed to their emergent identities. We noted changes in how mentors saw themselves as STEM persons. Reflecting on the impacts of the AirProject experience on their STEM identities, some mentors shared an enhanced sense of confidence in educational and career trajectories in becoming an engineer. Participation in the AirProject prompted mentors to reconsider commitment for becoming a STEM educator, which for many of them is a renewed learning pathway. Charlotte is "thinking a lot more creatively about what I could do with my degree that might involve education and STEM together." As mentors participated in learning and teaching air-quality subjects in a collaborative, transformative context, they forged new identities, focusing on being able to "build shared understanding of what is happening and what will happen next" (Nasir et al., 2020, p. 198).

Discussion

Despite the strong interest that universities, faculty, and schools have in outreach and engagement, it is not simple to organize or to effectively implement. Our study has implications for how educators could employ innovative participant and activity structures in designing for productive STEM learning pathways, and consequently, ways to explicitly enhance the design and enactment of university-based educational outreach efforts. Our research contributes to describing how such systems can be mutually supportive of the various participants and the roles they need to play. The AirProject participant-activity structure provides an ecology that supports the learning and

development of participants along multiple pathways across roles and sites. University students learned air quality science and monitoring technology engineering; they also had the opportunity to learn how to teach within a context highly supported by university instructors and high school teachers. Mentors' learning pathways were situated in multiple sites, as they moved across university classes, self-selected sites for data collection, and high school settings. This ecology provides the time, place, context, scientific tools, and milestone events for evolving interactions, inquiries, and practices, all of which facilitated mentors' developmental pathways. Besides its benefits in concurrently scaffolding STEM learning for two communities of learners, the AirProject also prepares for a rippling effect of role modeling (Hinojosa, 2018). University instructors acted as role models to mentors as more advanced engineers and experienced educators; mentors acted as role models to high school students; and teachers acted as role models to mentors as educators. The design of this distributed activity system across university and rural high school settings provides one example of how learning pathways can be supported to provide more equitable access and participation in engineering, a field that has historically marginalized many.

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International Society of the Learning Sciences

Less is More: Balancing Tradeoffs in an Engineering Design Task During a Teacher Workshop

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Abstract: Despite the recent emphasis on the importance of K-12 students engaging in engineering content and practices, there has been little research done about how teachers learn engineering practices through teacher workshops and even less on how they utilize those experiences to teach engineering in their classes. Using methods of interactional ethnography, we analyzed data from an online teacher workshop in which elementary teachers engineered solutions to a multi-criteria problem in which balancing tradeoffs was a key practice. We found that teachers tended to focus on one criterion rather than both and lacked strategies to consider balancing these tradeoffs. We also found that a second iteration afforded all groups to demonstrate learning through improvement. Implications are discussed related to the importance of a focus on balancing tradeoffs in teacher learning and on pedagogy of engineering projects.

Engineering practices in Elementary Science Settings

Using engineering practices to teach K-12 science concepts is a relatively new paradigm (NRC, 2012) but offers many potential benefits as reviewed by Cunningham and Carlsen (2014), such as enhanced motivation to learn science, cognitive gains resulting from iteration (Capobianco, 2011), and enhanced problem-solving skills. Cunningham & Carlsen (2014) also advocated better understanding of how the practices manifest differently in science and engineering. A review of studies about engineering led Cunningham and Kelly (2017) to propose sixteen *epistemic practices of engineering* that are used to propose, communicate, assess, and legitimize knowledge. Among these practices are persisting and learning from failure, envisioning multiple solutions, and **making trade-offs between criteria and constraints** (Cunningham and Kelly, 2017).

Teachers trained before the *Framework for K-12 Science Education* (NRC, 2012) have no engineering experience, so they require professional learning opportunities. Particularly in engineering, it is recommended that teachers first experience design activities as a learner (i.e. "the student hat") and then have time to reflect on the problems and opportunities teaching it may present (i.e. "the teacher hat") (Sargianis et al., 2012). Changes in teacher practice have been demonstrated when science professional development has been focused on pedagogy (Enderle et al., 2014). Increases in teachers' learning about nature of science, self-efficacy for teaching and improvements in teaching have also been shown when teachers engage in the science practices (Sadler et al., 2010). However, teacher learning of the practices of engineers has so far been understudied.

Theoretical Framework

We approach this study with a sociocultural understanding of classroom work. It is guided by empirical studies of professional scientists and engineers. We also view the teacher learning through the lens of professional vision, where they learn to teach through interactions with instructors and as they get practice in the classroom.

Studies looking closely at the professional practice of STEM professionals (i.e. "science studies") give us insight into the ways in which disciplinary experts create knowledge. These epistemic practices are constructed socially, are situated in activity, rely on prior discourse and/or artifacts, and matter to what counts as knowledge (Cunningham & Kelly, 2017). Teacher learning is also sociocultural as they develop a professional vision. Goodwin (2015) describes how members of a profession learn discursive practices by observing phenomenon in a specific context, then marking or highlighting the specific aspects that are salient and producing representations of these practices. In learning to teach, teachers must first notice what is important in a teaching situation and understand why it is important. Particularly as these teachers learn new content and practices, they must consider these interactions in classroom environments and reflect on them as they gain experience teaching. Our r**esearch question was,** How and in what ways did the teachers collectively **balance the trade-offs between criteria and constraints of a multi-criteria engineering problem**?

Methods

This is the first study of a larger funded project that seeks to understand how teachers from rural school districts learn about engineering through professional learning opportunities and how they utilize local funds of knowledge

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to help their students make connections between their own lives and engineering. For this study, four pairs of teachers from three different buildings within two small, rural school districts in the mid-Atlantic region (~80 students per grade level) were observed engaging in engineering practices during one four-hour session of a 16 hour long professional development series. These teachers were selected for the study because they attended the school district in which they now teach, have at least 5 years' experience in teaching elementary school, and had not previously taught engineering.

Due to the COVID-19 pandemic, the workshops were changed from two days in-person to four remote, half-day sessions covering the same topics. The teachers were in pairs in a school conference room with the materials they needed to construct and test their prototypes. However, the workshop was conducted over Zoom, using Google Classroom for distributing the course materials (other than the physical material, which were delivered) and for collecting evaluation data, photos, and videos from the teachers. Our data collection and analysis are described below, but can be read in greater detail (Johnson, 2021).

On Day 1, teachers engaged in an activity called, "Perspiring Penguins" (Schnittka & Bell, 2010) to introduce them to engineering practices. The teachers designed an enclosure given a variety of materials to protect a penguin ice cube from mass loss during a five-minute exposure to a heat box, attempting to **minimize cost** and **minimize percentage of mass (of the penguin ice cube) lost**. The materials that can be more easily used to protect the penguin cost more money. Trying to minimize both cost and mass loss are in direct conflict and require balancing tradeoffs. The cost and percent mass loss were graphed, and teachers went through a second design iteration after discussing how to improve their designs. They then reflected on the steps they took to design the best enclosure possible through discussion and in an engineering journal given the criteria and constraints to consider engineering practices.

We chose to use interactional ethnography (IE) as an approach to study our research question. IE is an approach that borrows from sociolinguistics, cultural anthropology, ethnomethodology, and critical discourse analysis and is used to study cultures-in-the-making to consider the use of discourse, and actions in the co-construction of the participants' reality (Kelly & Green, 2019). This is useful in addressing socially situated talk and action, and is also a systematic approach to observational data collection that enables the analysis of locally defined and enacted roles and responsibilities that are difficult to identify using experiments, pre/post, or other techniques (Watkins et al., 2014).

To analyze, we made event maps (Kelly et al, 2001; Author, 2019) to understand the overall activity of the teachers and to identify episodes for more detailed analysis. Then transcripts were compiled by using the transcription capabilities of Zoom and YouTube and then cleaning the word-by-word transcripts by fixing mistakes and assigning speakers to the lines of text. Using the event maps to identify the interactions of interest, we then compared the interactions between the four groups to find patterns and differences. As participant observers, we got to understand the norms of the groups and typical interactions, and using audio-visual recordings, we were able to reduce the dependence on premature interpretation and reducing the importance of the observer. Discourse analysis of this type is useful for not only generalizing classes of phenomena, but also about the unique properties of individual instances (Lemke, 1998). A more detailed description of methodology can be found (Author, 2019).

Findings

Based on the interactions we analyzed relating to balancing trade-offs, we argue two potentially important claims.

1. In the first iteration, none of the groups demonstrated strategies for, or an emphasis on balancing tradeoffs, as they focused either on cost or performance, but not both.
2. In the second iteration, they were able to compare their designs to others, and all demonstrated improvement through a focus on balancing tradeoffs between criteria and constraints.

Designing an enclosure for an ice cube penguin that prevents melting but minimizes cost is fundamentally at odds. We were interested in how the teachers approached this challenge and which strategies they used to balance these competing criteria. During the initial design, the four groups exhibited three distinct approaches. Nikki and Heather focused almost exclusively on keeping cost as low as possible. They decided they only wanted to use a reflective "roof" to protect the ice. They tested each of the materials to see which would be the most effective at reflecting the incoming radiation from the heat lamps. After comparing aluminum foil and mylar, they decided to compare the relative value of adding a second layer of foil. In this interaction with the facilitator (Walter), Nikki emphasizes this point:

> 24:11 – Heather: So one liner is 125 [dollars] and two for 250 [dollars]. So if one layer is best, that's what we want to go with.

After testing, they determined that there was minimal value to a second layer and used one layer for a total of $125.

> 27:44 – Walter (facilitator): Alright, so you're going with a pretty minimal design trying to benefit most on cost, right? And that was based on the evidence you collected?
> 27:54 – Nikki – Yes. Less is more.
> 27:56 – Walter – Less is more in your test. Okay.

However, in the group from the other school in the same district, Jared and Bea emphasized the criteria of preventing the penguin from melting. Their design cost $700 (compared to the first group's cost of $125).

> 35:45 – Jared – You want a piece on the box. Something on the bottom because that felt that's in there is going to be hot and we're going to set it [the device] on it [the felt]. So you don't want a piece of foam or something on the bottom. Yeah, maybe this is going to be pricey. We're going to be expensive, but we're going to save our penguin!

The other two groups focused more on function than Nikki and Heather, but more on minimizing cost than Bea and Jared. In fact, an interesting conversation between Paris and her facilitator Wendy arose about the relative cost of their device. (Note: It is important to keep in mind that there was no maximum cost of the device, and the groups were in different locations so they were unable to compare their costs.)

> 46:55 – Paris – We're expensive. Yeah. 192[$] Okay, so we were. We just had to measure everything and calculate everything out and we're expensive!
> 47:07 – Wendy (facilitator) – It's ok, sounds good. I don't know. You'll like compare your costs versus how much your penguin lives and you'll see that there's like a balance and then you'll try to improve your balance when you get to the next iteration, so it's all good.

After testing the four initial prototypes and plotting them on a scatterplot (Fig 1), groups were given the opportunity to improve their design. Three of the groups focused on finding ways to decrease the cost of their original design without sacrificing much in its ability to save the penguin. Group 2 from Athens focused on ways to decrease the cost by identifying expensive materials while still providing insulation for the ice cube. Jared described the process:

> 56:50 – Jared – So, um we're going to try to eliminate the things that we think probably were not as effective, but also the things that were expensive. We lined the bottle on the bottom with the cotton balls. We put 10 cotton balls in the bottom to try to keep some of that heat from coming up. Uh, but they're 30 dollars a piece so we ten of those so that's three hundred dollars, so if we can get rid of a few cotton balls maybe, and maybe make our base that [the penguin] is sitting on a little smaller that could decrease our cost.

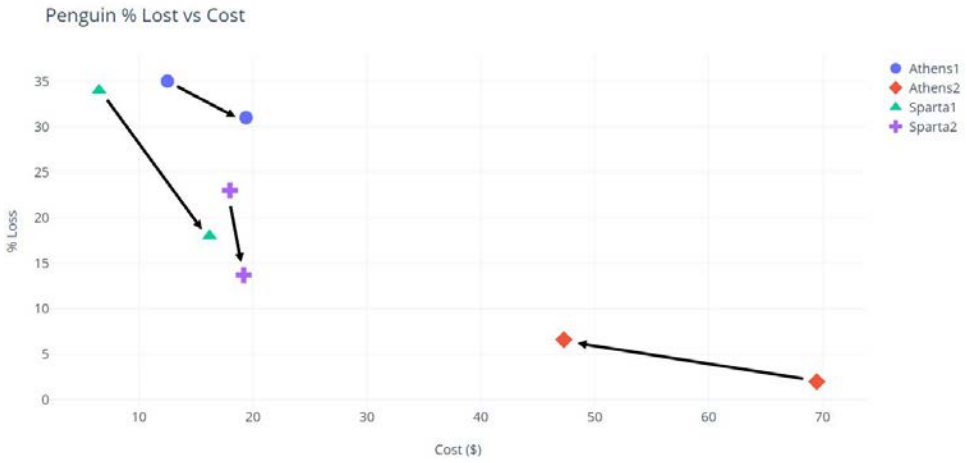
Figure 1 is a graph showing the changes for each of the four groups. With a multi-criteria problem like this with even emphasis placed on both cost and percent loss, improvement is shown by any movement that decreases the distance to the origin of the graph (i.e., $0 and 0% is the theoretical best score). All four groups improved, although Athens2 improved the least. The arrows point from the first iteration to the second.

Conclusions and Implications

Our findings suggest that without an emphasis on and strategies for balancing tradeoffs in teacher workshops, both teachers and their students will miss a key practice of engineers (Cunningham & Kelly, 2017; Madhavan, 2015). Three of the four teacher groups focused on cost, and three of those groups thought their designs were "expensive" because they did not know what the other groups spent and were not given a maximum cost. However, when given the opportunity to improve, each of the groups' designs better balanced the tradeoffs, a demonstration of learning. This strengthens the argument that learning can be demonstrated through improvement in engineering (Capobianco, et al, 2011; Author, 2019), and that this learning should be assessed because most engineering education projects do not provide reliable evidence of learning (Svihla & Petrosino, 2008)

Among the many engineering practices outlined by Cunningham and Kelly (2017), the idea of balancing tradeoffs is among the most consequential from a pedagogical standpoint. As opposed to scientific inquiry, where the goal is progress toward "truth" (Cunningham & Carlsen, 2014), the contextual nature of engineering design means that there is not one correct answer. Further, the teacher or curriculum designer can completely change the activity by altering the criteria/constraints. Performance can be weighted more heavily than cost. Cost can be limited by a maximum amount in which students might use extraneous materials as long as they don't reach that maximum, but cost can also be minimized. However, to be able to lead engineering activities in elementary settings, teachers need to first experience this practice, reflect on it as a teacher, and develop strategies to support student learning (Sargianis et al., 2012). Our next analyses will investigate closely these workshop teachers as they teach engineering and help their students navigate the engineering practices like balancing tradeoffs.

Figure 1
Each group improved in the second iteration because the points are closer to the graph's origin



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Care and Complexity: Designing for Holistic Understandings of and within a Pandemic

Abstract: The COVID-19 pandemic spans multiple systems and dimensions – social, scientific, emotional, and axiological. This paper describes the collaborative design process of an elementary-age program addressing COVID-19, systems thinking, and photography from this multi-dimensional perspective. With the COVID-19 pandemic as both curricular content and design context, an educational design emerged that includes care as the centerpiece of both design structure and process. Using an ethnographic approach, we outline the evolution of the curricular theme – from relationships, to protection, to care – and how this theme is realized in our design. Through a perspective of care, we consider what it means to include socio-emotional elements in systems thinking, specifically axiological considerations. This paper contributes to the need for educational designs that consider COVID-19 from multiple dimensions, to understandings of how collaborative processes can shape design, and to (re)theorizations of systems thinking in the learning sciences.

Introduction

The effects of COVID-19 have cascaded throughout nearly all aspects of our lives – some anticipated, others unpredictable. Global and local systems are responding to the pandemic's effects on the economy, healthcare, education, and individual well-being. To think critically and adapt in the pandemic necessitates systems thinking to make sense of the interrelated and emergent phenomena arising from COVID-19. The pandemic reaches into social, scientific, emotional, and, we argue, axiological (i.e., pertaining to ethics and values) spheres. This paper describes the collaborative design process of an elementary-age (8–11-year-old) informal curriculum addressing COVID-19, systems thinking, and photography from this multi-dimensional perspective.

The Care and COVID curriculum attempts to weave together multiple dimensions of the COVID-19 pandemic – spanning from individual to global systems. Care and COVID was designed during the pandemic, almost entirely over Zoom, a context that fostered unique perspectives for design that shifted with the collaborators' personal reflections of relationships, protection, and care in the pandemic. The inclusion of zoonotic disease science concepts, multi-dimensional systems thinking, and photography intends to engage learners with concepts of agency, ethics, and care. Care and COVID underwent three thematic shifts in our collaborative design process, outlined in this paper, that refocused the curriculum from what and how we protect from COVID-19 to why we should protect ourselves and others from COVID-19. The curriculum has not yet been implemented with students, with plans to do so in Spring and Summer 2022.

The goals of this paper are to describe the evolution of the Care and COVID design, how the contribution of multiple voices led to the theme of care, and to describe our emergent design conjecture, that attending to care in design may bring socio-emotional, and axiological dimensions into systems thinking. This paper presents the design process and elements of our first iteration of Care and COVID that reflect a multi-dimensional approach to systems thinking, offering a possible (re)theorization of systems thinking within the learning sciences as well as an understanding of how collaborative processes may shape such design.

Theory

The COVID-19 pandemic and our potential entry into a "viralocene" (Kristensen, 2020) present urgent imperatives for us to make sense of the complex relations and interconnections involved in emerging disease systems while imagining new forms of resilience with/in them. The pandemic reminds us of the intricate, mutual inextricabilities among environmental destruction, viral mutation, and multi-species relations, to name a few. The learning sciences have long attended to such forms of biological complexity and relationality in terms of *systems thinking*. Diverse approaches to systems thinking within the field share a general commitment to investigating and supporting reasoning about complex phenomena in ways that attend to multiple factors interacting across a wide variety of micro- and macro-scales (e.g., Hmelo-Silver & Azevedo, 2006; Penner, 2000; Resnick, 2006; Sabelli, 2006). Most approaches to systems thinking focus on rational-cognitive forms of understanding emergent processes (Resnick, 1996), system elements and dynamics (Chandler & Boutilier, 1992), and structure-behavior-function relations (Hmelo-Silver & Azevedo, 2006). While these remain important, the lived poignancies of the current pandemic – as both context and content of our design project – have made visible some of the affective and axiological lacunae within predominant approaches to systems thinking.

The pandemic's impacts on education have brought into frame fundamental questions about the relationship between learning and what it means to care for one another. Because of this, we also theorize our

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emerging curriculum design in terms of *care* as described by Hobart and Kneese (2020) as "strategies for enduring precarious worlds" composed of an "affective connective tissue" formed by "a relational set of discourses and practices between people, environments, and objects that approximate… 'empathy,' 'sympathy,' or 'fellow feeling'" (p. 2). This turn toward theorizing care beyond the strict locus of the individual to "span a breadth of localities: selves, communities, and social worlds" (Hobart & Kneese, 2020, p. 2) resonates with the cross-scalar holism of the systems turn in learning sciences while better disclosing the socio-emotional and axiological dimensions of complex systems.

Methods

The designers of *Care and COVID* co-developed the curriculum within the context of a broader participatory-design partnership (Bang & Vossoughi, 2016; DiSalvo et al., 2017). The partnership includes racially, geographically, and professionally diverse formal and informal educators serving rural, historically non-dominant communities, as well as university educators and researchers. We aim to contribute to the diverse and emerging approaches to participatory work in the learning sciences by responding to the research question of how the curriculum's core thematic focus has developed and refined over time through co-design. We aim to provide an ethnographic account (Erickson, 1984) of the curriculum's history (and imagined future) that interrelates: (1) analysis of records and artifacts from our design process, (2) our own evolving theoretical perspectives on what it means - or could mean - to support the development of systems thinking about the pandemic, and (3) reflections on the evolution of our own collaborative relationships and processes. Our data include collaboratively produced notes and written reflections spanning nearly a year, as well as fieldnotes and Zoom recordings of design meetings.

Members of the *Care and COVID* design team met for one hour weekly between February 2021 and April 2022 and completed asynchronous tasks outside of meetings. Early stages of design included consultation with teaching artists, medical practitioners, and advisory members. Over this period, the design team was tasked with developing a 10-hour curriculum. From initiation, the design team believed that centering the curriculum around a systems-focused theme may support elementary-aged learners to elucidate systems thinking. The development of this theme – beginning with relationships, then evolving to protection, and ultimately coalescing around care – highlights a shift in our design team's thinking about the intersection of photography, systems thinking, and the COVID-19 experience. We describe the evolution of our design below, a process that leads us to conjecture that attending to care may bring socio-emotional and axiological dimensions into systems thinking and that photography may engage students in acts of caring.

Design evolution: Relationships, protection, and care

Relationships

Early design sessions of Care and COVID, beginning in February 2021, included open brainstorming around photography, visual literacy, and the COVID-19 experience. The social heteroglossia (Bahktin, 1981) was evident as the six initial design team members had a wide variety of professional and educational backgrounds, spanning K-12 education, adult education, science and art education, research, and healthcare. Participants were excited to leverage the arts to engage learners in acts of storytelling, especially in regard to the inequities of healthcare and COVID-19. Each weekly meeting was abuzz with ideas, constructed from the diversity of voices and personal pandemic experiences. Challenged to include COVID-19 disease science, photography, and systems thinking in the curriculum, the design team grappled with how to connect these topics in a way accessible to elementary-aged learners. Our own emotional and relational experiences with COVID-19 surfaced and revealed the many ways we tried to relate to one another. As a result, relationships became the beacon not only for our work as a team, but for our curriculum as well.

We saw the theme of relationships as one that could bridge curricular needs across photography, systems thinking, and COVID-19. We viewed relationships as a potential way to include multiple dimensions of COVID-19 systems, including socio-emotional perspectives. Specifically, the design team included a focus on students' relationships with their own bodies, families, and communities, as well as their trust and distrust of healthcare and information. We then employed photography as a way to elicit and communicate relationships and emotions. By March 2021, initial drafts of the curriculum included three segmented foci – relationships with self, relationships with communities, and relationships globally – specifically attending to how COVID-19 interplays within and across these scales. This curriculum structure - having students consider relationships at varying scales - became a fixture in Care and COVID that remained throughout design. At each level, photography became the anchor

through which learners could explore COVID-19 relationships in both affective and scientific ways, and a medium to express, compare, and contrast their lived experiences with their peers. An activity at this stage of design prompted students to take photographs of playgrounds in the pandemic to explore their personal and their community's relationship to these shared spaces.

Protection

In June 2021, the *Care and COVID* design team shifted from six to four members as two community educators opted not to extend their involvement beyond the initial commitment. The remaining four team members included the principal investigator, two graduate students, and one community educator with expertise in arts education. At this time, the *Care and COVID* curricular theme shifted from relationships to an agentic focus on protection. The shift to protection was prompted by a desire to move into action surrounding COVID-19, rather than only analyzing COVID-19 connections and impacts. We wanted to empower students as agentic members of their communities and society with valued stories about protection to be shared through photography. For example, the design team co-designed a lesson positioning students as community protectors. Here, students take self-portraits as protectors in their community, tapping into their own stories and understandings of what protection looks like. Prior design work around relationships ensured that the theme of protection was not exclusively scientific (e.g., learning about how masks reduce transmission), but also included social elements of resilience around COVID-19 (e.g., examining healthcare access in rural communities). We viewed protection from COVID-19 as relational, encompassing the previous theme, with individuals relating to themselves, their communities, and society through protective action. We embraced protection as an expansive concept, reflected in our design by moving students from activities about individual protection, to community protection, to societal protection – keeping the structure originally implemented with the theme of relationships. For example, a curricular feature on the societal scale has learners create photo narratives of protection (or lack thereof) to tell stories of systemic assets or barriers to protection. These stories come from their own notions and ideas of what protection can and should be, and allows for the overlapping of individual, community, and social protections.

Care

In October 2021, *Care and COVID* underwent its most recent thematic shift when the design team collectively reflected on the essence of the overall curriculum. Initially focusing on relationships, and then protection, the notion of care ultimately solidified as the curricular theme. We view the current theme of care as a transition to not only explore *what* and *how* we protect, but also *why* we should protect ourselves and others from COVID-19. This axiological shift in the curriculum encourages students to value their own lives and the lives of others and to consider which actions represent care. For example, one activity has students write, act out, and photograph skits depicting what it looks like to care for the preciousness of their lives, specifically the preciousness of their health, bodies, and families. Throughout the curriculum, students explore acts of care through theatrics, self-portraits, and photo narratives. *Care and COVID* positions art as an empowering, accessible, physical, and emotional way to care for others, to engage in multi-scalar systematic care through photography and storytelling.

The design team also notes care as integral to our co-design process. The design of *Care and COVID* has occurred during the COVID-19 pandemic; care for ourselves and for each other has been imperative. We ask and listen to each other, we adapt to the needs of team members, and we bring empathy to the forefront of our design conversations. Maintaining the heteroglossia of our team has become a collective act of care throughout our design process. The focus on care within our design team has allowed each of us an opportunity to voice our passions and diverse expertise in design.

Conclusion

The evolution of *Care and COVID*'s design theme, from relationships to protection to care, represents an expansion from solely cognitive to also include socio-emotional and axiological dimensions of COVID-19 systems. Our team is exploring how these dimensions, when integrated into systems thinking, can give learners a holistic understanding of a phenomenon, in this case, protection from COVID-19. Through our co-design process, we identified care, focusing on the protection of oneself and others on multiple scales, as one way to bridge the many dimensions of COVID-19. Using photography, we are exploring the integration of the arts as an act of care; we are exploring how to support learners with tools to personally make sense of COVID-19 and to care for themselves, and others, through their art.

Future work will investigate the implementation of *Care and COVID*. We will examine how the curriculum does or does not support learners in considering COVID-19 systems from multiple dimensions. We

wonder: How does the inclusion of care in design support multi-dimensional understandings of systems thinking across socio-emotional and axiological spheres? What role does arts-integration play in expanding the dimensions through which students understand systems? We conjecture that design centered around and within care, utilizing strategies of arts-integration, may support students in developing holistic understandings of systems on multiple scales and in multiple dimensions.

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Designing learning environments with iterative conjecture mapping to support teachers' computational thinking learning

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Abstract: One way to help develop foundational computational literacy skills for K-12 students is to integrate computational thinking (CT) into science and math, but teachers have struggled to implement CT. This work investigates secondary science and math teachers' CT outcomes as they engaged in a four-week summer institute. This study uses conjecture mapping to inform iterative design, implementation, and evaluation of the institute over two years. This paper characterizes teacher learning outcomes and the specific aspects of the institute design that led to those outcomes. Findings suggest the institute's design led to increased CT knowledge and confidence in CT. Specifically, teacher outcomes were supported by teachers' engagement as learners in discussion, reflection, and interaction with computational tools. Challenges encountered were used to inform redesign and a second implementation.

Purpose

Computational tools and methods are increasingly important in STEM disciplines. As such, it has become important to include computing in K-12 science education, both to enable students to understand the science, and to develop foundational computational literacy (Wilensky et al., 2014). One way to achieve this is to integrate computational thinking (CT) into core classes, such as science and math. CT, as conceptualized by Papert (1980), described the process of thinking about a phenomenon through using, creating, and constructing computational tools. While the potential benefits of CT integration with science and math are evident, teachers have struggled to design and implement CT in their classrooms. Several barriers impede CT's uptake such as lack of appropriate technology and infrastructure, teachers' limited experience with CT and computing, limited time to teach content, and limited professional development resources (e.g., Aljowaed & Alebaikan, 2018). Thus, it becomes increasingly important to support teachers in learning about and implementing CT. Our research team has worked with teachers to integrate CT into science and math classes for several years. Our approach has evolved from researcher-designed units to complete co-design with teachers. This co-design took place in 2019 during a four-week summer institute (CTSI), which also included workshops to support learning about CT, how to integrate CT, and how to teach CT. The research is guided by the following research questions. After a four-week summer institute where teachers engaged in workshops and co-design, 1) What were the teacher learning outcomes? And 2) How did the summer institute's design mediate teacher outcomes?

Framework

Table 1
Initial PD Conjecture Map About the Design of the 2019 PD

Conjectures	Embodiment	Mediating Processes	Outcomes
Teacher engagement in workshops and co-design will lead to learning about CT and how to integrate CT.	Workshops in which teachers participate in lessons about CT. Co-design in which teachers worked with researchers.	Interacting with computational tools Designing and creating computational tools	Learning about CT & computational tools Learning about how to integrate CT

Conjecture mapping was used to investigate how the design of the summer institute led to teacher learning outcomes (Sandoval, 2014). Elements of a conjecture map specify how the design of a learning environment enables desired outcomes. Conjecture maps consist of high-level conjectures (initial ideas about supporting learning through the learning environment), embodiment (the learning environment design elements), mediating processes (the activities and/or interactions connecting the embodiment and desired outcomes), and outcomes (the

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desired outcomes of the learning environment). Project researchers made an initial conjecture map before data analysis, which was then used to test design ideas, and data was used to refine the conjecture map. Table 1 depicts the initial conjecture map of hypothesized connections between design and outcomes.

Methods

The summer institute

The summer institute was four weeks with eight teacher participants. During the first week, teachers participated in workshops aimed to help them understand CT and its integration. Workshops included engaging the teachers as learners in several exemplar CT integrated lessons. The subsequent three weeks were dedicated to co-design where each teacher worked with one researcher to design new CT-integrated science and math units. More details about the summer institute are described elsewhere (Wu et al., 2022).

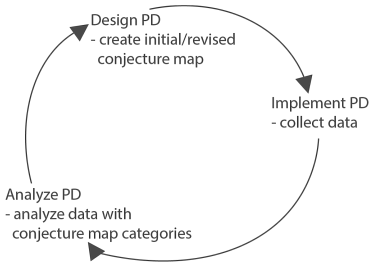
Data sources

Multiple data sources were collected throughout the summer institute. At the end of each week, the teachers filled out a reflection form to provide feedback. The group also discussed aspects that went well, aspects that were challenging, and goals for the next week, which was followed by a weekly exit ticket that each teacher filled out. At the end of the summer institute, teachers completed a post survey and a 45-minute semi-structured interview where they discussed their experiences. Audio and video recordings of the workshops were also collected.

Analysis

We utilized conjecture mapping design cycles to first identify desired professional learning outcomes and then to guide the design, implementation, data collection, analysis, and revision of the learning experience (Figure 1). We developed an initial conjecture map to plan and design the learning experience (Table 1). This qualitative study to investigate the how the learning experience contributed to outcomes took place through several rounds of inductive and deductive coding with triangulation between data sources (Miles et al., 2014). In the first round of coding, we investigated data sources to identify outcomes. Next, authors one and two coded data for connections between the identified outcomes and specific design elements (embodiments) and how they led to the outcome (mediating processes). These findings were used to modify the conjecture map to represent the actual learning experience implementation. A third round of coding was implemented to identify issues and areas for improvement that arose during the learning experience implementation. The refined conjecture map based on implementation data was used to redesign the learning experience.

Figure 1
Conjecture Mapping Design Cycle



Results

Teacher learning outcomes

Three categories of teacher self-reported outcomes were identified through the qualitative analysis: 1) Learning about and how to use CT tools, 2) Learning about pedagogy to support CT integration and scaffolding, and 3) Changes in values and attitudes regarding CT. Table 2 shows examples coded for each outcome. These results indicate the summer institute led to positive outcomes in teacher learning and shifts in values and attitudes.

Table 2
Teacher Learning Outcomes

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Outcome	Quotation Example
Learning about and how to use CT tools	"I learned a lot about how to program NetLogo, as well as how to use various computational tools effectively in instruction" (Derick, Post CTSI Survey).
Learning about pedagogy to support CT integration and scaffolding	"Brainstormed new ideas for modeling the unit, interesting ideas for models that I wouldn't have thought of, like pulling in the data snapshots to model and having students place sensors" (Lacey, Post CTSI Survey).
Changes in values and attitudes regarding CT	"I have really learned a lot and will be more confident using CT with the students. I think I may even be able to do a little trouble-shooting and be less reliant on the team that observed my classes." (Tracy, weekly reflection 7/25)

Design mediated outcomes

The initial conjecture map was refined based on teacher responses, and then used to investigate the connections between outcomes and the summer institute design (Table 3). The Embodiment column describes the workshops and co-design teachers engaged in during the summer institute. The Outcomes column shows the outcomes identified from the data in the prior section. The Mediating Processes column describes the processes teachers engaged in during the embodiment that led to the outcomes. For example, when teachers engaged as learners in a workshop session (embodiment), they interacted with computational tools (mediating process), which led to learning about CT and computational tools (outcome).

Table 3

Conjecture Map for the design of the 2020 PD

Conjectures	Embodiment	Mediating Processes	Outcomes
Teacher engagement in workshops as learners followed by explicit reflection leads to learning about CT and changes in perceptions of CT.	Workshops in which teachers engaged as learners.	Answering questions in the CT-STEM units	Learning about and how to use CT Tools
	Workshops in which teachers reflected on pedagogy, CT content, science content, and planned their unit design.	Interacting with computational tools	Learning about pedagogy to support CT integration and scaffolding
Co-design allows for learning about CT and changes in perceptions of CT.	Feedback from other teachers and STEM experts.	Discussions	Changes in values and attitudes regarding CT
	Co-design in which teachers worked with researchers.	Designing and creating computational tools	CT-integrated units

Four mediating processes were identified within the data: 1) Answering questions in the CT-STEM units, 2) Interacting with computational tools, 3) Discussions, and 4) Designing and creating computational tools. The video data provided evidence of connections between mediating factors and outcomes, thus triangulating the various data sources. The connections between mediating processes and outcomes suggest the design of the summer institute led to teacher learning and changes in values and attitudes regarding CT. The overall conjecture map led to the development of two major conjectures about the design of the summer institute. First, teacher engagement in workshops as learners followed by explicit reflection leads to learning about CT and changes in perceptions of CT. Second, co-design allows for learning about CT and changes in perceptions of CT.

Although the 2019 summer institute led to several important outcomes, teachers did experience challenges and tensions. Some teachers felt unprepared to pick a unit topic after the first week. Teachers felt that workshops and design time could have been better interwoven to allow for reflecting on how to incorporate the ideas in their context. The red text in Table 3 represents new additions to the PD for the following year (2020). To address challenges, we began co-designing and planning earlier in the PD and allowed for reflection and planning with each workshop. To facilitate discussion and feedback, we added several sessions where teachers discussed their units with each other and with STEM professionals outside the project.

Findings presented elsewhere showed the 2020 teacher participants experienced similar outcomes, such as learning about CT practices, CT tools, and how to teach with integrated CT (Wu et al., 2021). Teacher's 2020 workshop reflections indicate they appreciated receiving feedback from STEM professionals. "Loved the feedback from the three-four people I spoke with. Loved connecting with a post-secondary professor to discuss some missing pieces when vertically building awareness in skill and content planning" (Matthew, 2020 Workshop Reflection). Similarly, teachers valued feedback from other teachers in the institute. "The team feedback and cross-team feedback were incredibly valuable" (Kathy, 2020 Post CTSI Survey). After the first week of the institute teachers were asked what went well, and several teachers indicated the time spent brainstorming along with workshops was beneficial. "I feel very accomplished with the brainstorming that [Jack] and I have begun. Looking forward to getting started next week!" (Jeremy, Week 1 Exit Ticket). These responses indicate the modification to include planning time earlier in the institute was helpful for teachers. Teacher participants in both summer institutes (2019 and 2020) successfully co-designed and implemented CT-integrated science and math units. Full units are available on the project website (ct-stem.northwestern.edu).

Discussion

Our research builds on and extends existing literature (Hestness et al., 2018, Yadav at al., 2014) by connecting the design of a learning environment with teacher outcomes through specific embodiments and mediating processes, adding to the literature knowledge about how to support teachers in learning about CT and feeling confident with teaching CT. Significant outcomes identified in this research also suggest that the summer institute addressed some of the barriers to implementing CT in schools, such as limited computing experience and limited professional development resources. Findings suggest the workshop design (engaging as learners, discussion, reflection, interaction with computational tools) led to increased CT knowledge and confidence in CT, which prepared the teachers for co-design. Co-design of new CT integrated units supported learning about CT tools and how to integrate them and increased confidence with CT through discussions, interactions with computational tools, and the design and creation of computational tools. Co-design pathways and cases of specific co-design approaches are detailed elsewhere (Kelter et al., 2021).

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Navigating Moments of Tension and Uncertainty in Co-Design of University Curriculum

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Abstract: Student co-design promotes an alternative educational structure where students are involved in the classroom design process, honoring students' agency in their learning. However, co-design differs from other design processes because it is a largely collaborative and symbiotic process where groups of designers and facilitators are required to work collectively while navigating disagreements and tension. Due to the unique nature of the co-design environment, moments of tension and uncertainty are common in the design process and can potentially interfere with group productivity. Common examples of tension that often impede designers from progressing include uncertainty of how to move forward or disagreements in creating the design product itself. Through data gathered from a co-design journey involving college students working on redesigning an undergraduate education course, this paper illustrates the design processes needed to navigate moments of uncertainty and tension during co-design to ultimately achieve a collaborative and authentic design outcome.

Major issues addressed

Co-design is a design process in which designers collaborate as participants in the creation of a design product. Our paper focuses specifically on student co-design, a design process involving university student designers redesigning an undergraduate university course curriculum. The collaborative nature of co-design allows for the potential of designers' experiences and insights to be equally valued and heard, disrupting the usual hierarchies that exist in curriculum design (Iversen, Smith, & Dindler 2017; Tierney, Horstman, & Tzou, 2021). Such a process not only creates a product that is reflective of the most important components of the course curriculum but also one that is also most authentic to the designers (Pitt, et al., 2019; Tierney, Horstman, & Tzou, 2021; Yip et al., 2017). However, because co-design relies on group work and healthy collaboration to be successful, unity and productivity among the designers is crucial. Yet, it is unrealistic to expect disagreements and uncertainty to never arise in group work, creating a need for processes to navigate these scenarios. Our research questions for this work are: In moments of tension and uncertainty, what are the different ways designers and facilitators resolve tension or uncertainty? In what ways does tension positively and/or negatively impact educational co-design (put another way, is tension in co-design necessarily a bad thing)?

Potential significance

Other studies of co-design have acknowledged its effectiveness in education and design (Camino & Zeldin, 2002; Tierney, Horstman, & Tzou, 2021; Yip et al., 2017). However, despite the praise that co-design receives, there is a lack of research regarding its processes. Specifically, there is a need for research that outlines the processes required for successful co-design to occur. While this paper contributes to education research in general, it specifically contributes to literature in Learning Sciences focused on design stakeholders and design processes. This paper highlights the nuanced practices of facilitation and group work during co-design. Through the approach to co-design used in this study, participants' perspectives and experiences are incorporated in ways that impact the design and redesign of learning environments. Without attuning to how facilitators and groups operate during co-design, student co-design can run the risk of reifying hierarchical power dynamics when students are involved in performative ways that do not incorporate their voice or remediate the historically marginalized roles within education (Camino & Zeldin, 2002; Giroux, 2009; Kirshner, 2015; Tierney, Horstman, & Tzou, 2021; White & Wyn, 2013). Through our data, we identified some critical components in the actions of designers and facilitators in navigating moments of tension and uncertainty. We also examined whether all tension is a disruptive force and found that productive tension can be an asset that design groups should not try to avoid. These findings offer guidelines for both facilitators and designers to resolve moments of tension and uncertainty.

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Theoretical approaches

In our design work and in this paper, we take a sociocultural perspective on student co-design, in that we view participation and learning as an interaction between individuals (in this case university students and faculty) and the contexts in which they participate (Holland, Lachicotte, Skinner, & Cain, 1998). The process of learning, while a different conceptual category, cannot be separated from the process of emotion, belonging, or identity development (Nasir, Roseberry, Warren, & Lee, 2006). We also used communities of practice (Wenger, 1998) as a theoretical frame of how individuals participate within learning communities, examining the ways in which participation shifts over time in a community of practice.

Goals, values, and practices are in part inherited from the history of the group and its domain of practice, both from the individual histories of its members across various social worlds and through their ongoing negotiation within a community of practice. Different members of a community have different positional identities, with different kinds and levels of influence over the group's activity (Holland et al., 1998; Holland & Lave, 2001). So too, the identity and learning of the community, as a collective, shifts over time. We used Wenger's (1998) concept of "joint enterprise" to capture ongoing negotiations of a co-design group's sense of itself, what binds members to the group, and what they accomplish together. Group members' participation in the group both determines and is influenced by this sense of "what we are about." To this we add the construct of *productive friction* which Ward et al. (2011) defined as "dissonance… when two or more social worlds conflict that leads to more sophisticated practice" (p. 14). In our analysis, we use productive friction to understand moments of tension in the design process, negotiating new practices, and directions in joint enterprise.

Methods and data sources

This work was set in the context of a university aiming to transform its education courses by centralizing just, equitable, and inclusive education. Due to the pandemic, all design sessions were conducted online over the conferencing application, Zoom. All documentation of the design process was also recorded virtually, using Zoom audio and video recordings. The designers also used Miro, an online whiteboard that was captured and saved after every design session. The design team consisted of six main designers (Katherine, Jeff, Mitch, Hannah, Vanessa, Chrissie), three feedback groups (in which Author one, Sharon, participated), and one facilitator (Author two, Gavin). All designers, including those in the feedback groups, had taken the Adolescent Development course with the facilitator, Gavin, as their professor in the past two years. This paper examines the behaviors of the six main designers and the facilitator as they redesign the undergraduate Adolescent Development course.

Because all meeting sessions occurred over Zoom, ten sessions of video and audio data were collected. Miro, the virtual whiteboard the design team used, was also documented at the end of every session. Qualitative data analysis occurred in four coding phases: open coding, focused coding based on research questions, writing analytic memos looking in and across codes and data, and generating hypotheses. We used initial qualitative coding and analytic approaches that are inductive and abductive – grounded theory (Corbin & Strauss, 2008). Open coding of participants' own words was conducted to examine how participants co-constructed the design space and the norms and practices within. The videos that were analyzed were chosen based on the amount of significant changes that occurred on the Miro whiteboard. The sessions where the most changes occurred on the whiteboard signified shifts in practice (compared to refining already established practices) and so were chosen to examine potential tension during those shifts. The videos were also analyzed in chronological order to preserve the linear co-design process. Video and audio recordings of the design sessions were analyzed by looking for recurring themes or actions taken by members of the design team. Those themes and actions were translated into codes, grouping similar moments together. These moments in the design process were then reanalyzed through the lens of tension and uncertainty, pinpointing moments where disagreement and confusion arose.

Major findings

Through data gathered during the design sessions, we identified three processes that focused on addressing tension and uncertainty in the co-design environment: 1) Facilitator Guidance, 2) Community Building, 3) Productive Tension. Two of these findings deal with the resolution of tension and uncertainty, while the third relates to the nature of tension and uncertainty, assessing whether these moments are necessarily unproductive.

Facilitator guidance

Facilitator guidance is an integral part of navigating tension in co-design due to the facilitator's ability to act as a guide for the designers. How facilitators provide guidance is essential in moments of tension or uncertainty because they are usually the person with the most knowledge on both the subject matter and the co-design process. As such, this kind of *deeper knowledge of content and design process* can help designers find their way out of tension. One example of this occurs when the design group is introduced to some changes that a feedback group had made on their Miro board in design session five. The feedback group had previously left comments on the group's Miro whiteboard for them to consider. Gavin offers the group multiple ways to alter the Miro board based on their feedback. Ultimately, Gavin leaves the final decision up to the designers. This example demonstrates the benefit of experience and knowledge in the design process. Because Gavin has more insight in the design process and the subject matter, he can guide the group, giving them options on how they should proceed. With his expertise, the design group is shown possible routes to incorporate new information into their design, aiding the group in finding the best way forward. This moment is also significant due to Gavin's leaving the decision up to the designers, providing a space for the design team to negotiate their joint enterprise. Here, he demonstrates that facilitators should be involved in the design process, but that designers should make the final decision to ensure an authentic design product.

Another form of facilitator guidance is their *perspective as a meta-designer*. Student designers often become so involved in the design process that they can no longer see the bigger picture or produce new ideas capable of pulling them out of disagreements and confusion. Facilitators can thus bring new perspectives, aiding the designers in pivoting their thinking. An instance where the facilitator uses their perspective as a meta-designer occurs when the design group is introduced to the idea of equitable and inclusive education (JEIE) in session six. As the designers take some time to look over both the ideals of JEIE and their Miro board, they struggle to combine them. When Gavin asks the group how they would merge these ideals into their Miro whiteboard, he is met with no response. Eventually, Hannah asks, "Um, do you mean incorporating JEIE towards the principles that you've brainstormed and added, or towards what we've done already?" Then Katherine comments on the challenges that connecting JEIE to their Miro board might pose: "I feel like we will struggle less putting JEIE into some constellations, whereas others like Biological Development…we might struggle a little more." Noticing their confusion, Gavin offers the designers a question to redirect them: "Are the ideals of equitable and inclusive education central in the Adolescent Development course, or are they only present?" This instance demonstrates the importance of having a facilitator who is "out of the weeds" and has a "bird's eye view" of the design process. In this instance, Gavin identifies the group's struggle between incorporating and centralizing equitable education, naming space that they are experiencing tension, something the designers may not have caught themselves. The facilitator's unique perspective led the design group to rethink their trajectory, providing an opportunity for productive friction and negotiation, eventually clearing up group uncertainty and giving them a direction to pursue.

Community building and temporary leadership

Community building primarily deals with designers feeling comfortable around each other. The goal is for the designers to feel safe offering opinions, challenging ideas, and questioning one another. Community building is vital in co-design because it increases designers' willingness to step into certain roles to guide the design group out of tension. Often, the group requires temporary leadership, allowing designers to step into roles they may not always be in, and lead the group out of tension or confusion. Feeling comfortable and safe in a creative environment also allows designers to take risks, leading to more creative and innovative design outcomes.

A moment that illustrates how roles centered in community building can be used to reduce tension or uncertainty occurs in session six when the design group struggles to organize their sticky notes in the constellation "classroom environment" while also incorporating the ideas of JEIE. The six main designers were in the process of incorporating JEIE into each of the main constellations from the original curriculum. However, uncertainty arises when the group struggles to organize their Miro board in a way that connects "Classroom Environment" with JEIE. Jeff offers his opinion and says, "I was just thinking we could take the JEIE stickies that we had and make a more direct correlation between the subject matter and JEIE." After going into more depth about his idea, he asks if anybody in the group has any ideas that may be different from his: "As long as that works for everyone else, because I don't want this to just be my own thing. Does anyone else have, like, a way they think would be better at going at it?" This moment is significant because it demonstrates how stepping into leadership roles can provide the group with direction when confronted with uncertainty. By shifting his positional identity and taking on a leadership position, Jeff changes the dynamics within the group, allowing designers to collaborate differently. Jeff also

demonstrates that leadership is not limited to decision making. Rather, Jeff opens the floor to other designers, illustrating how embodying both the leadership role and the team member role allows for more collaboration and negotiation of the group's joint enterprise. We are currently in the process of further analyzing data to identify specific processes and tools to support designers building community and taking on temporary leadership roles.

Productive tension

Productive tension refers to moments of disagreement or friction in design where the outcome does not detract from the design process but rather enhances or improves the final design product. These moments should be seen as meaningful disagreements that push the design process forward rather than obstacles. One moment that illustrates productive tension occurs in session six. Hannah brought up an alternative redesign method that works backwards to centralize equitable and inclusive education in the badge design. Hannah asks the group "I wonder, because the goal of this is to make JEIE, like, the central part, right? If we relate the JEIE stickies to the concept, and then to the stickies that we've already made?" Here, Hannah is referring to the existing "stickies" or sticky notes that the rest of the design group have previously made on the Miro board. The rest of the group reacts positively to the idea but are unsure of how to execute it. After a moment of silent thought, Jeff introduces a proposal to the group: "We kind of did that at first with the stickies we have to the side of Educator Role. We do it in a similar way in terms of putting down quick ideas of JEIE to the whole thing while we're thinking about it in a broader scope." Although Hannah's proposal led to even more confusion and uncertainty, the group acknowledged the idea had merit and worked through how they could possibly implement this process into their design. This moment is significant because it demonstrates how not all conflict or tension is unproductive. While Hannah's idea spurred more uncertainty among the designers, she also added a better method for the redesign, demonstrating how uncertainty and tension have the potential to improve the design process. Designers should not actively seek to minimize all moments of tension but instead embrace them as they arise. Risk and discomfort are spaces where original ideas come from, and we should not seek to reduce them (Heath & Smyth, 1999). However, productive tension is most effective if it is related to the design work and designers feel supported by the design group. In addition, feelings of support among the designers are essential for this type of risk-taking in productive tension to occur, which is why community building and facilitator guidance are so crucial. These aspects of the design process build meaningful relationships, increasing designers' willingness to take risks and enter spaces of discomfort and tension.

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Unpacking Iteration: Exploring Forms of Iterative Practice in Physics Labs

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Abstract: Iteration is pervasive in current perspectives of student reasoning, but it is also often assumed, backgrounded, or minimized in favor of other empirical interests and results, despite being foundational to reasoning processes and inquiry. This paper forefronts iterative practice while examining student reasoning in a reform-based undergraduate physics lab course. We present an instrumental case study analysis of a single student group, documenting how they engaged in micro- and macro-levels of iterative practice at the nexus of experimental activity and sensemaking throughout their experimentation. These results illustrate the nuance in students' iterative practice at different levels and prompt new questions about how different forms of iterative practice may impact student learning.

Background and Theoretical Perspectives

In the Learning Sciences, there is widespread recognition of the importance of iteration. Iteration occurs as part of student reasoning within engineering design (e.g., Smith & Tjandra, 1998), scientific modeling (e.g., Windschitl et al., 2008), makerspaces (Ramey & Uttal, 2017), argumentation (e.g., Herrenkohl & Cornelius, 2013), and experimental physics (e.g., Holmes & Wieman, 2016). However, iteration is often assumed without extensive definition or backgrounded in favor of other empirical results. For example, Windschitl et al. (2008) describe an iterative framework for scientific modeling but do not empirically investigate the iterative elements of the framework in learning contexts. Thus, we have limited knowledge about the structure of iteration and its relationship to larger reasoning processes. This paper aims to shed new light on iterative practice in student reasoning by presenting an instrumental case study analysis of students' iterative practice at the nexus of experimental activity and sensemaking in a reform-based undergraduate introductory physics laboratory course. We highlight how a focus on iterative practice may serve as a conducive mechanism for analyzing complex student reasoning in scientific learning environments.

Experimental Activity and Sensemaking in Physics Labs

We define iteration as a successive process that builds and improves upon previous outcomes of theory, design, or experimentation (e.g., Elliott, 2012). While many forms of iterative practice abound, we rely upon experimental and epistemic iteration, the processes by which scientists repeat experimental steps to improve empirical results or protocols (Collins, 1992) and successively alter and refine scientific knowledge to improve accuracy or explanatory power (Chang, 2004). These constructs help conceptualize how iteration might be prevalent in students' experimental activity and sensemaking.

We conceptualize experimental activity as a hierarchical process composed of macro- and micro-level activities. At a macro-level, experimental activity involves students carrying out broad experimental actions, such as making predictions, data collection, troubleshooting, and data analysis, in the lab setting to complete experimental goals (e.g., Wieman, 2015; Zwickl et al., 2015). These macro-level actions are composed of micro-level experimental actions, such as preparing apparatus and adjusting software parameters. Each hierarchical level can evoke iteration, whereby students repeat experimental steps to increase accuracy or explanatory power. For example, at the macro-level, students can experimentally iterate between making predictions, collecting data, and comparing measurement results to predictions to produce more accurate scientific models. At the micro-level, students engaging in troubleshooting can iterate between identifying issues with apparatus, generating and testing causes, and repairing apparatus or procedures (Dounas-Frazer et al., 2016). While prior research has documented these experimental activities in physics labs (e.g., Wieman, 2015; Zwickl et al., 2015), they often minimize iteration and implicitly obscure authentic accounts of student experimental activity.

We conceptualize sensemaking as a process of iteratively constructing and critiquing explanations and procedures to resolve inconsistencies through developing a knowledge framework, recognizing an inconsistency, and enacting sensemaking moves such as mechanistic reasoning and analogy building (Odden & Russ, 2018; 2019). Students frequently engage in sensemaking processes during both macro- and micro-level experimental activity. For example, troubleshooting involves iterating between the micro-level actions to identify and resolve procedural inconsistencies. Similarly, students often iterate between conceptual and experimental elements while

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sensemaking at the macro-level to recognize and resolve inconsistencies between experimental evidence and hypotheses. We suspect that students' iterative practice is simultaneously experimental and epistemic, allowing improvement of experimental results and generation of new conceptual knowledge.

We ask the following research question: In what ways do undergraduate students engage in iterative practices at the nexus of their experimental activity and sensemaking in undergraduate physics lab settings? To answer this, we examined thirteen student groups' experimentation in a reform-based undergraduate physics lab course. To provide a detailed analysis, we present an instrumental case study of a student group, highlighting their iterative practice at the macro- and micro-levels of experimental activity and sensemaking.

Research Methods

This study was conducted in an Introductory Physics for Life Sciences (IPLS) laboratory course at a large, research-intensive university in the western United States. The course was recently reformed to prioritize students' autonomous engagement in authentic scientific experimentation. Enrolled students were predominantly life science majors who planned on attending medical school. The student population was majority upper-division (86%), white (67%), and male-identifying (53%). In the course, students work in groups to complete multi-week investigations by developing research questions and experimental designs to model a biological phenomenon, conducting the experiment, and developing and presenting a scientific argument to their peers and instructors.

Data from 13 groups across four labs included screen capture data of their computers and external video and audio. We first identified macro-level categories of students' experimental activity composed of micro-level actions; for instance, macro-level data collection composed of micro-level actions of adjusting experimental equipment, reviewing technical documentation, or preparing biological samples. These categories were used to code random selections of the video data, and we refined the categories until reaching saturation. Two authors then conducted interrater reliability measurements, achieving near-perfect agreement (κ=0.83) after a single round of coding changes. The first author then coded the remaining data. Next, we reviewed the coding to identify the entry (inconsistencies) and exit conditions (resolutions) in students' sensemaking. We identified sensemaking episodes related to both micro-level procedural and macro-level conceptual inconsistencies and then examined how students worked towards resolutions. We focused on both direct sequences of actions and iterative cycles across multiple actions and searched for instances where students iterated between collecting evidence, analyzing data, engaging in mechanistic reasoning, or constructing explanations (e.g., Odden & Russ, 2018).

To provide an in-depth analysis of students' iterative practice, we present an instrumental case study analysis of iterative practice from a group of four students (Lisa, Chloe, Margo, and Edmund; pseudonyms) whose iterative practice broadly represented the data corpus. This group was chosen via intensity sampling (Creswell, 2007), as it had rich, but not extreme, evidence of iterative practice. The group's experimental activity focused on investigating whether the concentration of microspheres housed within a fluid impacted their rate of Brownian motion (i.e., random motion of particles suspended in a fluid). Specifically, the group collected and analyzed video data of microsphere samples moving in fluids to determine how the concentration of microspheres impacts their rate of Brownian motion to model how medical drugs diffuse within and between human cells.

Analysis

Micro-level Iteration

Throughout their experimentation, the case study group engaged in multiple iterations of micro-level experimental activity cycles while sensemaking to resolve inconsistencies in their experiment. These micro-level iterations typically involved four steps: *proposing causes* for an inconsistency, *planning* micro-level experimental actions to work towards resolution, *carrying out* these actions, and *assessing* the action's outcomes against desired resolution. We highlight an example from early in their investigation when the group encountered a micro-level procedural inconsistency during data collection that sparked a sensemaking process.

When preparing a microsphere sample for video collection, the group recognized a procedural inconsistency: the second sample (labeled 500x) had fewer microspheres than the first (labeled 100x), contradicting their expectation that the 100x sample had a lower concentration. This inconsistency recognition initiated the group's iterative micro-level sensemaking process, where they enacted multiple iterations of micro-level experimental activity actions in direct sequence. In Step 1, the group *proposed causes* for the inconsistency, including inconsistent mixing (Chloe: "Did I shake it too much?") or microsphere settling (Chloe: "It might have just settled."). In Step 2, the group *planned* micro-level experimental actions to resolve the inconsistency. They planned to collect a new sample of their microsphere solution more carefully from the bottom of a properly mixed vial (Edmund: "Maybe closer to the bottom … not touching the bottom necessarily but just the closest you can get without touching."). In Step 3, the group *carried out* this micro-level experimental action, preparing their new

sample according to their plans. In Step 4, the group *assessed* the outcome of this micro-level experimental action, identifying that the new microsphere sample looked "weird" and "squished" rather than evenly dispersed and spherical. Without resolution, the group completed additional iterations with similar experimental actions to resolve the inconsistency and move forward, reaching resolution with instructor assistance. When comparing this case to others in the data corpus, we found that most observed groups engaged in multiple iterations of micro-level experimental activity cycles while sensemaking about procedural inconsistencies, with variation in the sequence of steps, the role of instructor support, and the nature of the formal resolution.

Macro-Level Iteration

At a macro-level, we found that the group iterated between four steps that involved experimental activity and sensemaking to construct an explanation that accounted for experimental evidence. In Step 1, the group engaged in *experimental activity to collect evidence*, either through qualitative observation or through quantitative analysis. In Step 2, the group *compared their collected evidence to their initial experimental hypothesis*. In Step 3, students *recognized an inconsistency* between their collected experimental evidence and their initial experimental hypothesis, initiating a period of sensemaking. In Step 4, students *engaged in sensemaking* to attempt to resolve the inconsistency. After most iterations, the group would determine that additional evidence was needed for their explanation and then collect new evidence, initiating a new iteration.

Early in their experiment, the group engaged in the four macro-level steps while collecting videos of their microsphere samples, shifting from experimental activity to sensemaking through recognizing an inconsistency between their evidence and hypothesis. In Step 1, the group *collected experimental evidence* about speed and concentration by looking at the microsphere sample via the microscope camera and computer. In Step 2, the group *compared their observational evidence with their initial experimental hypothesis*; shortly after their initial observations, Lisa said: "Just eyeballing it, I don't think the one with more spheres was moving more." We infer that her phrasing "I don't think" suggests she had an initial expectation, from the group's hypothesis, that the sample with a higher concentration of microspheres would have faster Brownian motion, contrary to their observations. This statement leads directly to Step 3, where the group formally *recognized an inconsistency* between their observational evidence and hypothesis (Lisa: "I mean, our hypothesis could be incorrect, you never know."). Lisa recognized an inconsistency between their observational evidence and their initial hypothesis, though she was hesitant to argue outright that their hypothesis is incorrect based solely on qualitative evidence ("The data will confirm."). In Step 4, the group *enacted sensemaking moves* to resolve the inconsistency. Following Lisa's comment, Edmund and Chloe engaged in mechanistic reasoning to develop an explanation of the mechanisms that could support their initial hypothesis, even though it does not account for their preliminary evidence. Edmund incorporated his understanding of diffusive processes ("if there are more spheres in an area … they are going to want to move out.") to support the group's initial hypothesis. Chloe added description that higher microsphere concentration should result in more collisions, which she equates to more overall Brownian motion ("They're colliding with each other … so, they should be moving more."). At this stage of their experimentation, the group seemed to be confident in using their initial hypothesis for their final explanation, but they were open to revising it based on additional evidence (e.g., "The data will confirm."). After Edmund's last statement, the group shifted back to collecting additional evidence.

The group iterated through this four-step cycle several times during subsequent experimentation. For example, later, the group computed diffusion coefficients (a quantity representing the rate of Brownian motion) during several rounds of quantitative data analysis (Step 1), compared their data to their initial hypothesis (Step 2; "Just eyeballing your number, so far it doesn't look like it's bigger than eleven."), recognized the inconsistency between their evidence and hypothesis (Step 3; "I thought it was supposed to be … bigger."), and engaged in sensemaking to resolve the inconsistency through constructing new explanations (Step 4). In Step 4, the group used mechanistic reasoning to construct an explanation that reinforces their initial hypothesis. Edmund recognized that the conceptual elements of the group's hypothesis cannot support a formal explanation of their results: "Technically, similar equilibrium … they should all be distributed somewhat equally, even though there's more spheres in one or the other, how they're spaced … it's not like, in one video there's a bunch in one spot and not another, and in another video they're all …" The group recognized that developing an explanation to reinforce their hypothesis may not resolve the inconsistency since the explanation does not account for experimental evidence or align with their studied system. The group then decided to collect additional evidence.

After collecting and analyzing their final evidence, the group shifted to a final sensemaking period to explain their results and the underlying mechanisms at play. The group built multiple analogies to address elements of their system, including equating microsphere Brownian motion to "when you're in a crowded elevator" and contrasting this phenomenon with billiard ball collisions ("If you just had microspheres but got rid of the fluid, like a bunch of billiards balls that interacted with each other, that's not [your system]."). Through additional

sensemaking discussion, the group eventually developed a consensus explanation (e.g., Lisa: Because when [a microsphere] bumps into a fluid particle … it's just gonna change its course versus, like, stop it from moving. When it runs into something with its same size, it's kinda gonna stop moving.").

In summary, the group frequently shifts between four macro-level steps throughout experimentation, iterating between collecting experimental evidence, comparing their evidence to initial hypotheses, recognizing an inconsistency, and engaging in sensemaking. We found that most groups in the data corpus enacted similar macro-level iteration to construct explanations, though there was variety in the iterative sequence, flexibility of initial hypotheses, and reliance on experimental evidence during explanation construction.

Discussion

This study utilizes a theoretical lens of iterative practice to analyze student reasoning at the nexus of experimental activity and sensemaking. The results highlight two distinct forms of iteration within micro- and macro-level experimental activity. While the experimental activity observed here has been documented elsewhere, focusing on students' iterative practice begins to shed new light on the progression of student reasoning during experimental activity in ways minimized in other literature. This work sheds light on how iterative practice exists at different scales within multi-dimensional learning environments; future research can explore how iterative practice may be prevalent at different cognitive and procedural levels within student learning in other contexts. As well, while this study broadly focuses on experimental and epistemic iteration, other forms of iterative practice may be more ubiquitous in other learning environments, such as course-based undergraduate research experiences (CUREs). Beyond empirical studies, these results reinforce our knowledge that student learning in science is often nonlinear and iterative, further stressing the need for new pedagogical approaches in science education.

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Graphing with Balance Board Math: Critical embodied design for regulation and learning

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Abstract: Some forms of movement, such as rocking, are common means of sensory self-regulation yet are discouraged in classroom contexts. We analyze the ableist underpinnings of this approach, and ask instead: could sensory-attractive activities such as rocking instead be solicited to serve content learning? Our design-based research project, Balance Board Math, fosters sensory–cognitive opportunities for the regulatory movement of rocking to serve as an intrinsic interaction resource for exploring mathematical graphical representations, with a focus on properties of sinusoidal functions such as frequency and amplitude. We analyze the role of balance/vestibular activation in pilot participants' exploration of graphing before, during, and after Balance Board Math activities.

Theoretical framework and design objective

Research on the relationship between bodily movement and learning flourishes in the learning sciences separately from fields such as psychology and occupational therapy (OT). While learning sciences researchers, inspired by the embodied turn in the cognitive sciences (e.g., Newen et al., 2018), are actively evaluating interactive designs that recruit bodily movement to enact concepts (Lee, 2015; Zhong et al., 2021), psychologists and occupational therapists advocate the maintenance of optimal alertness levels by engaging sensory stimuli that are of an adaptive intensity for one's neurological sensory processing profile (Dunn, 1997). As such, embodied cognition and sensory regulation paradigms currently offer distinct implications for understanding and fostering learning. Embodied cognition views of education construe movement as a means of exploring concepts (e.g., walking along a number line); sensory regulation construes movement as a means of regulating one's arousal state to sustain engagement (e.g., bouncing on an exercise ball). These two bodies of literature remain disparate due to the assumption that regulation and cognition are independent processes. We ask: might these siloed theoretical perspectives mutually inform each other towards a more holistic understanding of movement in learning? What if students' spontaneous regulatory activity, such as rocking or fidgeting, were resources for novel forms of instruction? We investigate these questions by creating a math instructional context where the sensory regulatory behavior of rocking is invited to participate in math conceptual exploration: Balance Board Math (BBM).

Self-initiated sensory-regulatory movements, such as pacing or rocking, are often read as disruptive, and such readings are compounded by the divergent sensory practices of many learners with disabilities (for example, learners on the autism spectrum; see Nolan & McBride, 2015) as well as racialized readings of students' bodies (Annamma et al., 2013). Situated within the Special Education Embodied Design (SpEED) design-based research framework (Tancredi et al., 2022), BBM sets out to deconstruct ableist norms of bodily engagement in schools, legitimizing learners' diverse sensory regulatory movements within the classroom. Inspired by the ubiquity of spontaneous vestibular-activating movement such as rocking and pacing, we imagine vestibular-driven mathematical conceptualizations that could offer new resources for inclusive instruction. Acknowledging the spectrum of sensory profiles (Dunn, 1997), BBM seeks to offer children the opportunity to engage their vestibular sense at an intensity adapted to their specific neurological thresholds and needs.

Design

Balance Board Math (BBM) (Figure 1) is a motion-graphing learning environment (Duijzer et al., 2019), where learners explicitly recruit and refine their capacity to attend through their vestibular sensory modality as their means of mathematical exploration. BBM establishes a whole-body relation to graphs, mirroring observations of skilled graphers "being the graph," not just "seeing the graph" (Gerofsky, 2011). In BBM, a sensor detects the board's angular shifts. As learners rock on the board, they draw a live graph representing properties of their rocking which is projected on a screen in front of them (Figure 1).The speed and sensitivity of the graph is

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calibrated at the onset to each student's comfort. Learners' left/back rocking correlates to an upwards trajectory and right/forward correlates to a downwards trajectory. BBM activities focus on sinusoids to solicit the rhythmic and repetitive rocking patterns that are characteristic of sensory regulation. BBM's discovery-based learning activities explore different aspects of a function: graphing, amplitude, and frequency (Figure 2). Learners are tasked with figuring out how to generate and maximize a focal color (here: green) within each activity. In Function Exploration, the user's line turns green if they trace a function displayed on the screen (Figure 2, left). In Amplitude Exploration, the graph turns green when they rock at a target amplitude (Figure 2, center). In Frequency Exploration, only periods of a focal length turn green (Figure 3, right). Users come to identify and control different parameters of their graphs. The specific focal amplitude, frequency, or function can be modified, serving primarily as a context to guide users to attend to different aspects of their rocking.

Figure 1

Rocking on a balance board (left) generates a graph (right)

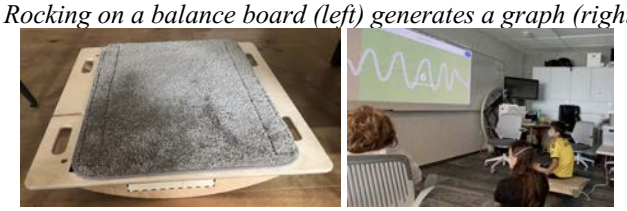
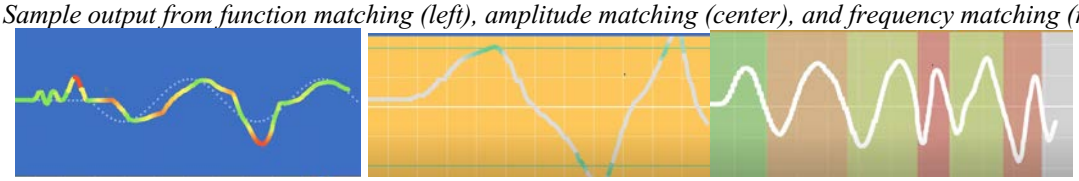


Figure 2

Sample output from function matching (left), amplitude matching (center), and frequency matching (right)



Research questions

1. What roles do vestibular-stimulating movement play in learning when invited into math instruction?
2. Does BBM change children's perception of graphs, as expressed through their speech and gestures? If so, how?

Methods

BBM was piloted through semi-structured clinical interviews with six children grades 2-6 individually or in pairs in a lab or after-school learning center. Upon trying each activity, participants were prompted to ideate on what made green and offered to try again until they were satisfied with their explanation and outcome. Before and after the interviews, participants were prompted to describe three static images of sinusoidal graphs using gestures and words. We transcribed and coded video for rocking pattern, task strategy, and regulatory activity, and two raters blinded to pre/post order coded graph gestures quantitatively for the "seeing" vs. "being" the graph criteria in Gerofsky (2011). For a more in-depth description of methods and analysis, see (Tancredi et al., in press). Here, we draw examples from the case of one 6th-grade boy, Kyle, for whom we had the most complete data.

Results

Balance Graphing Interactions

Participants rocked to explore each BBM activity. Participants expressed a range of vestibular sensory preferences during these activities, from gentle rocking with limited amplitude to intense rocking across the board's full range of movement. Our focal case student, Kyle, explored the three activities together with a peer, Cory, for several rounds, continuing after Cory departed. Kyle generally rocked with greater intensity than Cory. The pair were able to identify and control the focal parameter in each activity through cycles of graphing and reflection, and to communicate about their products across their different rocking styles.

Consistent with a sensory regulation perspective (e.g., Dunn, 1997), during activities like listening that entail less inherent vestibular stimulation, the children spontaneously rocked on the board. Children informally identified as highly sensory-seeking by their parents or instructors exhibited a higher frequency and intensity of such rocking. In one instance, Kyle was engaged in such rocking when the interviewer commented, "you mentioned earlier something about the distance between each hill." With the words "distance between each hill,"

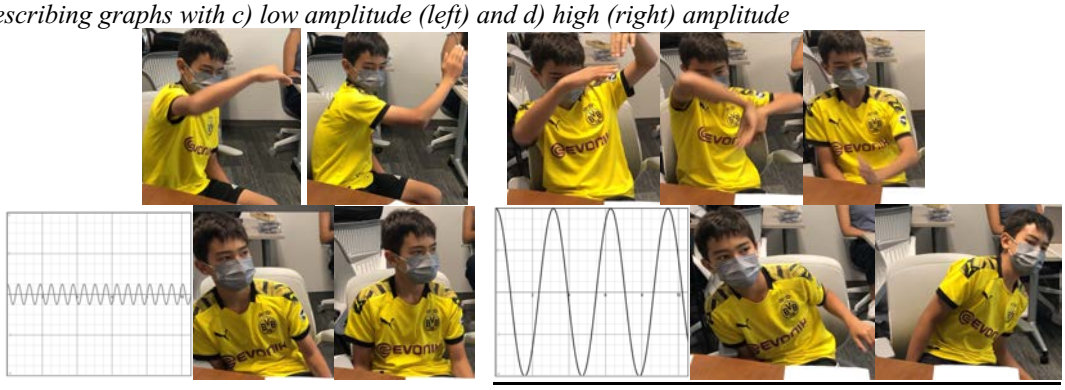
Kyle's rocking suddenly shifted to slow, sweeping rocks, corresponding with how he would have created spaced out graphical features earlier. What would traditionally be interpreted as background movement-for-regulation fluidly transformed into movement-as-thinking as Kyle acted out the conjecture raised by his interlocutor. At times, such rocking seemed to participate directly in his thought process. For example, when asked, "what did you notice this time about green?" Kyle responded, "Maybe it's not how far it is, but… [rocks right, left, right, left, slows to a stop in the center]. I don't really know." Rocking was enfolded within his sense-making utterance, perhaps reanimating the actions that produced his graph, perhaps expressing a thought not yet verbalizable, as observed in gesture–speech mismatch (Church & Goldin-Meadow, 1986). What would traditionally be interpreted as sensory-regulatory behavior in this context fluidly interacted with the meaning-making process.

Pre and Post Graph Interviews

Across participants, there was a statistically significant increase in mean being-the-graph gesture index scores from pre to post ($t = -2.19$, $d.f.=11$, $p < 0.05$) (see Tancredi et al., in press), reflecting progress from "seeing" towards "being" the graph on Gerofsky's (2011) scale. For example, during all three pre-interview graphs, Kyle positioned his gestural graph's *x*-axis at roughly shoulder height and spanned from nose/forehead down to heart for the *y*-axis (Figure 3a). During the post-interview, his gestures covered a broader span, with the *x*-axis falling at heart level and the y-axis spanning from the top of his head to his waist (Figure 3b). Kyle also showed newfound core-muscle and spine engagement in the post interview. Furthermore, during the post-interview, Kyle exhibited rocking movements accompanying his speech descriptions: he he rocked his upper body left to right as he described one graph as "quicker," and another as "slower um but like rocking a lot farther" (Figure 3c, 3d). Kyle's rocking gestures also reflected graphs' relative amplitudes. When describing a low amplitude graph (Figure 3c), he rocked about 15 degrees from vertical, whereas for a high amplitude graph, (Figure 3d), he rocked about 25 degrees from vertical. Kyle's rocking motions during verbal descriptions suggest that applying the balance board instrument as a means of drawing graphs has shaped his *utilization scheme*: he perceived graphs as affording rocking (Vérillon & Rabardel, 1995).

Figure 3

a) Kyle gestures sin(x) (pre, upper left) and b) cos(x) (upper right); Kyle rocks while verbally describing graphs with c) low amplitude (left) and d) high (right) amplitude



Discussion

These preliminary findings suggest that dynamic/interactive/whole body experiences with BBM may residually affect how students perceive traditionally static graph displays even when off the balance board, enriching their enactive landscape (Kirsh, 2013). They also suggest that BBM could be a rich context to study the intersection of regulatory and mathematical movement. This design-based research project offers a prospective proof-of-concept for recruiting regulatory activity into mathematical discourse, as well as for the viability of vestibular experiences in conceptual learning. Future work will further evaluate the interaction between different sensory profiles and BBM activity and seek to evaluate BBM in inclusive education settings across profiles. To this end, BBM will expand into multi-user activities and other access modalities such as sonification.

Conclusion

BBM not only provides enhanced opportunity for vestibular sensory regulation, but also positions vestibular experience as integral to mathematical exploration. The project seeks to bridge previously disparate research on sensory regulation and math education and ultimately contribute evidence to elaborate upon embodied cognition theory through a sensory perspective. Embodied design (Abrahamson et al., 2020) calls for instructional design

to embrace and build from learners' embodied resources. Grounding in these preliminary results, we propose that to do so, instructional design must 1) offer students access to a range of sensory stimulation to support regulation, and 2) think beyond the restrictive norms of classroom bodily engagement and the narrow focus on dominant instructional modalities like vision and audition. BBM focuses on rocking and the vestibular sense, but implications may carry over to other senses commonly engaged for sensory regulation such as the tactile and proprioceptive senses. Legitimizing sensory regulation within educational practice can help deconstruct ableist instructional norms that disadvantage sensorially minoritized learners and introduce new entry points into academic concepts for all learners.

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Discovery of Similarities across Debugging Tasks in Relations within and between Virtual and Physical Objects

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Abstract: Analogical reasoning is critical in debugging. Still, the literature is unclear on how non-CS major novice programming learners draw inferences from previous debugging tasks when attempting to understand the present debugging task. We addressed the research question *How do novice programming learners discover relational commonalities across debugging tasks in which block-code contains structural relations within itself and with a corresponding robot?* We used a theory-informed coding scheme to analyze interviews and screencasting data. We found that (a) noticing similarities in *function* between the target task and the source task(s) guided learners to discover *relational commonalities within block code* between the source task(s) and the target task, (b) functional analogy was not necessary for discovery of every relational commonality between the target task and the source task in block code, and (c) noticing and using relational commonalities did not always lead to successful debugging.

Introduction

Strategies to facilitate analogical mapping between a source context and a target context have been studied in many domains. In programming learning contexts, strategies tend to involve analogies connecting unfamiliar programming concepts and rules to familiar ones (Muller & Haberman, 2008). But there has been less attention paid to how non-CS majors draw inferences from their previous debugging task when attempting to understand the present debugging task. Doing so requires that multiple relations be highlighted to make analogical comparisons within debugging. That is, comparisons are not just between one structure (of a source task) to another structure (of a target task) (e.g., leaves : a tree :: petals : a flower) but also for one set of structures from multiple relations within a source debugging task to another set of structures from multiple relations within a target debugging task. In this study, debugging tasks contain both virtual and physical objects and their relations. For example, comparing *block code* in a source debugging task to *block code* in a target debugging task is part of analogical reasoning, but so is comparing *relations between block code and the robot* in a source debugging task to *relations between block code and the robot* in a target debugging task. As shown in the figures below, there are common relational structures between virtual objects, Figure 1 (the source) and Figure 2 (the target). The relation between the repeat # times block A and the movement blocks B is that B is repeated # times indicated in A. There are relational structures also between the block code (the virtual object) and the robot (the physical object) in that the robot is moved by the block code (the robot moves # times depending on the parameter in the repeat function), which also creates parallel connectivity between the source debugging task and the target debugging task.

Figure 1
Source Task (Tracing a Square Once)

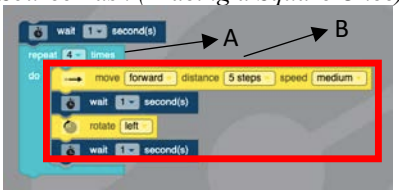

Figure 2
Target Task (Tracing a Rectangle 3 Times)

Research shows that people can recognize relational commonalities even with "conflicting object matches" between two tasks (Gentner & Smith, 2013, p. 4). For example, when given one picture showing a tow truck towing a car and the other picture showing a car towing a boat, people are highly likely to choose the boat in the second picture as a corresponding object to the car in the first picture due to the common structural relation between towing and being towed (Gentner & Smith, 2013). Block code in the present study was not an object as familiar as daily objects like vehicles to our participants and also contained symbolic, visual, and material forms. Thus, our research question was: *How do novice programming learners discover relational commonalities across debugging tasks in which block-code contains structural relations within itself and with a corresponding robot?*

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Conceptual framework

Our conceptual framework was grounded in the analogical reasoning (e.g., Gentner & Smith, 2013) and computer programming (e.g., Clement, Kurland, Mawby, & Pea, 1986) literatures but also design studies that investigated analogical reasoning during design (e.g., Ahmed & Christensen, 2009; Chai, Cen, Ruan, Yang, & Li, 2015; Cheong, Hallihan, & Shu, 2014; Gero & Kannengiesser, 2004). Our framework includes three perspective angles. Analogical reasoning *processes* include the encoding, inferring, mapping, applying, and verifying phases (Gentner & Smith, 2013; Sternberg & Rifkin, 1979). Analogical reasoning *foci* include visual, functional, behavioral, and structural analogies (Chai et al., 2015; Gero & Kannengiesser, 2004). Analogical reasoning *forms* include analogical comparisons in virtual objects, physical objects, and relation between virtual and physical objects. Our framework defines small, large, and mixed analogical reasoning distances between the source and target tasks, meaning a small distance having greater superficial similarities (Ahmed & Christensen, 2009; Muller, 2005).

Methods

Participants and context

Participants were 19 undergraduates who engaged with a robotics and play unit in a required three-credit play-based activities course in an early childhood and elementary education program of a large public university in the northeastern United States. The unit was for 90 minutes per week for eight weeks. All but two participants had completed field experience at the preschool, kindergarten, and/or lower elementary grades. All but one participant indicated no to little programming knowledge prior to the unit. Both members of the pair reported in this proposal - Judith and Anne - were female and juniors. All names have been changed.

Debugging tasks

Participants were invited to debug a series of buggy code segments given along with descriptions that explained expected behaviors of robots in an early childhood's play and learning context. In total, nine debugging tasks with increasing difficulties were given, five of which were done in class as paired debugging tasks and four of which were done as homework individually. Three practice tasks were given between debugging tasks. In this proposal, we present one debugging task called "Cleaning the Playroom" as the target task (Figure 4), and its similarities and dissimilarities with one of the source tasks called "Color Game" (see Figures 3 and 4).

Figure 3
Code for the Color Game Task

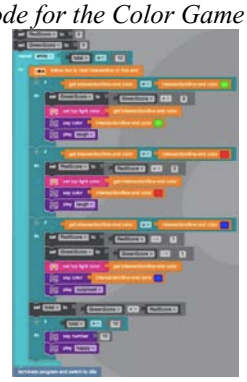
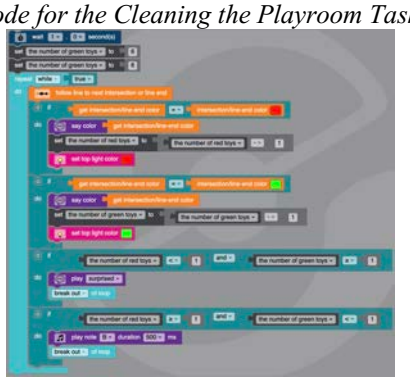


Figure 4
Code for the Cleaning the Playroom Task



Data collection

Participants' computer screens were recorded during debugging. Their reflections and final code were collected during the unit and interviews were conducted after the unit ended. The total length of all screen-recordings was about 33 hours. Anne and Judith's screen-recording was about 3.5 hours. They were also video-recorded.

Data analysis

We developed a coding scheme based on our conceptual framework grounded in the analogical reasoning literature (Chai et al., 2015; Clement et al., 1986; Gentner & Smith, 2013; Gero & Kannengiesser, 2004, 2014; Gero & McNeill, 1998; Ruppert, 2013; Sternberg, 1977; Sternberg & Rifkin,1979). The coding scheme included encoding and inferring, mapping, applying, and verifying as high-level nodes. All nodes had sub-nodes for small distance, large distance, and mixed distance. *Mapping* sub-nodes were used to code visual, functional, behavioral, and structural analogies. Applying sub-nodes were used to code correct and incorrect uses of relevant or irrelevant similarities and dissimilarities. We first pilot-tested the coding scheme by applying it to

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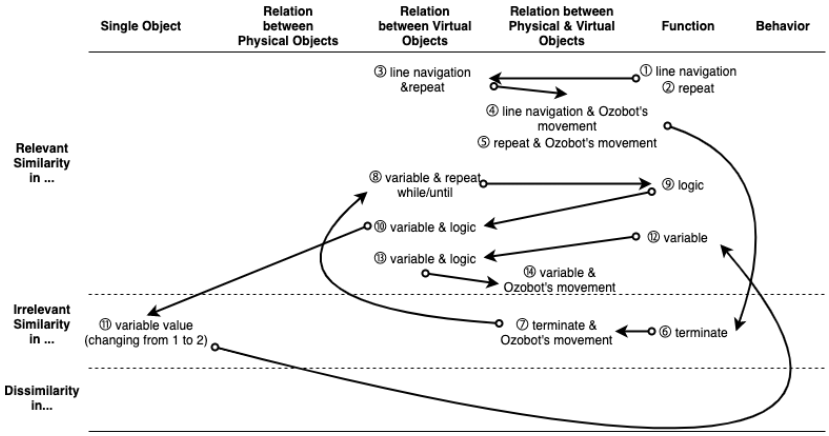
data from two participants' debugging tasks (Octagon and Hexagon). After coding independently, we met to reach consensus and address discrepancies in coding. Then, we independently coded two other participants' data from debugging the Energy versus Obstacle task. We met again to reach consensus and address discrepancies in coding. Then, we did another round of independent coding for data from Anne and Judith's debugging the Energy versus Obstacle task. Upon completion of the third pilot coding task, we again met to discuss coding, and decided to add mixed distance to the coding scheme. Then, we recoded using the revised coding scheme independently and reached consensus. Finally, we coded Anne and Judith's data from their Cleaning the Playroom debugging in NVivo. The average interrater reliability ICC score was 0.849.

Findings and Discussions

Figure 5

Summary of Anne and Judith's Analogical Comparisons during Debugging



Noticing similarities in *function* between the target task and the source task(s) guided learners to discover *relational commonalities within block code* between the source task(s) and the target task. For example, analogical comparisons that Anne and Judith went through from ① to ② and ③ in Figure 5 depict that they did not begin seeing ③ the *relational commonality* between the target task (the Cleaning the Playroom task) and the source task (the Color Game task) in the structural relation between the line navigation and the repeat blocks until they noticed ① ② the functional commonalities of line navigation and repeat blocks between the target and source tasks. The role of such a functional analogy, in this case, is productive considering that it eventually led to the discovery of ④ ⑤ *relational commonalities* between the block code and the robot in the target and source tasks. Such a productive role of functional analogy is contradictory to findings in analogical reasoning literature in which functional comparisons were found to limit reasoners' capacity to identify relevant analogy (Cheong et al., 2014). The multimodal forms of objects in the present study may have impacted this finding. Due to symbolic, visual, and material forms used in debugging tasks and relational structures embedded within and between the multiple forms, understanding function of objects was critical to understanding objects and structures within them and associated with other objects. It seems natural to use tangible analogies ① ② to visualize analogies that are not immediately visible ③. Table 1 shows the pair's discourse and actions during analogical comparisons.

Functional analogy was not necessary for discovery of every relational commonality between the target and the source tasks in the structure within block code. As shown in ⑧, the participants were able to map the relation between the repeat while and the variable blocks in the target task to that in the source task. Noticing this relational commonality led to attention to ⑨ functional commonalities of logic blocks in the target and source tasks. While functional analogies were used again to understand the logic blocks and their structures in ⑨, as in ①, this could be attributed to less familiarity with logic blocks compared to more familiarity with repeat blocks built through analogical comparison from ① to ⑤.

Noticing and using relational commonalities did not always lead to successful debugging. For example, when Anne and Judith noticed ⑩ the relational commonality between the target and the source tasks in the structural relation between the variable and the logic blocks, they then fixated on ⑪ analogical comparison of the numeric value in the math block between the target and source tasks. This analogy was unrelated to bugs in the target task, thereby leading to studying ⑫ the function of variable blocks.

Implications for research and practice

The present study contributes to advancing the analogical reasoning literature by adding empirical findings of novice programmers' learning processes that involve tasks with complex relational commonalities. It also enriches research on debugging through the lens of analogical reasoning. Its practical contribution is to CS education in that understanding of non-CS majors' reasoning during debugging can be used in broadening participation in CS.

Table 1

Part of Anne and Judith's Debugging Episode

Debugging scene	Source task	Target task	Analogical comparisons
Judith: Why do you think the Ozobot did what it did? Anne: Because this [follow line to next intersection or line end] block wasn't here [in the repeat block] like this if statement (*She pointed out the if/do condition for red intersection to indicate the correct place for the follow line to next intersection or line end block)* ① ②	Line navigation block was within repeat block before logic block, which made the robot move continuously.	Line navigation block was out of the repeat block in the buggy code.	They focused on the location of line navigation block in the target task: outside of repeat block, not inside repeat block. The pair noticed similarities in function of line navigation and repeat blocks between the target and the source tasks ① ②, which made the robot move continuously.
Judith: What is a rule? Anne: but like a movement [line navigation block] before the if statement ③. I don't know.	Line navigation block was within repeat.	Line navigation block should be within the repeat block to make line navigation block work repeatedly between intersections.	They began noticing similarity in relation between line navigation block and repeat block between the target and source tasks ③.
Judith: All right. What if we put a follow line or line navigation block underneath of a repeat block ③ in order for it to follow a grid [on the map]? ④ ⑤ *(She indicated the rule by highlighting the correct place of line navigation block within repeat and its relation with the robot's movement)*	The robot moved on the map because line navigation block was within the repeat block.	The robot did not move on the map because line navigation block was outside of repeat block.	They developed a rule indicating the relationship between line navigation block and repeat block ③. They then noticed similarity in relation between line navigation block within repeat block and the robot's movement on the map in the target and source tasks ④ ⑤.

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The Tensions of Making Space: How Teachers Work Toward Heterogeneous Science Sense-Making

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Abstract: As science education navigates the tensions between convergence-seeking and heterogeneity-seeking images of science, this paper investigates how elementary science teachers work within and around these tensions as they make space for student sense-making. We focused on two teachers who participated in a multi-year professional development and analyzed moments when they engaged in both responsive and culturally responsive teaching practices. The first teacher used distributed scaffolds (i.e., zooms) to expand participation in science activities and foreground students' prior knowledge about the phenomenon, but often toward canonical or dominant cultural knowledge. Our second teacher showed a shift in her practice by restructuring a categorization activity from a pre-determined worksheet to having students determine the categories. We argue that making space practices that align more with culturally responsive and sustaining pedagogies could help teachers pursue students' ideas towards heterogeneity-seeking images of science.

Motivation and research questions

According to one of our teacher participants: "The process of [science] is really organic, not as static as we make it...we just have this really narrow vision of what science has been." The "we" refers to teachers and stakeholders with power (e.g., district leaders, policy makers) to enforce standards that K-12 science teachers feel immense pressure to cover. The most recent science standard reforms represent an important paradigm shift from focusing on knowledge attainment to authentic practices (NGSS Lead States, 2013). This paradigm shift is often implemented in convergence-seeking ways: students work to collaboratively build shared understandings and knowledge, drawing from their diverse initial ideas towards an accepted set of understandings represented in state standards (e.g., "storylines;" Reiser et al., 2021). This image of science is fundamental to making scientific progress, though it can often overlook the messiness, uncertainty, and multiple existing theories about science phenomena common in professional science practice (Pickering, 1995). Therefore, a heterogeneity-seeking image of science, where divergent explanations and processes for pursuing ideas about scientific phenomena are valued, is a lens used to validate students' multiple ways of knowing (Warren et al., 2020) moving towards more equitable sense-making and science learning. As we re-imagine how these two images of science (convergence-seeking, heterogeneity-seeking; Pierson et al., 2020) inform science lesson planning and enactment, we ask: How do science teachers navigate working within—or around—the tension between accountability to standards and to equitable sense-making?

Theoretical framework

In response to our teachers' desire to broaden the vision of what science can be, we built on the work of Haverly et al. (2018) and asset-based pedagogies (Warren et al., 2020) to contribute to conceptualizations of how teachers can *make space* for equitable sense-making—collaboratively constructing knowledge with students' diverse epistemic resources—in classrooms. Our PD design also built on *responsive teaching* (Robertson et al., 2015) and *culturally responsive teaching* (Gay, 2018). In our PD, we tried to support teachers to see students' disciplinary strengths from a responsive teaching lens, but this pedagogical approach often assumes science is neutral or objective and that the goal of science education is conceptual change, usually toward a specific learning objective. At the same time, we saw examples of our teachers enacting culturally responsive and *culturally sustaining pedagogies* (Alim & Paris, 2017). As we continue to make space for students' diverse ideas to be added to collective scientific sense-making, we must also consider: "the ways in which young people are enacting race, ethnicity, language, literacy, and their engagement with culture is always shifting and dynamic" (Alim & Paris, p. 7).

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In this paper, we explore how teachers, supported by both responsive teaching and culturally sustaining approaches, navigated tensions between convergence-seeking and heterogeneity-seeking images of science that made space for and successfully sustained a greater range of children's sense-making resources and prior experiences. To examine our research question (How do teachers navigate the tension between accountability to standards and to equitable sense-making?), we present two cases that elucidate some ways teachers navigated both *within* and *around* tensions between these two images of science.

Methods

We focused on two of nine teachers who were all part of a larger, multi-year project in a Southeast city of the US. Our first case study (Yin, 2014) follows Anne, who taught first grade and was in her second year of teaching. Soren is our second case study teacher, who taught kindergarten, and was in her 14th year of teaching. We collected video data from two to three lesson observations per teacher and four video club professional development meetings each academic year where teachers presented a recorded clip from their classroom practice to collectively reflect on representations used in cross-grade-level groups (Sherin & van Es, 2005). We present data from classroom (observations and recorded clips) and video club data in our findings. Our research team then engaged in iterative video analysis using interaction analysis (Jordan & Henderson, 1995). We (1) time indexed and content logged videos (Derry et al., 2010); (2) wrote memos and timestamped episodes when teachers made space (e.g., validated student thinking, adding zooms on diagrams); and (3) collectively viewed episodes to refine our hypotheses (Engle et al., 2007) about how teachers worked within or around the tensions between convergence- and heterogeneity-seeking images of science.

Findings

Our first case study showed Anne used common distributed scaffolding practices (Tabak, 2004; e.g., zooms on diagrammatic representations) to make space for broadened student participation. We argue space was made for students from historically minoritized backgrounds to contribute to the science storyline, but towards an image of science that was mostly convergence-seeking. Our second case study (Soren) represented an example of how a teacher's making space and distributed scaffolding practices shifted from convergence-seeking to more heterogeneity-seeking images of science, presenting more and different opportunities for sense-making. These examples will show the variety of perspectives teachers may be operating under in respect to the paradigm shift we propose, and how there was still room for teachers to push forward toward authentic epistemic heterogeneity and validating students' epistemic agency to author their own sense-making processes.

Anne: A zoom that prompted a teacher reflection on epistemic authority

In Anne's classroom, she used diagrammatic representations to help first graders understand the relationships between heat and energy. Specifically, the tool Anne used was a *zoom*. The zoom was introduced during PD as a learning scaffold that "lets us see something that is not really observable." Using this tool as "microscope eyes," students can make visible something that was not seen before. This analysis centers on Anne sharing a clip of her classroom teaching during a video club with other teachers.

In the classroom video, Anne followed one student's idea to add a zoom coming from a stick figure's foot. Then, the student suggested adding "red stuff" to the foot inside the zoom because "your feet will be red if they burn." Anne used the color red as a convergence-seeking scaffold to highlight relationships between heat transfer and the sun. Pivoting to the whole class, she took up the student's comment about red burns asking, "Does anyone else know anything about burns? Anyone ever had a sunburn?" When only one student replied "yeah," Anne responded, "Maybe? Maybe?" After a beat, Anne called on the student who replied and continued her line of questions about sunburns. "What happens to your skin when you get a sunburn?" Anne asked. "It—it turns red," the student replied. From this affirmation, Anne turned to the representation on the board, added a zoom, and drew a foot inside it—toes and all. When the video was paused, Anne explained to the video club group that mentioning the sunburn "was an 'uh-oh' moment" because as "a white teacher when I think later, I was talking about a sunburn… And, I was like, 'Well that was a privileged moment of me.'" In this moment, Anne recognized that her assumption that all students could relate to having a red sunburn was based on the notion that everybody had experienced red sunburns, when "not all of [her] kids get a red sunburn." From this "uh-oh moment," Anne pressed on in the video. "What color do you think we should color that foot?" Anne asked. In response, she got two answers from her students, "red" *and* "brown." In this moment the tension became fully realized and Anne had to navigate between the lived reality of students' different races (of which a majority were non-white), and the color red that had surfaced as a scaffold for the transfer of energy as heat. To reconcile this tension, Anne offered one student a skinny brown marker to "scribble-scrabble" in the color of the foot, while at the same time, Anne leaned over to color in spots on the foot with a skinny red marker to signify a "burn on [the] foot from [the]

sun." Overall, this episode portrayed the tensions teachers navigate between convergence- and heterogeneity-seeking images of classroom practices particularly as teachers attend to experiences different than their own.

Soren: Evolution of an activity

We now compare two instances of Soren teaching a similar lesson in Year 1 and Year 3 (Y1 and Y3).

Activity Structure

In the Y1 video, Soren designed an activity for students to record properties of materials at each of several stations; in the Y1 classroom video students were at the wood station. Soren constrained students' observations of wood objects by directing students on what part of the spatula to draw on their papers: "Draw the stick part, that's the wood part." In contrast, in the Y3 classroom video, Soren asked students to explore "different ways that we can sort" putting them in groups with bags including a mix of materials. In the Y3 video club, Alexis (3rd) noted she liked how Soren gave "them the space to pick out what things they see…it's like a mix of different reasons that they had to sort it." Alexis emphasized opportunities Soren designed to allow students' onto-epistemic authority (Warren et al., 2020) to define how to sort and what were reasonable sorting decisions. Indeed, Soren's design made space for students to sort by color, use, material, and sound. In Y1, Soren worked to ensure that students recorded information on their worksheet towards the convergence-seeking image of science where the standards correct answers were treated as the only right answers. In contrast, Soren in Y3 worked to create space for students' onto-epistemic agency and drew upon their contributions as part of meaningful disciplinary sensemaking.

Interactional Patterns

There were significant shifts in interactional patterns from Y1 to Y3. In Y1, Soren emphasized a one-on-one in series interactional pattern (Keifert, 2015) in which a teacher talked to one student, and then the next without other children talking (though they could observe). This is visible in Y1 when Ben wanted to connect the sharp point on his pencil to the sharp points of the pinecone that another student had identified, Soren responded "Oh, I'm asking [another student] but I like your connection. If you hold onto that connection, we'll talk about it." In contrast, in Y3, Soren emphasized collaborative discussion when one of the three students in the group described their decision making for their sorting, she responded, "Orange Tiger, do you agree with that?" and "Blue Cheetah, I like your thinking, but you need to share it with your group," to support students to learn how to engage with one another. In the Y3 video club, Regina (K) acknowledged developing this practice as a challenge and noted the practice of supporting shared sense-making between students could be difficult because they are still learning how to "verbalize their thinking." Regina emphasized to Soren, "You checked in with each kid in the group. Like 'You shared this, did you hear what he said? Do you agree? Do YOU agree?'" The Y3 shifts to encourage students to speak to each other was valued by teachers but also acknowledged as a challenge.

Feeling Phenomena

In Y1, Soren directed students towards what they should be noticing with their eyes, hands, and ears. For instance, when a child was struggling to describe the texture of a stick, Soren provided significant guidance when she said "Look. Is it smoo-oo-ooth (rubs hand slowly over surface of the floor) or bumpy (lifts hand and moves it in a wave-like gesture)?" and then repeated the question and gesture several more times before responding to the student with, " Good job! It's bumpy! Excellent! That's how it feels. You can write that down." In this exchange, Soren pushed the student towards describing what he felt to match her expected answer. In Y1, Soren also supported a student in attending to sound as he tapped a block of wood: "I saw you hitting it with your hand (*Soren hits her own hands together)*. What are you trying to discover?" and affirmed that the wood was hard. In Y3 when a child knocked two plastic items together, she asked: "What were you doing? Show us again what you were doing with them." This time the student replied, "Because they sound the same so I put them together." Soren affirmed saying, "Oh, you were testing…how they sound and that helps you know what they were made of?" Even though she affirmed students' reasoning in both cases, in Y1 Soren dictated what kinds of properties should be used while in Y3 Soren focused on revoicing student thinking. Thus, in Y1 Soren directed what to sense while in Y3 she followed students' reasons for their ways of investigating the materials.

Discussion and Implications

These case studies help answer the question of what happens after space is made for student sense-making, by showing how elementary science teachers navigated tensions within and around the convergence-seeking and heterogeneity-seeking images of science education. With Anne, she embodied the attribute of culturally sustaining teaching as comprehensive and inclusive. Even though her lesson used a collective model that our PD unknowingly communicated as a convergence- or consensus-seeking tool, Anne welcomed an unexpected piece

of cultural knowledge to the class model. Soren also showed us how culturally sustaining teaching can be empowering: she redesigned her activity from Y1 to Y3 so that the children directed and decided the rules of the categorization activity, allowing them to use an expansive set of sense-making resources (e.g., matching colors, hitting materials and comparing the hardness or sounds). As researchers, we are continually learning alongside our teachers as we pursue a heterogeneity-seeking image of science in our classrooms. While these examples are not an exhaustive list of ways to promote culturally sustaining and heterogeneity-seeking pedagogies in the classroom, we do want to highlight these moments as starting points to continue studying what making space and validating multiple ways of knowing look like in classrooms where there is still tension and immense pressure to meet predetermined convergence-sought standards. In future PD meetings, we hope to design resources more intentionally to promote heterogeneity-seeking images of science.

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International Society of the Learning Sciences

Designing for technological sovereignty: Forms of relating with culture and technology through community workshops

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Abstract: As new technologies proliferate our world, many well-meaning efforts seek to expand access to and broaden participation in STEM education and careers, yet many of these efforts disregard the fact that science, technology, and design are cultural processes. Building on a growing body of work, we examine how families experience and design together at the intersection of culture and technology. Drawing on Indigenous science and culturally sustaining/revitalizing perspectives, we investigate the ways in which families engage with culture and technology during a plant walk led by Tribal Elders that included a Tribally-designed virtual reality (re)interpretation of the experience. Insights from our findings highlight ways in which one Tribal Nation balanced culture and technology in ways that reclaimed their uses to maintain technological sovereignty and self-determination as designers.

Objective

One persistent challenge to broadening participation in and access to STEM is that the majority of these efforts operate from the assumption that science is acultural resulting in deep epistemological tensions (Bang & Medin, 2010; Brayboy & Maughan, 2009). Not only does this ignore the cultural, historical, and political roots of science, but it also marginalizes Indigenous peoples, who take an ecological approach to science and recognize it as inextricable from culture (Aikenhead, 1997; Bang & Medin, 2010). From this stance, we argue that the perpetuation of technological disparities is rooted in (mis)representation and lack of representation of Indigenous culture, education, and science. As a result, emerging technologies do not support or engage Indigenous ways of being and knowing and often they harm, silence, or further traumatize Indigenous peoples (Litts et al., 2020).

In response and resistance, scholars push for "technological self-determination and sovereignty" (Winter & Boudreau, 2018). We further posit that *who designs* matters as it inherently determines the cultural process of design and therefore the product of what is designed. To contribute to this ongoing conversation, in this paper, we share a four-day community workshop, *Shoshone Plant Experience*, designed with the Northwestern Band of the Shoshone Nation (NWBSN) to support engagement with culture, science, and art through digital and "original technologies" (Barajas-López & Bang, 2018). Our inquiry is guided by the research question: *how do culture and technology intersect in a community workshop?* Drawing on Indigenous science and culturally sustaining/revitalizing perspectives (McCarty & Lee, 2014), we investigate the *forms of relating* to culture and technology that families engage during a plant walk led by Tribal Elders and through creating digital (re)interpretations to share with the broader Tribal community. Given the tenuous history of technology with Indigenous peoples, our goal is to understand the ways Indigenous communities relate with digital technologies.

Perspectives

Indigenous Science

At the forefront of our work is Indigenous knowledge systems, science, and storywork. Indigenous knowledge systems are epistemologies rooted in science and storywork (Battiste, 2002; Brayboy, 2005). Indigenous science is a "culture-dependent collective rational perceiving of reality" (Ogawa, 1995, p. 588) often shared within communities through narrative experience and oral histories (Archibald, 2008; Kawagley, 2006). Indigenous stories frequently include narratives of origination and shared community experiences, and should be viewed as the equivalent of western theory and practices (Brayboy, 2005). In particular, storywork is the act of bringing Indigenous storytelling experiences into educational contexts (Archibald, 2008). In our work, Indigenous storywork as science is understood an inherently social process shaped by culture, history, and politics that is relationally intertwined with land and place.

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Culturally sustaining/revitalizing

We take a culturally sustaining/revitalizing approach (McCarty & Lee, 2014) to our work. Culturally sustaining/revitalizing pedagogy builds on Paris' culturally sustaining pedagogy (Paris, 2012) and focuses on understanding and conceptualizing educational practices specific to Indigenous learners. Culturally sustaining/revitalizing pedagogies are shaped by a deep recognition of Tribal sovereignty and need for decolonizing learning toward sustaining/revitalizing identities of Indigenous learners (McCarty & Lee, 2014).

Methods

Methodological approach

In our broader project, we adopt a community-based design research (Bang et al., 2016) approach, which consists of "design efforts that work from within the "ongoingness" of communities" (p. 11). Specifically, we take a *community-driven design research* (Litts et al., 2021) approach, a collaborative design process in which Indigenous partners maintain sovereignty as designers, to our partnership work. This methodological orientation recognizes the historical, cultural, and political nature of partnering with Indigenous communities, as well as embraces the needs for inviting community-wide, intergenerational participation and addressing systemic and historical challenges. From this stance, we take up an *intrinsic case study* (Stake, 2008) approach where we seek to understand the *Shoshone Plant Experience* itself as a case. Thus, the case is bound by the four days of the workshop. In this paper, we focus on moments where culture and technology intersect.

Setting and participants

The NWBSN is a community of about 575 enrolled members most of whom are dispersed across urban and rural areas in Northern Utah and Southern Idaho. Historically, NWBSN are a nomadic people without a designated reservation land. We held a four-day workshop, *Shoshone Plant Experience*, which consisted of one day of exploring native plants with Tribal Elders in a local canyon and three days of developing (re)interpretations of the plants' stories using a variety of media. As part of the workshop, Tribal community members also developed a virtual reality (re)interpretation of the plant walk (see: daigwade.org/shoshoneplants) to share cultural and experiential knowledge with the broader Tribal community. Family participation varied across days, but we had 20 participants throughout the workshop who consented to the research.

Data Collection and Analysis

In this paper, we present findings from a range of qualitative data collected throughout the *Shoshone Plant Experience*. Data include fieldnotes from four researchers, audio and video recordings, design work, and semi-structured interviews throughout the workshop. Across data, we developed the *Shoshone Plant Experience* as a case by tracing the ways in which families engage culture and technology through descriptive and in-vivo coding (Saldaña, 2009). We then examined the ways in which families experienced, described, and reflected on their relationship with culture and technology in moments where they intersected. Kimmerer (2013) explains how land is woven into storywork practices: "our relationship with the land cannot heal until we hear its stories" (p. 9). It is this act of relating that frames our analyses. We share Bang and Marin's (2015) commitment to "relational epistemologies," which is rooted in the belief that all things are "connected in dynamic, interactive, and mutually reciprocal relationships" (p. 534).

We collaboratively developed analytic insights through oral sharing and reflection in weekly meetings. Tribal Elders of the research team reviewed written accounts of these oral meaning-making sessions to establish resonance. With this collaborative meaning-making process, we collectively triangulate interpretations and claims (Creswell, 1998) across partners, perspectives, and data types.

Findings

While analyses are ongoing, we present here three *forms of relating* (reciprocity, preservation, and experiential) with the intersection of culture and technology that families shared through the *Shoshone Plant Experience*. Analytic contributions from Tribal Elders are presented as direct quotes.

Reciprocity of learning culture and technology

In the Shoshone Plant Experience workshop, we noted several demonstrations of the "mutually reciprocal relationships" (Bang & Marin, 2015) between cultural knowledge and digital technology. Tribal Elder Rios Pacheco (Author 2) unpacks how Raymond, a 13-year-old Tribal member, illustrated this relationship: "When her boy came and he came and asked you know quietly and… and I told him you know okay lets go over here and

look at these plants. So we went through and looked at them and said well we'll take this one… and I told him to watch out because of all the thorns on that plant. So we took a sample of that plant and we kept on going and then we found another one and I asked him how it felt and what it was for… so he had that contact of one-on-one. Then he turns around and when we were ready to leave, you asked if he wanted to help Jake with the drone, so now he's able to have contact with a complete circle… So what happens is we have that contact with one-on-one and then now we have this interest in technology of how he can show that one-on-one. Not just by being there in person and seeing that plant, but also using technology to see that plant 3D and see the whole valley in 3D. So that's what the future of technology is: bringing what you see in life into a better understanding to someone that doesn't have that opportunity to see it in life." (Data Analysis Meeting, 07/05/2021).

In this example, the cultural knowledge exchange between Rios and Raymond prompted Raymond to craft a (re)interpretation using virtual reality technologies, which in turn prompted deeper exploration of cultural knowledge and so forth. We found that families who attended the in-person plant walk experienced the plants and learned about their uses and then re-experienced that learning in their interpretations with digital technologies.

Preservation of culture with technology

Through the *Shoshone Plant Experience* workshop, families expanded the ways in which culture can be preserved with and through technology, especially as designers. Family participants who continued with the three workshop days at the Tribal Offices, developed their own interpretations of cultural knowledge that they learned on the plant walk. These took the form of digital stories or movies, informational graphics or videos, and more. Tribal Elder Patty Timbimboo-Madsen (Author 3) reflects on the impact of developing these interpretations: "... to me in the end, I can see it giving us an easier way for preservation to retain the information and to be able to pass that on to the people of the Tribe. It's in our words and through our eyes and to me it's a gift giving back to the people of the Tribe" (Data Analysis Meeting, 07/08/2021). Building on this point, Tribal Elder Gwen Davis (Author 4) contributes, "Well technology is something that we have to embrace, because it's here… I believe it's going to be a way in which we learn how to use it to preserve ourselves, whether it's our culture or whether it's how we learn how to do things. It's a way of teaching…" (Data Analysis Meeting, 07/08/2021).

Moreover, when considering the traditional oral ways of preserving culture, Tribal Elders grappled with the tradeoffs of using technology for cultural preservation. Patty explained, "Oral histories are good because you can tell it anyway you want. Is there a wrong way or a right way? But once it's cemented on paper, or on a computer or on a tape or whatever, it's more permanent instead of trying to make the story up again. I think any time you try to elaborate it more or make it more funny or add your two cents to it, it kind of changes." (Data Analysis Meeting, 07/08/2021).

Rios further expounds, "Yeah I don't think technology is going to change anything, it's just like oral history. You carry on what you heard, but you also have that opportunity to add to it and you have the opportunity to take away from it. Same way with technology. You're not going to say everything word for word, because you have the capability of changing those words… The only ones that will stay the same are the ones that are true to what they're saying and what they want to convey… But [technology is] also good, because you can have a thought and it [moves] all the way throughout the world. But your oral thought can only be conveyed with that small group that's around you. That's the big difference."

Experiencing culture through technology

Using virtual reality to recreate the *Shoshone Plant Experience* is aligned with how the Tribe hopes to use technology to preserve and share culture, yet it does have limitations in the relationship between their storywork and the land. Tribal Member Alicia Martinez (Author 6) describes the loss of human essence as a limitation of this technology stating, "I don't know I mean just even technology itself, separate from culture, you know I think one of some of the complaints, maybe or the criticism of it is the loss of the human essence" (Data Analysis Meeting, 07/05/2021). She further argues that we need to restore the human/more than human essence by maintaining space for the relational connections between technology, culture, and the land. Curiously, we did note all of this woven together in one key moment, which we share here as an illustrative example.

The use of this technology was initially a pragmatic solution to engage people who could not participate on the workshop days, which became one of its key affordances. During the three design workshop days, NWBSN community members put on Oculus Go headsets to view the VR footage we captured from the plant walk day. This became an intergenerational learning experience where Ruby, a 10-year-old Tribal Member, quickly became the go-to teacher for how to use the Oculus Go. In exchange, many of the NWBSN community members immediately began sharing stories and memories based on what they viewed through the headset. For example, Garry, a Tribal Leader, exclaimed, "Oh whoa… Holy Moly!!... That is awesome!" Once oriented to the Oculus Go, he began sharing his own cultural knowledge and stories based on what he saw in the virtual canyon as if we

were all standing there together. In addition to providing insights for how the intersection of culture and technology facilitated Elder-youth interactions and exchanges of knowledge, this example also demonstrates the unique affordance of experiential or immersive technologies in prompting deepening and furthering of relational sharing of cultural knowledge. This also reinforces the *reciprocity* of culture and technology previously discussed.

Insights & Significance

Insights from our findings highlight three forms of relations (reciprocity, preservation, and experiential) that the NWBSN community engaged with at the intersection of culture and technology. These forms of relations were illustrative of the collective move in the community to reclaim their uses of technology by maintaining technological sovereignty and self-determination as designers (Winter & Boudreau, 2018). Specifically, the reciprocal relationships that emerged in the *Shoshone Plant Experience* workshop sheds light on how Indigenous communities can build new relationships with technology when maintaining sovereignty and self-determination over their engagement with it. To this end, as we continue to grapple with the early findings of our work, we persistently wonder about the significant and complex role of *land* in our work, particular for the NWBSN. Our work builds on and contributes to existing efforts to center Indigenous science and culture and expand current notions of *who* counts as designers of technology.

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Learning to Do Substantive Relational Work in Research Practice Partnerships: An Apprenticed Autoethnography

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Abstract: Relationships are at the core of doing community-based research that works and matters. However, the process through which university researchers learn to engage in relational work is often *presumed* to be understood rather than explicitly articulated. Building on approaches that conceptualize relationality and critical historicity as central to the success of equity-oriented approaches in education, we present a polyvocal autoethnography where researchers in a RPP featuring YPAR elements learned to engage in what we call *substantive relational work* (relational work with commitment to *caretaking relations* and *critical bifocality*) with community partners. By analyzing everyday moments, we highlight the invisible learning process of a scholar-in-training working alongside a university researcher, program staff, and youth leads at a non-profit organization. We discuss how relational work is both work necessary to move equity-oriented community-based research forward, as well as work that matters in itself for researchers to reconceptualize discursively and materially.

Introduction

Scholars studying research practice partnerships (RPP) have written on the importance of building relationships with community partners (Coburn et al., 2016) in doing "work that matters" (Penuel et al., 2015) toward educational improvement. However, given the often-extractive history of research within communities, RPP scholars face the multifaceted, abstract task of "avoid[ing] perpetuating existing systems of injustice" in not only their research foci, but also their relational approach with communities (Denner et al., 2019, p. 2). We hope to expand on RPP scholarship centering relational work as key to doing community-based research that disrupts systems of inequity on practical and structural levels. We examine two otherwise "invisible" (Jurow, 2016) elements of relational work: building substantive relationships, and learning how to do so effectively within the academy. We build on the insights of participatory design research, which "attends to the ways in which (a) critical historicity, (b) power, and (c) relational dynamics shape processes of partnering and the possible forms of learning that emerge in and through them" (Bang & Vossoughi, 2016, p. 173-174).

In this paper, we present a scholar-in-training's apprenticed learning around what we refer to as *substantive relational work*. To define this concept, we draw on *critical bifocality* (Weis & Fine, 2012), and *caretaking relations* (TallBear, 2019) from critical and decolonial perspectives. Rooted in indigenous ways of knowing, caretaking relations represents a narrative based in "relations and obligations in the here and now" (TallBear, 2019, p. 25)—alternate to a settler-based society that "objectifies the land and water and other-than-human beings as potentially owned resources" (p. 32) for relentless "American dreaming" of production and progress (p. 24). At the same time, critical bifocality requires researchers' responsiveness to the ways higher-level structures and inequities hold "attendant consequences for the local level with regard to lived-out social and economic practices of individuals and collectivities" (Weis & Fine, 2012, p. 3). At the core of substantive relational work is therefore the idea that centering caretaking relations in research is not an abstract point of sentimentalism detached from real world concerns—it is a quotidian political stance centering connection and wellbeing in the face of the demands of White supremacy and exploitative capitalist structures.

We situate our study within the first cycle of a youth participatory action research (YPAR) project in a two-year RPP with a non-profit organization. The RPP goal is to understand through a YPAR approach—which positions youth as researchers with expertise/agency (Caraballo et al., 2017)—how youth voice shapes improvement of out-of-school career pathway programs. Authors 1 and 2 joined as adult co-researchers supporting youth leads in this project. We approached our inquiry with the exploratory question: **What does it look like in practice for a scholar-in-training researcher to learn to engage in substantive relational work alongside university researchers, youth, and program staff in a YPAR-infused RPP?** Overall, we hope to contribute to

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scholarship which highlights relational work as an "expert educational practice" with "unarticulated assumptions" to be honored, made explicit, and mentored (Bevan & Penuel, 2017, p. xxii).

Methods

Distinct from conventional autoethnographies, this apprenticed autoethnography is a polyvocal piece that weaves between first and third person perspectives to capture personal and shared learning reflections. Through the lens of the researcher as an instrument of data collection (Denzin & Lincoln, 2003), we collected field notes and memos from Authors 1 and 2 throughout the 14-week YPAR project cycle to capture everyday interactions and learning (Holmes & Hall, 2020). Authors 1 and 2 wrote field notes/memos during and following each session with each other, program staff (Chloe and Khat), and youth leads (Emily and Michelle). Memos were guided by the following prompts: What's coming up for me after this [event, session, meeting etc.]?; Are there any highlights/healthy tensions?; What am I noticing about the relationship or the project this week? The final data corpus consisted of 32 single-spaced pages of university researcher field notes and memos.

Throughout a month-long series of discussion, Authors 1 and 2 analyzed these documents and identified pivotal points of relational work. Using these moments as a way "in" to the relationships, we coded for critical bifocality and caretaking relations among the selected excerpts and wrote analytic memos to demonstrate how the learning of substantive relational work mapped onto everyday moments. All partners' names have been replaced with pseudonyms.

Findings

In this section, we shift to a first-person perspective to walk through reflective vignettes which guided my (Author 1's) learning of substantive relational work as apprenticed by community practice experts. Our findings 1) show the interconnection of critical bifocality and caretaking relations in the quotidian learning of substantive relational work and 2) illustrate the importance of language, informality, and recommitment as areas with the potential to rupture bifurcated roles and asymmetry in power. We emboldened segments within each vignette which demonstrated researchers' consciousness of critical bifocality (in blue) and caretaking relations (in red).

At the start: Learning to navigate language, history, and power in research

We demonstrate how navigating historicized dynamics through language served as an opportunity for relational learning in the initial phases of the RPP. The following excerpt reflects on an initial meeting where program staff and researchers introduced themselves and their roles in the project. My (Author 1's) use of technical domain-specific language in explaining university researchers' roles and inviting our partners to engage as co-researchers—especially when understood alongside extractive histories of research in communities—visibly confused and unsettled program staff members Khat and Chloe. Through mentorship from Author 2, I reflected on the role of language and immediacy in relational work:

> Talking to Chloe **I realized that I was talking [like] how I'm used to talking in academia.** [...] Like Author 2 told me [...] **it's important to know who we are talking with and how the language we're using can affect the way that the people we're trying to build relationships can feel…especially since Khat said this was the first time they were working with researchers who wanted to learn more about what they're doing and actually try to integrate into it.** [Author 2 and I] both stayed on after Chloe left (I think he could tell I was feeling some sort of way about the exchange) and we talked it out. I appreciate [Author 2] being there. **I'm starting to see how this big deal in the literature sometimes really can be as simple as noticing how someone's feeling and staying after to talk.**

Working through these tensions with Author 2 provided me with the space to practice critical bifocality by processing and reconciling into local context the structural and historicized implications of research language—namely how it has been used to reinforce hierarchies of expertise and stifle non-researcher voices (Bevan & Penuel, 2017). As aware of these tensions as I was in the moment, I found myself unable to escape or resolve them. Through discussion and reflection, I came to see the nuanced perspective-taking and awareness of structural dynamics required to navigate how I position myself in relationships with partners through quotidian means like language. Additionally, the immediacy with which Author 2 addressed these tensions demonstrated elements of caretaking relations. Through this interaction, I realized that in addition to prioritizing relational obligations in the "here and now" (TallBear, 2019, p. 25), it was of equal importance to consciously expand who I considered as part of my spatial web in relational work. Until this point, I had conceptualized relational work in RPPs as an endeavor directed toward community partners, not fellow university researchers. Author 2 showed me

that substantive relationality is an ongoing stance—regardless of roles within a project—that pushes back on exploitative rhythms and hierarchies of work.

In the thick of it: Learning to cultivate affective connections through informality

RPP scholars detail the importance of establishing collaborative ways of work to advance relationships, but are less explicit about how this process might unfold. In the following excerpt, I (Author 1) reflected on the importance of informal interactions between program staff and youth leads in fostering collaborative routines:

> Emily, a youth lead, sat in [a YPAR session planning meeting] (totally of her volition after a check-in with Chloe where Chloe casually invited her to the meeting) and gave great feedback. **It's because of those moments of connection between people outside of meetings that so much is shared, and new doors and routines open which further cement the heart of the work we're trying to do—in this case, incorporating youth input in more of the planning.**

I learned that Chloe met with youth leads and participants individually outside of sessions to hear youths' personal updates and programmatic input, positioning them as fellow contributors and stakeholders. Just as Author 2's choice to attend those around him was rooted in critical bifocality, Chloe's commitment to caretaking relations "outside of meetings" created informal spaces for affective connection to intentionally rupture conventional hierarchies between youth and adults. This vignette demonstrates how informal moments—despite often being under-documented, undervalued, and invisible, especially in task-oriented environments—can be critical to establishing deeper routines of collaboration within RPPs.

Seeing how committing time to informality and affective connection could transform relationships, I texted Michelle, the youth lead I was paired with, to ask if she was free in the upcoming week to check in. This one-off meeting quickly became joyful weekly working sessions where we shared life updates and spirited suggestions for project directions. Throughout our relationship, I saw Michelle step into her role as a caring and passionate team lead who energized and drew out the strengths of our group members to craft an inspired youth-led project. From a critical bifocal lens, I saw how taking initiative to carve out informal, affective spaces in the RPP served as a local opportunity to push back on structures that neglect the voices of marginalized youth in social change (Caraballo et al., 2017). This instance highlights how seemingly small actions rooted in caretaking, such as reaching out and cultivating spaces for affective connection, is relational work which can transform relationships and make more democratized, synergistic work in RPPs possible.

Reprise: Learning to recommit to substantive relational work as a political stance

Part of the challenge of relational work is its nonlinear nature, which requires re-commitments and renegotiations between competing priorities and challenges. In this section, we draw attention to an everyday moment of tension between sanctioned, often rewarded markers of progress, and invisible relational work. Although not mutually exclusive, these moments of tension can serve as opportunities to engage in the unlearning and relearning required to make intentional decisions that align with who we aspire to be as researchers—amidst the backdrop of settler notions of production/progress (TallBear, 2019) which have infused social science research.

As the end of the cycle drew near, university researchers and youth leads grew increasingly conscious of the tensions between the varied academic and domestic commitments of marginalized youth and the time needed to execute their ambitious YPAR projects. Following discussion, youth leads gave their teams the option to scale down their project deliverables (i.e., fewer interviews and smaller scale surveys). In the following reflection which was crucial to my own learning regarding relational work, Author 2 reflected on his relational recommitments throughout the last few weeks of the cycle, how youth lead Emily's approach catalyzed this process, and how this decision led to new possibilities in the YPAR project space:

> I feel like I've let go of most of the impulses around scientific validity that I was struggling with in past weeks and **have tried to focus on the interpersonal and political foundations of participatory research. Being paired with Emily, who is a college student and a youth lead, I've appreciated their approach to prioritizing relationship building by building in substantial check-ins during our breakout sessions.** A few weeks ago, **I suggested integrating appreciations at the end of our group meetings as a way to build community amongst our groups.** I feel like these small gestures have helped to facilitate more engagement from everyone, but especially the younger and more quiet high schoolers in our group. Currently, we are planning the presentation. [...] **There seems to be some energy around designing a presentation that isn't an "academic" presentation, but one that integrates a**

bit more creativity and interactivity since we have several artists in the group. I think it's a great way for our group to continue to unsettle the professionalized and "scholarly" modes of research.

Through critical bifocality, Author 2 sensed the tacit obligation to commoditize the group's time and effort toward fulfilling the project to an intangible standard reflective of larger settler notions of "American dreaming" ingrained in our systems and psyches (TallBear, 2019). Reinvigorated by Emily's commitment to caretaking relations, Author 2's suggestions demonstrate a conscious decision to subvert settler mindsets of productivity (TallBear, 2019). Furthermore, this vignette demonstrated how recommitting to relationships created moments of rupture that further rebalanced asymmetries in power while pushing RPP work in innovative directions. Through deep discussion with Author 2, I realized that choosing to balance on the one hand, project deliverables and the dreams of progress they represent, and on the other, relational work with the people in front of me—despite the time commitments, emotional labor, and discomfort that came with it—was one way to unlearn these notions and disrupt systems of inequity on local and structural levels.

Conclusion, limitations, and implications

By foregrounding substantive relational work and its learning, we emphasize the importance of not reducing relationality to a broad discussion about methods, partners, or milestones— "but rather [seeing it as] a way of living and interacting with the world" (Ritterbusch 2019, p. 1300) that dictates and enables the different forms, methodologies, solidarities, intimacies, and trajectories social change projects might take. For RPP researchers committed to addressing complex issues of equity, substantive relational work in daily practice is critical to doing community-based research that both works and matters—as well as work that matters in itself.

A limitation of this paper is its focus on researcher learning. Our insights were possible in large part to the relational sensibilities each of our partners came into the space with, likely influenced by their prior work and community organizing experiences. A future direction is the amplification of community partners' rich expertise surrounding the dynamics of language, informality, and recommitment in substantive relational work. Additionally, we acknowledge that structural dynamics within the academy may incentivize particular timelines and interpretations of community-based research that may dilute substantive engagement with communities, encouraging "lite pedagogies" of relationality (Ritterbusch, 2019). As such, our insights prompt a push to design RPPs around relationally sensitive timelines and epistemologies, mentorship, and reflection opportunities to allow for substantive relational work and its learning. As equity-oriented educational improvement continues, we look to perspectives from the margins to deepen our commitments to such work with communities.

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International Society of the Learning Sciences

From Queer Feminism to Anti-racism: A Sociocultural Analysis of Activist Learning Across the Lifespan

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Abstract: Learning scientists have begun to spotlight social movements as important sites of learning. In this paper, we build on this growing literature by analyzing how a White lesbian activist came to learn anti-racism through her participation in the queer feminist movement. Although researchers recognize the longitudinal nature of activist learning, due to resource constraints ethnographic studies often last no longer than a couple of years. Here we respond to this challenge by presenting an analytical approach for tracing the learning of anti-racism over *extended* timescales (e.g., decades). Specifically, we suggest the potential of memoirs to illuminate learning processes across social settings and across the lifespan.

Introduction

Scholarship in the learning sciences has shown that racism, particularly White supremacy, remains a modern societal problem (Nasir, 2011). After George Floyd's public murder in the United States in 2020, people across the globe engaged in new forms of anti-racist activism. However, few studies have investigated anti-racism as a *learned* phenomenon. This is significant because empirically grounded theories of anti-racism learning have the potential to make educational efforts more effective, thereby bringing us closer to a racially just world.

In this paper, we argue for a lens on this problem that examines learning across settings and across the lifespan. To that end, we analyze the anti-racism learning processes of a grassroots organizer named Mab Segrest (hereafter referred to as Mab), as narrated in her book *Memoir of a Race Traitor* (1994). Mab's story is compelling because after growing up with a racist family in deeply segregated Alabama, this White lesbian woman became active in queer feminist movements and eventually came to identify as a "race traitor," resisting White supremacy and committing herself to deep forms of anti-racist activism. Drawing on situated and sociocultural perspectives on learning (Lave & Wenger, 1991; Wertsch, 1998), we explore the following research question: *What aspects of anti-racism did Mab learn, and how can that learning be described in terms of the relative availability of sociocultural artifacts related to race, identity, and activism across her lifespan?*

With this study we aim to make two main contributions to research on learning in social movements (Curnow & Jurow, 2021). First, we offer the beginnings of an analytical approach designed to trace activist learning across *extended* timescales. Specifically, we explore the unique affordances of memoirs as a data source for analyzing learning. Second, our findings reveal novel insights about activist learning, particularly how some activists might learn to accept the risks associated with grassroots activism.

Prior Research

In recent years, researchers have begun to conceptualize social movements as important sites of learning (Curnow & Jurow, 2021). Regarding anti-racist activism specifically, several studies have drawn on sociocultural perspectives to document anti-racism learning processes in a range of settings (e.g., environmental justice movements—see Curnow et al., 2019). Methodologically, learning scientists in this area have recognized that learning is distributed across both space (i.e., social setting) and time (Jurow & Shea, 2015). Understanding the full complexity of how, where, and when people learn to be activists requires an analytical approach that traverses what Erickson (2021) calls the "fuzzy boundaries" of people's lives: how learning travels between people's personal and professional lives, as well as between childhood and adulthood. With respect to time, Erickson (2021) has argued for researchers to employ a "diachronic approach to ethnography—ethnography in time depth" (p. 156). Whereas many prior studies have taken a longitudinal approach, due to resource constraints they can often only trace people's learning over a couple years at most. What is needed is a methodology that can capture the longitudinal, nuanced quality of activist learning.

Conceptual Framework

Anti-racism entered mainstream discourse in Europe in the wake of World War II. Since then, the field has neither settled on a single definition of anti-racism, nor does it seem wise to seek one given the adaptable nature of racism across geographic locales and social settings (Gillborn, 2004). Still, there is consensus that anti-racism goes

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beyond awareness to involve concerted *actions* (Paradies, 2016), and that anti-racism is intersectional with efforts to resist related oppressions (e.g., ableism, homophobia) (Dei, 1996).

To theorize anti-racism as a *learned* phenomenon, we draw on situated perspectives that characterize learning as shifts in participation in social practices (Lave & Wenger, 1991), as well as Vygotskian sociocultural theory, which emphasizes the cultural artifacts people deploy to accomplish goals and thereby mediate human activity (Wertsch, 1998). Artifacts come in material forms (e.g., a book that changes one's understanding of racism) or non-material forms (e.g., relationships with others that facilitate participation in anti-racist practices).

A key idea in the forthcoming analysis is the notion of *availability*. That is, people's thoughts and actions are mediated by those artifacts that are available to them within their lifeworld. Imagine a child who was raised in a certain type of White supremacist household: the artifacts primarily available to them would include racist narratives about White superiority, family members spouting those narratives, and racist signs like the Confederate flag. Even if the child rejects White supremacy later in life (i.e., as anti-racist artifacts become more available), we can speculate that legacy racist artifacts from their past may still exert a gravitational pull on their identities and how they live their lives. Thus, as we conceptualize anti-racism learning in terms of shifts in the relative availability of artifacts, we ask: how do various artifacts available in a person's life—across both time and setting—create the conditions for learning anti-racism?

A Brief Chronology of Mab's Life

Mab Segrest was born in 1949 in Alabama, a place with deep roots in slavery and a history of violent commitment to White supremacy. During her teenage years in the 1960s, Mab's own town became a national flashpoint of the Civil Rights movement as her school was being desegregated. Mab's discomfort with the treatment of Black people during this time led to tensions with her pro-segregation family. And while she did not identify then as queer, Mab's sexual identity further contributed to her feeling like an "outsider."

After completing graduate school in North Carolina, Mab decided to join a Southern queer feminist group that published a journal called *Feminary*. In part, this decision was driven by the break-up of her relationship with a woman named Pat, which led Mab to seek community with other lesbians and greater acceptance of her sexual identity. This period was crucial to Mab's eventual uptake of anti-racist organizing as a member of a Black-led group called North Carolinians Against Racist and Religious Violence (NCARRV).

Methods

We follow Jurow and Shea (2015) in using ontogenetic analysis to trace individual development over longer timescales. To that end, we explored the value of memoirs as data for making claims about learning. Not only do memoirs zoom in on micro-interactions (e.g., conversations between key actors), but they also often narrate events connected across many years. For this study, we searched for memoirs written by U.S.-based anti-racist activists since the turn of the 20th century. We chose Mab's memoir because of the critical role White people must play in resisting White supremacy. Additionally, Mab's intersectional identities as a lesbian woman in the South made her story particularly compelling.

Our analysis focuses on her time with *Feminary* (1976-1983; p. 37-47) because this was a significant pivot in Mab's life, as she learned ideas and practices related to queer feminist activism that set the stage for her work with NCARRV. We began by segmenting this memoir excerpt into episodes and identified each by interactions or activities that Mab was engaged in (e.g., leading an anti-racist workshop, attending a protest). We then tagged segments and clustered them thematically (e.g., intersectionality, coalition building). Finally, we independently made lists of material and non-material artifacts relevant to the activity in each segment, wrote memos and made visual representations, and met several times to compare and reconcile. Our identification of artifacts was informed in part by previous schemes for identifying sociocultural artifacts (e.g., Nasir, 2011).

We note that our positionalities—Shah (straight Brown man) and Hou (queer Han Taiwanese)—informed our highlighting of timescales, given the longitudinal nature of our anti-racism learning since childhood.

Findings

From a situated perspective, we found evidence of several shifts in the quality of Mab's anti-racism during this time (e.g., uptake of intersectionality; coalition-building across multiple social marker groups). Here we focus on one: Mab's shift towards high-risk, on-the-ground organizing. Specifically, the form of Mab's activism changed from a mostly ideological form of activism to a more grassroots form focused on direct action:

> With Feminary, our battle had been largely interior, a psychic confrontation with the lethal forces of the culture as we had internalized them. It was an intense, revealing, but sometimes

> insular process…By 1983, I had hit the limits of this internal work…Guided by the people who eventually incorporated North Carolinians Against Racist and Religious Violence, I set to work to learn to organize. (p. 52)

Outside her ideological training and writing at Feminary, Mab had begun to participate in several protests and civil disobedience actions. But what this quote highlights is the centering of grassroots organizing in her activism, which then precipitated in her move to NCARRV. Still, *how* did Mab learn this aspect of anti-racism?

Anti-racist organizing in the 1980s, in one of the historical hearts of Klan activity (North Carolina), was dangerous work. Sustainable activism requires a high risk-tolerance and sophisticated organizing skills. Next, we analyze how changes in the relative availability of certain artifacts mediated Mab's security in her sexual identity and her understanding of activism itself. In turn, we argue that these shifts facilitated Mab's learning of this aspect of anti-racism.

Self-acceptance affords greater risk tolerance

In 1976, Mab was at a low point in her personal life. For years, the position of "outsider" was a cultural artifact that took up considerable space in Mab's lifeworld (e.g., family tensions over race; uncertainty over her sexual identity). As a young adult, this narrative of being an "outsider" was temporarily assuaged after falling in love with Pat, her first serious lesbian partner. But in the loneliness and vulnerability that opened after Pat left, Mab redeployed the "outsider" narrative as an identity marker. It was under these conditions Mab joined *Feminary*.

Several new artifacts related to queer identity become available to Mab through various experiences in *Feminary*. In addition to material artifacts in the form of written histories of feminist and queer feminist movements, Mab was suddenly surrounded by lesbian women committed to empowering their communities. We can infer that these new relationships afforded Mab a model of queer people more firmly rooted in their sexual identities. About these friends and colleagues Mab wrote: "Their feminism was the language of my freedom, the necessary antidote to all my years of loneliness, self-hatred, and fear" (p. 44).

Alongside her growing acceptance of her sexual identity, Mab was also re-establishing a sense of safety and belonging in her personal life. Moving in with Carl and Allan—who she refers to as "gay brothers"—and with her friend and lover, Barb, helped Mab re-establish a sense of home that was lost when Pat left. This "alternative family," as she calls it, brought more stability into her life.

Overall, we argue that the stability Mab found through her queer feminist activism and home life laid a foundation for Mab to participate in higher-risk forms of activist practice. Of course, being a queer person in that time and place already took tremendous courage. However, anti-racist organizing represented a new level of risk. Our argument is this: when you feel like you belong, you are more likely to feel capable of participating in the collective work of high-risk organizing. The artifact of "outsider" became less available, or as Mab puts it: "Lesbian-feminism was my door into the possibility of belonging and self-acceptance…it was not long before the other issue basic to my identity—race—began to surface" (p. 46).

New artifacts shape Mab's perspective on the forms of activist work

In parallel with changes in Mab's feelings of personal acceptance and community belonging, new artifacts were also emerging that changed how she understood the work of activism itself. One formative experience in Mab's professional life was an anti-war protest she attended with thousands of women at the Pentagon in Washington, D.C. During the Pentagon protest, some of her fellow organizers were arrested, and Mab connects this to the desegregation battles during her childhood in Alabama:

> The armed guards at the Pentagon felt like the armed force that George Wallace had sent to surround my school. Its stone walls radiated the same coldness as the marble of the Alabama capitol. As I waited that night outside the jail in support of the last of our crew to emerge, I knew I was finally deciding to put my power against the power of the state." (p. 49)

There are several important sociocultural dynamics in play here. First, in recognizing "the power of the state," Mab is re-mediating how she understands her own activism and what it should be. The experience of watching her friends jailed at the Pentagon—the ultimate symbol of U.S. militarism—made available a new artifact in the form of a narrative about the high-stakes nature of anti-oppressive work. Second, the lines between Mab's past and present appear to blur, as she analogizes State-sponsored resistance at the Pentagon protest to her childhood experience of watching her community in Alabama resist desegregation. The common thread is the realization that activism transcends local conflicts—that both feminist and anti-racist activism must contend with State-level power.

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Another experience that re-shaped Mab's perspective on activism involved anti-racism workshops she facilitated with a colleague. Typically, these workshops consisted of participants personally reflecting on race in their lives and engaging in role plays, which afforded them opportunities to practice intervening on racism in authentic situations. These roleplays were intended to culminate in discussions of activism, but as Mab noticed, this rarely happened: "We found that participants became so absorbed in the interpersonal issues that we never got to the activism. Were we starting at the wrong end of the process?" (p. 49). In suggesting that grassroots activism might require higher priority, Mab was re-evaluating the nature of her own work. It appears that a greater urgency for direct action was becoming centered in Mab's activism, and NCARRV would offer Mab an opportunity to realize that urgency.

Discussion & Future Considerations

This paper contributes to research on learning in social movements by offering the beginnings of a methodological approach that attends to learning at both micro and macro timescales. In response to Erickson's (2021) call for greater "time depth" in such work, we have argued here for the potential of memoirs as data, which to our knowledge have not been used to analyze learning. Like all data, memoirs have limitations, but we believe they resonate with more established ethnographic approaches to studying learning.

In Mab's case, our analysis reveals that her learning did not hinge on a single epiphany about racism or a particular moment of clarity, but that instead it unfolded over long stretches of time in nonlinear fashion. We showed how fluctuations in the availability of different artifacts over many years help explain her eventual move to anti-racist organizing. The foregrounding of new artifacts (and backgrounding of others) created the conditions for new and deeper forms of learning. More broadly, we suggest that this study highlights the value in applying learning theory to questions of anti-racism.

We close with two questions for future consideration. With respect to research, if people's motivations for and learning of anti-oppressive activism is mediated by forces across the lifespan, then how can we design research that surfaces the historical nature of these learning processes? And relatedly, with respect to practice, how should anti-racism education initiatives account for the long timescales of anti-racism learning?

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Use of Crosscutting Concepts as Epistemic Heuristics

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Abstract: Drawing from analyses of teaching and learning and a framework for epistemic thinking, I use four levels of epistemic thinking (practical, epistemic cognition, epistemic metacognitive knowledge, epistemic metacognitive strategy) and an implicit-explicit dimension to distinguish among uses of and supports for the crosscutting concepts. This work has implications for the design of learning environments that can promote students' metacognition about the crosscutting concepts.

The issue addressed

One critical aspect of engaging all students in science learning is to prepare them to guide their own scientific intellectual work (Nordine et al., 2021). Metacognition refers to students' awareness and understanding of their own thought processes (New Oxford American Dictionary). Epistemic heuristics are rules for guiding one's scientific work (Knorr Cetina, 1999; Krist et al., 2019), such as the tacit rules that scientists use to develop explanations for how and why phenomena happen (i.e., Anderson, 2018). However, the epistemic heuristics that guide this work in school science have generally not been made clear to students, which prevents many students from developing metacognition. The crosscutting concepts (CCCs) in the Next Generation Science Standards can be interpreted as a representation of these epistemic heuristics (Anderson, 2018; Krist et al., 2019; Rivet et al., 2016) and there is agreement that the CCCs should be made clear to students, but there is a lack of consensus on how and why to do so (Miller & Shelton, 2021; Nordine et al., 2021). I present an equity argument to explain why it is necessary to make CCCs clear to students and a two-dimensional model (implicit-explicit, practical-epistemic) with four levels of epistemic thinking to describe how to make the CCCs clear to students.

Potential significance of the work

A lack of clear epistemic heuristics can prevent members of marginalized communities from fully engaging in science (Cooper, 2020), which is an equity issue. There is a need for clear teaching of epistemic CCC use so students can move toward self-regulation and direct their own scientific sensemaking. Teaching and learning that provides all students opportunities to learn how to use the epistemic heuristics will increase equity (Cooper, 2020; Fulmer et al., 2018; Nordine et al., 2021). Fick et al., (2020) introduced axes of support (practical-epistemic and implicit-explicit) with four categories of CCC supports. In this paper, a three-level epistemic thinking model describes three subcategories of epistemic CCC uses that are learning goals. Each subcategory of CCC use corresponds to specific instructional supports. This new two-dimensional model provides a more detailed framework for improving our understanding of the nuances of CCC use and how to provide instructional supports.

Epistemic thinking and epistemic heuristics

In general, *thinking* includes both the use of mental processes (i.e., cognition) and the knowledge and regulation of one's own mental processes (i.e., metacognition; Barzilai & Zohar, 2016). In the context of science teaching and learning, *epistemic* means related to the development of scientific knowledge. *Epistemic thinking* encompasses epistemic cognition and epistemic metacognition (Barzilai & Zohar, 2016). Epistemic cognition is a students' ability to use a mental process to develop scientific knowledge, while epistemic metacognition is a students' ability to monitor and control the use of a mental process to develop scientific knowledge.

Epistemic heuristics are mental processes for guiding scientific intellectual work (Knorr Cetina, 1999; Krist et al., 2019), such as the unwritten rules that scientists use to develop explanations for how and why phenomena happen (i.e., Anderson, 2018). The crosscutting concepts (CCCs) in the Next Generation Science Standards are statements of these epistemic heuristics (Krist et al., 2019; Rivet et al., 2016). In this paper, the term CCCs refers to their use as epistemic heuristics, which is important because how the CCCs are presented in instruction may result in non-epistemic use by students (Andersen, 2021; Fick et al., 2020). For example, students may look for patterns without knowing how or why they are doing so, which is an example of non-epistemic use. On the other hand, students can be supported to know how to use the patterns CCC, why to use the patterns CCC, and how to self-regulate the use of the patterns CCC, which are different aspects of *epistemic* use.

Describing CCC use with levels of epistemic thinking

A two-dimensional model (implicit-explicit, practical-epistemic) with three levels of epistemic thinking can help science educators distinguish among different kinds of CCC use and provide appropriate instructional supports.

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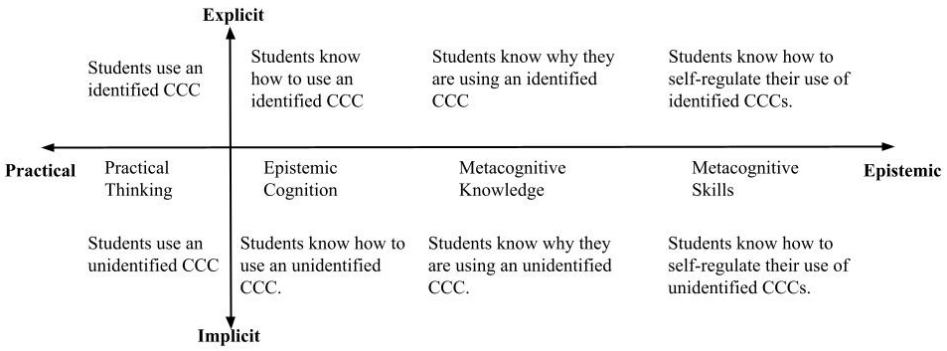
Prior theoretical work established axes of support based on two continua, implicit–explicit and practical–epistemic (Fick et al., 2020), which described four quadrants that represent four categories of CCC supports. The practical–epistemic axis was described as a continuum, but specific criteria to meaningfully compare and contrast levels of epistemic CCC supports on the continuum were not provided. I have modified the practical-epistemic axis using a practical-epistemic continuum with four levels—practical thinking, epistemic cognition, epistemic metacognitive knowledge, and epistemic metacognitive skill—to resolve the issue. In addition to providing defined levels of epistemic supports, this model also uses a modified definition of explicit. The definition Fick et al. (2020) used overlaps with the extant definition for epistemic thinking (i.e., Barzilai & Zohar, 2016), which made the two axes interdependent. The new model uses a revised definition that removes the overlap and improves alignment with the educational psychology literature. These modifications are explained in more detail in the next section.

Defining the implicit-explicit and practical-epistemic continua

Figure 1 is the new two-dimensional model of CCC use. The vertical axis represents the implicit-explicit dimension. *Implicit* use of a CCC is use without knowing you are using that particular CCC (Fick et al., 2020), such as when students use their intuitive ideas about CCCs (e.g., Goggins et al., 2021). However, in contrast with the prior definition of *explicit* as "including supports for students to know *how and why* to use the CCC..." (Fick et al., 2020, p. 854), I define *explicit* as including supports for knowing *that* you are using a particular CCC, removing the how and why component because the defined levels of epistemic thinking (e.g., Barzilai & Zohar, 2016) already account for that component. The lowest level of epistemic thinking, *practical thinking*, is use of a CCC based on intuition. The other three epistemic thinking levels make important distinctions between epistemic cognition and two levels of metacognitive thinking. *Epistemic cognition* refers to knowing how to use a CCC, while *metacognitive knowledge* refers to knowing why to use a CCC. In this way, how and why to use a CCC are addressed by epistemic cognition and metacognitive knowledge. *Metacognitive skills* are the ability to regulate one's own use of the CCCs (Barzilai & Zohar, 2016) and this highest level extends the Fick et al. (2020) practical-epistemic continuum to support students' agency and the engagement with multiple CCCs. Figure 1 indicates eight types of possible CCC uses or supports that provide a way to distinguish among different kinds of epistemic uses of CCCs, which was not possible with the Fick et al. (2020) model.

Figure 1

Two-dimensional Model of CCC Use



Example

In this section, an example of metacognitive knowledge support for CCC use from a fifth-grade science curriculum unit is examined. In the example, the teacher leads a discussion about the use of data from an investigation to figure out what happens to materials in our garbage over time (NYU SAIL, 2019).

> *To answer our question, we will record change in the properties of the garbage materials and the weight of the landfill bottle systems*. Direct students to look at the property and weight data tables in Investigation 2-1: Landfill bottles. Ask students to describe how the data tables are organized and how the data tables may be helpful in answering the investigation question. (The first data table allows us to record the properties of the materials at each time point. This will help us figure out whether the materials change over time. The second data table allows us to record the weight of the materials at teach time point. This will help us figure out whether the materials vanish over time. The second data table also has separate columns for the open and

> closed systems so that we can make comparisons between these conditions. (NYU SAIL, 2019, Lesson 2-1 p. 8)

This example supports students' metacognitive knowledge use of CCCs because the purpose of the discussion is for students to understand why they are using specific CCCs. Some of the CCC supports are implicit because the CCCs are not called out formally (e.g., patterns), while other CCC supports are explicit (change). The purpose of the discussion is to help students use multiple CCCs to develop a causal explanation for the changes they will observe in the landfill bottle. The discussion develops knowledge about each CCCs contribution to the causal explanation, which is why that CCC should be used (i.e., metacognitive knowledge). Later, when students construct explanations independently, they will need to have metacognitive skills to self-regulate their use of many CCCs. Providing all students with greater opportunity to learn why they to use specific CCCs and develop self-regulation is an equity strategy because typical instruction has denied such opportunities to students from underrepresented groups (Cooper, 2020).

Discussion: Interpreting the continua

Based on document analyses of a curriculum unit using the two-dimensional model (Andersen, 2022), I identified examples of the levels of epistemic thinking. Practical thinking is when students use their personal resources to access CCCs in science. One support for practical thinking with the cause-and-effect CCC was

> Say, *now that we have recorded our first set of data, we have to wait. What do you think will happen to the different garbage materials over time? Why do you think that?* Have students talk in partners about their predictions. Then tell students to write their predictions and reasons for their predictions... (NYU SAIL, 2019, Lesson 2-1 p. 11)

In this example, the teacher is asking students about their ideas for what will happen and why, which is a practical thinking support for students to use the cause-and-effect CCC in their own practical thinking. Practical thinking is an opportunity for students to use their home-based resources in science learning, which can increase equity (Goggins et al., 2021). Later in the unit, we see practical thinking support for the same CCC that is made explicit by calling out the CCC.

> How will you show what ***causes*** changes in the landfill bottles? Also, remind students about the process of microbes, In our model, it is important to think about the process. The ***cause*** is microbes. The ***effect*** is decomposition of food materials. (NYU SAIL, 2019, Lesson 4-2 p. 11)

Building directly on the knowledge that all students bring to school helps to build science identity and increase engagement in science for students from underrepresented groups, which is an equity strategy (Goggins et al., 2021). In this next example, we see epistemic cognition support for the systems and system models CCC.

> What we are doing today is different than a drawing you might do in art class. In art class, we might focus on making the drawing exactly like what we see. In science, we focus on details that are important to our investigation. We use symbols and a key to represent components of the ***system***. For example, in art class we would draw a real looking banana, but in science we could use a symbol of a circle to represent a banana and a symbol of a square to represent the aluminum foil. (NYU SAIL, 2019, Lesson 2-1 p. 11)

This example shows support for students to know how to use the CCC as they identify the system components (epistemic cognition). Andersen (2021) identified 290 examples of CCC supports through document analysis of the NYU SAIL (2019) curriculum, including supports for all four levels of epistemic thinking (practical, epistemic cognition, epistemic metacognitive knowledge, epistemic metacognitive strategies). These supports strategically facilitate learning experiences, or ***metacognitive experiences***, in the curriculum including discussion that describes the goals, concepts, and processes that scientists use to produce knowledge (Chinn et al., 2020), such as the examples provided above. In other words, the teachers' guide included many explicit supports that teachers could use to facilitate students' epistemic use of the CCCs (Andersen, 2021), which is different from the findings of similar studies of teaching and learning that showed mostly implicit supports (e.g., Fick et al., 2021; Markwordt et al., 2022). Providing explicit supports that facilitate students' epistemic thinking broadens students' access to science and can make science teaching more equitable (Cooper, 2020; Goggins et al., 2021).

Conclusion

Instructional supports can provide metacognitive experiences for the CCC uses represented by the eight regions in Figure 1. These supports are needed to help students move from practical use to epistemic cognition and eventually to metacognitive skill. Equitable science curriculum must provide intentional, strategic supports that allow all students to develop their epistemic thinking abilities, rather than relying on students to understand and internalize tacit norms, which has historically yielded inequitable results (Goggins et al., 2021). Epistemic thinking should begin with practical use of CCCs, then build to three levels of epistemic thinking—epistemic cognition, metacognitive knowledge, and metacognitive skills. I hypothesize that students epistemic thinking moves through the epistemic thinking levels as they engage in learning experiences, or metacognitive experiences, that require them to use CCCs at corresponding levels of epistemic thinking. Those metacognitive experiences are facilitated by teachers via curricular supports. Metacognitive experiences are relevant learning activities that develop the elements of epistemic thinking (Barzilai & Zohar, 2016). The eight distinct types of CCC use (Figure 1) suggest directions for future research to examine how curriculum and teaching can strategically and systematically support students' emerging use of the CCCs as epistemic heuristics. This work has implications for equitable science teaching and learning because without intentional supports many students will not take up these epistemic heuristics, particularly those who are members of marginalized groups.

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Shifts in high school students' conceptions of sensor-based devices and toys

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Abstract: Advancing conceptions of computing system internals—structural composition and dynamic behavior— is key to learning computing and critically engaging with it. However, novices' informal ideas challenge their engagement. In this study, I conducted and qualitatively analyzed ten students' interviews about a pair of functionally similar computing artifacts before and after a 14-week-long online electronic textiles unit. The analysis revealed that, post-unit, students had developed advanced conceptions of computing systems, both structurally and behaviorally. They frequently accounted for computing and explained internal dynamics in terms of data and control flow. I discuss implications of the findings for future computing education research and designs to promote critical computing learning.

Keywords: Computing learning, student conceptions, physical computing, electronic textiles.

Introduction & Background

A primary objective of introductory computing education is to help learners develop a conception of layers of abstractions between software and hardware that make everyday computing systems functional (CSTA, 2017). With devices such as automatic soap dispensers and facial recognition software critiqued for biases against marginalized peoples (e.g., Costanza-Chock, 2020), understanding the internal dynamics of computing systems is important. But, we barely know how learners think about computing devices and their internal workings.

Student conceptions of physical computing artifacts consist of structure, behavior, and function (Bhatta & Goel, 1997). The physical parts of the system and interconnections make the structural composition; roles of different elements cover the functional aspects; and the underlying logic causing outcomes through control and data flows accounts for the behavior. For sensor-based devices: (1) the *structural* aspects include microcontrollers, sensors, lights, and the physical interconnections; (2) the *functional* aspects consist of lights as outputs and sensors as inputs; and (3) the *behavioral* aspects include the underlying program logic that causes outcomes.

In prior studies, learners have been interviewed about coffee makers, stoplights, and smartphones to capture their conceptions (e.g., Przybylla & Romieke, 2014). Across, novices' limited understanding about these systems stands out. With only input and output components visible, learners develop naïve notions about the inner structural composition of these systems. A few studies (Cederqvist, 2020; Jayathirtha & Kafai; 2021) have noted how even students within computing courses have a limited understanding of these computing devices. Concepts of control and data flow—how inputs such as touch and light intensity cause different outcomes—were almost inaccessible to novices (e.g., Cederqvist, 2020). In this paper, we conducted and qualitatively analyzed student interviews (Creswell & Poth, 2016) before and after an introductory e-textiles unit within a high school online class. We asked: How did student conceptions, particularly their structural and behavioral understanding, of physical computing systems shift at the end of the unit?

Methodology

Context and participants

The study was conducted at a public charter high school located in a U.S. west coast city. An experienced high school computing teacher was teaching online an e-textiles unit within the *Exploring Computer Science* course (Kafai et al., 2019). To highlight the internal dynamics of physical computing systems, the teacher infused a variety of additional explanations and learning activities throughout the unit. In this paper, we focus on analyzing shifts in student conceptions about physical computing systems pre- and post-unit. The teacher chose ten of the 24 consenting students (5 male, 5 female; all except one identified as non-White) for interviews. All students were formally learning to program for the first time and had ~10 weeks of *Scratch* programming.

Data collection and analysis

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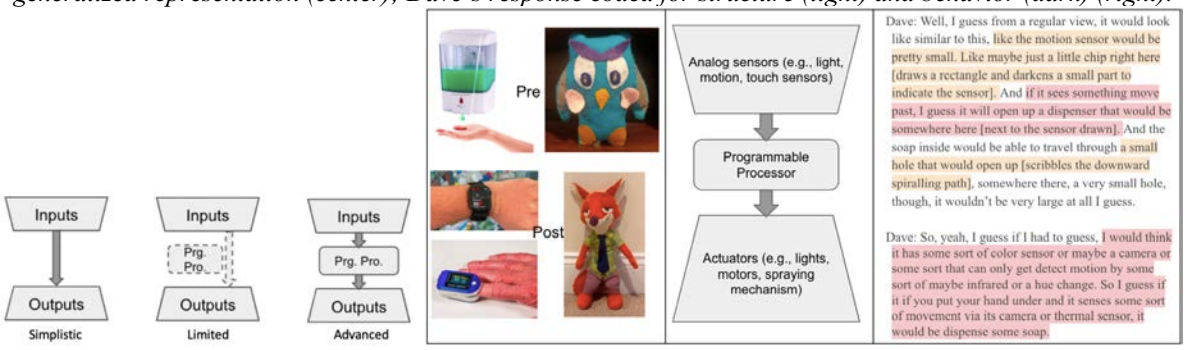
I interviewed students pre- and post-unit to capture their structural and behavioral understanding. Each interview (~20-30 mins each) had two sets of questions: one about the working of a sensor-based everyday device (automatic soap dispenser pre-unit and pulsometer post-unit) followed by another about an interactive toy (see Figure 1, center). All four artifacts were functionally similar, i.e., involved analog sensors and outputs but differed aesthetically (see Figure 1, center). The everyday technologies were not discussed in class and the toys were similar to student e-textile projects but more sophisticated. Students were given the functional description of the artifacts during the interviews and asked questions such as: "what do you think is inside? How do you think it works?". They were encouraged to draw and explain.

Student responses across pre- and post-unit interviews were thematically analyzed for structural and behavioral details (see Figure 1, right). Based on earlier work (Figure 1, left; Jayathirtha & Kafai, 2021), I deductively generated a codebook to identify structural and behavioral details and qualitative distinctions (*simplified, limited, advanced* in Figure 1, left). For instance, structural and behavioral aspects were separated in Dave's response (light and dark shades in Figure 1, right), and each was further classified as *simplistic* since there was no mention of any computation mediating inputs and outputs in the structural or behavioral explanations. Structural explanations that included a computing component but lacked apparent interconnections between parts were categorized as *limited.* Explanations with clear interconnections between computing, input, and output devices were coded as *advanced*. Within behavioral explanations, the mere mention of computing without further details about its role was coded as *limited*, and explanations with any further elaboration about how computing mediates the system behavior were categorized as *advanced*. I, along with another researcher, discussed the codebook and analyzed two students' (20% of the dataset) pre- and post-unit interviews. We agreed upon 15 out of 16 (93.75%) codes and resolved the discrepancy through discussion. We analyzed the rest of the interviews independently, verified their responses (~90% agreement), and clarified discrepancies.

Figure 1

Representation of categories of student conceptions (left), Pre- and Post-interview artifacts and their generalized representation (center); Dave's response coded for structure (light) and behavior (dark) (right).



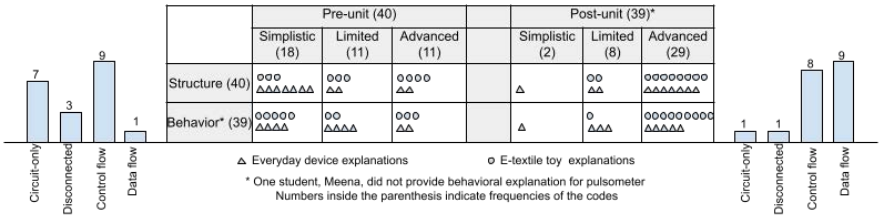
We further inductively analyzed (Creswell & Poth, 2016) behavioral explanations and captured four key themes: (a.) behavioral descriptions which involved only circuit-based mechanisms; (b.) explanations that treated programs and circuits as disconnected; (c.) explanations that only accounted for control flow (such as basic conditional logic) within the systems; and, (d.) descriptions that include both control and data/information flow between programs and circuits during program execution. The first two closely overlapped with *simplistic* and *limited* explanations. The latter two themes were evident within the *advanced* category, i.e., accounted for computing but by highlighting different aspects of its dynamic nature. The same researcher was presented the themes and example excerpts from student responses who agreed with most of them (85% agreement). Disagreements were resolved through discussion.

Findings

Overall, students' structural and behavioral understanding of sensor-based devices and toys shifted from simplistic or limited pre-unit to advanced post-unit (see Figure 2, central table). Pre-unit, structural explanations were mainly limited to input and output devices. Behavioral explanations either involved only electronic interactions between circuit elements or accounted for control flow similar to conditional logic in *Scratch.* However, post-unit, structural explanations included computational components and clearer interconnections. Further, behavioral explanations included data flow details involving sensor values and their processing.

Figure 2

Distribution of student responses across structural and behavioral details (table) and themes and frequencies within behavioral explanations pre- and post-unit (graphs either sides).



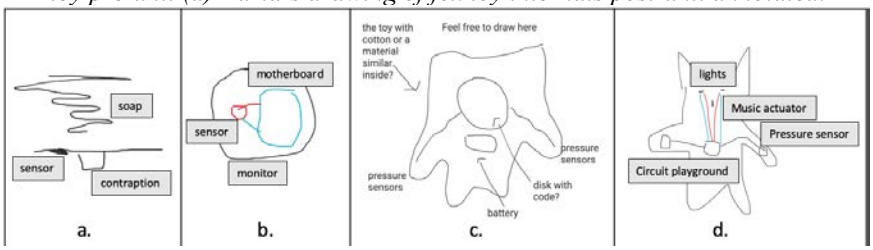
Towards advanced structural understanding

Most structural explanations pre-unit missed computing, more so in the case of automatic soap dispensers (Figure 2, Simplistic column along Structure row). Although the toy's structural composition was more accessible pre-unit, most responses still lacked interconnections between different components (14 out of 20). However, post unit, students' structural explanations across artifacts involved a computational component and interconnections (table in Figure 2, Structure row). Most descriptions included computing-related components such as "motherboard" and microcontrollers, and drew interconnections between input, output, and processing unit.

Across both interview artifacts, explanations about structural composition got more sophisticated post-unit. Pre-unit, more than half of the explanations (14 out of 20) missed any computing component or included one without a clear role. For instance, in pre-unit, Dave described the internals of the soap dispenser as involving only a sensor and a mechanical "contraption" for letting the soap out (Figure 4, a.; 020521, pre-unit). These explanations are unlike Karla's pre-unit response that involved a "disk with code" connected to the "pressure sensors" at the hands of the toy bird, without any connections with the "disk" (Figure 4, c.). However, at the end of the unit, most descriptions (15 out of 20) involved a separate microcontroller connected to input and output devices. Besides structural composition, there was a significant difference in how students explained interconnections post-unit compared to pre-unit. Unlike mentioning different parts without interconnections pre-unit, students made more elaborate connections post-unit. For instance, in his description of how a pulsometer works, Dave clarified that the sensor and the screen will be connected to the "motherboard" to receive values and display them onto the screen. This is comparable to Karla's explanation post-unit involving microcontroller and actuators with definite interconnections (Figure 4, d.).

Figure 4

(a) Dave's annotated drawing of internal structure of an automatic soap dispenser pre-unit; (b) Dave's pulsometer internals post-unit annotated; (c) Karla's structural drawing of the bird toy pre-unit (d) Karla's drawing of fox toy internals post-unit annotated.



Towards advanced behavioral understanding

Unlike structural understanding, pre-unit, students' conception of both systems' internal behaviors was simplistic or limited (Behavior row in Figure 3). However, post-unit, this shifted to more advanced understanding within behavioral descriptions across the everyday technologies and e-textile toys, more pronounced in the case of the toy. Further, students included more data and control flow details in their internal working explanations post-unit.

Before the unit, most behavioral explanations (15 out of 20) were either simplistic or involved computing in a limited fashion. For example, Santos explained the underlying mechanism for the toy as "two pieces of wires, when squeezed, touch and send a signal to the light. They turn brighter when you squeeze them harder" (022421, pre-unit). However, post-unit, students' explanations involved more computational details, moving between the

different layers of abstractions between the hardware and the software. Most (15 of 19) descriptions had computing mediating data flow between the input sensors and the actuators such as LEDs or the display; only 5 of the 19 explanations were simplistic or limited. Overall, learners more often acknowledged the role of programs in controlling the behavior of the system post-unit.

Students' behavioral explanations, post-unit, moved from predominantly circuit-based or control-flow-based to more data-flow-based (see Figure 3, graphs on either side). Pre-unit, a majority either involved only circuit-related aspects (7 out of 20) or treated circuit and program as separate entities (3 out of 20) or explained in terms of conditional control flow, drawing from *Scratch* they had just learned (9 out of 20). However, post-unit, students better articulated the mediating role of computing within these artifacts, at least in one of their explanations. A majority of explanations (9 out of 19) included some form of computation with numerical values produced by the sensors and programs as comparing values to make decisions for outcomes or performing arithmetic operations on them such as counting or incrementing based on the pulses sensed. However, a small proportion of students (2 out of 10) struggled to explain the behavior of the pulsometer.

Discussion

Students moving towards constructing advanced explanations of the internal dynamics of everyday devices and interactive toys post-unit is promising in a few ways. Unlike prior studies that reported school students across a wide range of ages having difficulty unpacking everyday devices (e.g., Cederqvist, 2020), our results noted that high school students within physical computing unit shifted their conceptions. However, given that this was one of the first studies exploring changes in learner conceptions across a semester-long unit, more work is needed to examine the role of curricular projects, the curriculum, and the context of e-textiles in deepening student conceptions about the inner workings of physical computing systems.

Analyzing students' structural and behavioral conceptions illuminated specific aspects of this conceptual shift. Learners not only developed a more detailed understanding of the structural composition and connections, but they had also developed a language to talk about different layers of abstractions between the hardware and software. Such a trend can be considered a step towards understanding the underlying designs of everyday devices that embody social injustices (e.g., Costanza-Chock, 2020). Thinking about the internal dynamics of devices such as automatic soap dispensers or digital pulsometers in terms of sensor values and their processing makes room for critical questions such as who's data is included and excluded in the device design and what are the implications for different user groups. Such questions can lead to recognizing how social aspects such as race, gender, sexual identity, etc., intersect with the design of these devices and developing computing literacy required to advocate for actionable design changes within everyday computing systems (Costanza-Chock, 2020).

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Exploring an Online Simulation Before Lecture Improves Undergraduate Chemistry Learning

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Abstract: This study tested whether exploring with simulations before instruction offers the conceptual benefits of "productive failure," compared to a more traditional lecture-then-practice method. Undergraduate students (*N*=218) in introductory chemistry courses completed an activity using an online simulation about atomic structure. Students either completed the simulation activity before (explore-first condition) or after (instruct-first condition) a lecture on the topic. Students in both conditions scored equally on an assessment of basic facts taught in the instruction. However, students in the explore-first condition scored significantly higher on assessments of conceptual understanding and transfer to a new concept, compared to students in the instruct-first condition. Students in the explore-first condition also reported experiencing greater competence and curiosity during the learning activities. A guided simulation activity prior to instruction can have both motivational benefits and deepen students' understanding.

Introduction

Exploratory Learning

Exploratory learning reverses the typical lecture-then-practice order of instruction, by giving students an exploration activity prior to direct instruction on the underlying topic. A growing number of studies have demonstrated that exploring before instruction improves students' conceptual understanding (Darabi et al., 2018; Loibl et al., 2017; Sinha & Kapur, 2021). Studies have also shown that students who explore first are better prepared for "future learning"— transferring their understanding to a related topic (Schwartz & Martin, 2004).

Completing a novel activity before instruction can be challenging, but also beneficial to learning. This process is considered "productive failure" for several reasons (Kapur, 2016). First, students consider what they already know about the content area, better integrating prior knowledge with the new knowledge (Newman & DeCaro, 2019). Second, students realize that they have gaps in their understanding—increasing the accuracy of their metacognition (Glogger-Frey et al., 2015) and heightening curiosity (Lamnina & Chase, 2019). Finally, students discern what features of the problems are, and are not, relevant to solving the problem (DeCaro & Rittle-Johnson, 2012; Glogger-Frey et al. 2015; Loibl et al., 2017; Schwartz & Martin, 2004).

Although exploratory learning has been shown to improve conceptual understanding, not all studies show this benefit (e.g., Chase & Klahr, 2017). More research is needed, in order to demonstrate when an exploration activity will benefit student learning or not. Additionally, little is known about whether activities that do not involve problem solving also have conceptual benefits when used as exploration activities.

Current study

The current study examined whether an online, interactive simulation benefits students' conceptual understanding when used as an exploration activity before a lecture, as opposed to practice after a lecture. *Interactive simulations* are graphically visualized representations of events, processes, and systems, designed to allow students to engage in scientific inquiry (Moser et al., 2017). When using a simulation, students can test hypotheses by systematically adjusting parameters and manipulating objects. Simulations have been increasingly accessible and popular to use in STEM classrooms (Blake & Scanlon, 2007). Despite their differences from the problem-solving activities typically used in exploratory learning, simulations present many of the same features thought to be useful (Kapur, 2016). For example, completing a simulation before instruction is potentially challenging but engaging, students can use prior knowledge to work on them, they offer feedback that can help students discern important problem features, and they include a wide problem space for students to explore.

In a controlled experimental design, students in undergraduate chemistry courses were randomly assigned to condition. Each condition included the same materials in different order. Students in the *explore-first condition* completed an online simulation activity on atomic structure, then were lectured on this topic. Students

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in the *instruct-first condition* completed lecture, then the simulation activity. All students then completed a survey assessing their perceptions of the learning activities. Finally, students completed a posttest assessing knowledge of facts directly taught during the lecture, targeted concepts, and transfer of knowledge to a new, related concept.

We hypothesized that the benefits of exploring before instruction would not be found on assessment of the taught facts, but rather on the conceptual and transfer items (e.g., Loibl et al., 2017; Schwartz & Martin, 2004). We also explored whether general motivational factors (situational interest, curiosity, self-efficacy, competence, belonging) would increase in the explore-first condition. Some prior studies have shown evidence of improved interest, but results have been mixed (e.g., Weaver et al., 2018), and most studies have not examined these factors. Such results would demonstrate that simulations can be used effectively as exploration. Moreover, conceptual changes may arise from a technique that is easy to implement, even in large undergraduate STEM courses.

Methods

Participants

Participants (N=218) were all undergraduate students (M_{age}=18.7, SD=2.38, 44.5% female) enrolled in two sections of an introductory chemistry course who completed both the simulation activity and posttest. Additional students were excluded from analyses for not attending the full class session (5 students), or for illegible writing on the posttest that precluded scoring (1 student).

Materials

The class sessions included four phases that varied in order: simulation activity, lecture, survey, and posttest. Students in the *instruct-first condition* (n=116) completed the lecture, then the simulation activity. Students in the *explore-first condition* (n=102) completed the simulation activity, then the lecture.

In the *simulation activity*, students explored the *Build an Atom* Physics Education Technology (PhET) interactive simulation (https://phet.colorado.edu/en/simulations/build-an-atom) using their own devices. Students were given a worksheet to guide their exploration, and most students worked individually. The worksheet consisted of brief instructions on how to operate the simulation, followed by guiding questions (e.g., Place a neutron in the nucleus. What is the name of the element?"). In the *lecture*, the course professor gave direct instruction on the topic of atomic structure accompanied by presentation slides. The lecture began by introducing the basics of atoms, followed by description of atomic structure, isotopes, and atom identity.

Survey items assessed motivational factors related to the learning activities, using a 5-point Likert scale (1=*Strongly Disagree*, 5=*Strongly Agree*). Items assessed students' perceived *self-efficacy* (2 items, α=.72; adapted from Findley-Van Nostrand & Pollenz, 2017; e.g., "I feel confident in my ability to learn these kinds of topics"), *competence* (2 items, α=.37; Findley-Van Nostrand & Pollenz, 2017; e.g., Thanks to today's learning activities, I feel more competent in this topic area), *situational interest* (3 items, α=.62; Rotgans & Schmidt, 2014, e.g., "I enjoyed working on these activities"), *curiosity* (3 items, α=.60; Naylor, 1981; e.g., "I want to know more about what I was working on"), and *prospective belonging uncertainty* (4 items, α=.82; adapted from Walton & Cohen, 2011; e.g., "Sometimes I worry that I do not belong in college." The belonging items were reverse coded, so that higher scores reflected greater perceived belonging. Next, students completed the *Mental Effort Rating Scale,* a measure of cognitive load (1 item; Paas, 1992; "In completing the learning activities I invested…"). This item was rated on a scale from 1 (*very, very low mental effort)* to 9 (*very, very high mental effort*). Additional survey items were not included in the current report. Finally, students provided demographic information.

The *posttest* included 12 open-ended questions developed by two content experts (chemistry professors). Six items assessed facts taught during the lecture (6 points; α=.76; e.g., "What is the name of the particle that has no charge?"). Five items targeted conceptual knowledge (10 points; α=.31; e.g., "Explain the difference between an atom and an ion"). One item tested knowledge transfer (2 points; "What is the charge of an ion that has 12 protons and 13 electrons? Explain your answer").

Procedure

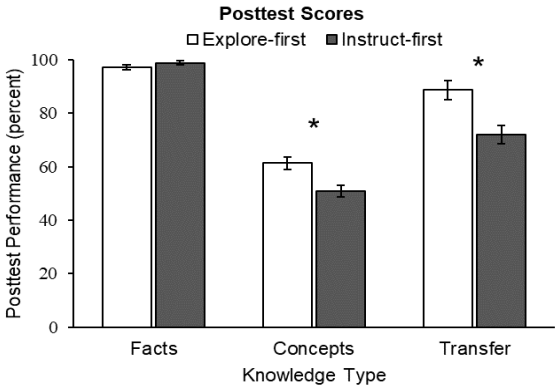
Students were enrolled in two sections of an introductory chemistry course, taught by the same professor in large lecture halls. Each course section was randomly divided into two groups and asked to attend on Wednesday (instruct-first condition; n=102) or Friday (explore-first condition; n=116), in a 50-min session. The explore-first condition began with the simulation activity (approximately 15 min), then the lecture (approximately 15 min). The instruct-first condition completed the lecture then simulation activity. Then, students completed the questionnaire (5 min) and posttest (10-15 min) on paper, without computers or notes. Students were told that responses would not be graded and assessed how they learned from the activities. Weeks later, the instructor sent a debriefing email with the option to withdraw data. All procedures were approved by the university IRB.

Results

Learning Outcomes

Posttest scores were examined using a 2 (*instruction order*: explore-first, instruct-first) × 2 (*knowledge type*: facts, concepts) mixed-factorial analysis of variance (ANOVA), with instruction order between-subjects and knowledge type within-subjects. A significant main effect of instruction order was found, $F(1,216)=5.63$, $p=.018$, $\eta_p^2=.03$. On average, posttest scores were higher for students in the explore-first condition ($M=79.22\%$, $SE=1.31$) than in the instruct-first condition ($M=74.94\%$, $SE=1.23$). There was also a significant main effect of knowledge type, $F(1,216)=649.82$, $p<.001$, $\eta_p^2=.75$, with higher scores on questions assessing basic facts ($M=97.96\%$, $SE=0.63$) than concepts ($M=56.20$, $SE=1.60$). These effects were qualified by a significant interaction, $F(1,216)=13.71$, $p<.001$, $\eta_p^2=.06$ (Figure 1). Follow-up ANOVAs revealed that fact knowledge scores were not significantly different between the explore-first ($M=97.06\%$ $SE=0.91$, *95% CI*[95.28, 98.86]) and instruct-first ($M=98.85\%$, $SE=0.86$, *95% CI* [97.16, 100.54]) conditions, $F(1,216)=2.05$, $p=.154$, $\eta_p^2=.01$. Concept knowledge scores were significantly higher in the explore-first ($M=61.37\%$, $SE=2.34$, *95% CI*[56.76, 65.98]) than the instruct-first condition ($M=51.03\%$, $SE=2.19$, *95% CI*[46.71, 55.36]), $F(1,216)=10.40$, $p<.001$, $\eta_p^2=.05$. A separate ANOVA demonstrated that students in the explore-first condition ($M=88.73\%$, $SE=3.63$) scored higher on transfer than those in the instruct-first condition ($M=71.98\%$, $SE=3.41$), $F(1,216)=11.29$, $p=.001$, $\eta_p^2=.05$.

Figure 1
Posttest scores as a function of knowledge type and order of instruction. Error bars = ± 1 SE.



Survey

Instruction order had no impact on reported cognitive load (Table 1), $F(1,209)=1.61$, $p=.207$; by the end of the class session, students in the explore-first condition did not perceive higher mental effort. To assess differences between instruction orders on the other survey items, a MANOVA was used. A significant overall effect of instruction order was found, $F(5,174)= 2.89$, $p=.016$; Wilks' $\Lambda=.923$, $\eta_p^2= .08$. On average, students in the explore-first condition rated these measures as higher than the instruct-first condition. Examining each scale, significant differences were found for curiosity, $F(1,178)=4.81$, $p=.030$, $\eta_p^2=.03$, and competence, $F(1,178)=6.04$, $p=.001$, $\eta_p^2= .06$ (Table 1).

Table 1 *Descriptive Statistics for Survey Subscales*

	Explore-First			*Instruct-First*		
	M	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Cognitive Load	5.51	0.15	5.21–5.80	5.24	0.14	4.96–5.52
Self-efficacy	4.35	0.05	4.24–4.46	4.28	0.06	4.16–4.39
Belonging	4.04	0.08	3.88–4.20	3.98	0.09	3.81–4.15
Curiosity	**3.79**	**0.05**	**3.68–3.89**	**3.58**	**0.08**	**3.41–3.74**
Competence	**3.78**	**0.08**	**3.63–3.92**	**3.41**	**0.09**	**3.24–3.57**
Situational Interest	3.97	0.06	3.85–4.08	3.86	0.07	3.71–4.01

Note: Bold=statistically significant at p<.05. Cognitive load 9-point scale; all others 5-point scale.

Discussion

Students given a guided simulation activity before lecture in an undergraduate chemistry course scored higher on assessments of concept knowledge, and transfer to a new concept, compared to completing the same simulation activity after instruction. Students in the explore-first condition also showed motivational benefits, with higher ratings of curiosity and competence. Motivation often predicts desire to continue learning about a topic (Deci & Ryan, 2000). These results suggest that exploratory learning may have benefits for future learning and persistence.

These findings expand the exploratory learning literature by examining the impact of using simulations, rather than problem-solving activities, as exploration activities before lecture. These results also extend this research to an undergraduate chemistry course. This research used a controlled classroom experiment, manipulating only the order of the activity and lecture, demonstrating a causal effect. Materials were created and administered by chemistry professors, increasing ecological validity.

More research is needed to replicate these findings, with other types of simulations, learning domains, and other instructors. One limitation is that the instruct-first condition was given earlier in the week than the explore-first condition, thus the professor may have become more fluent in giving the lecture. However, the professor had taught this course for many years, reducing the likelihood of practice effects.

Simulations are becoming increasingly accessible in STEM courses. These results suggest that a minor change in the timing of these simulations—given before, rather than after, instruction—can deepen students' understanding and support their perceived competence and curiosity for the information.

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Achievement Motivation in Writing: Exploring the Pursuit of Multiple Goals and Keystroke Behaviors During Writing Tasks

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Abstract: Few studies have investigated the applicability of structured motivation frameworks across more subjective academic tasks such as writing. By using person-oriented analyses and fine-grained data channels to build upon existing theories of motivation in writing tasks, ongoing research can work towards capturing how motivation impacts students' writing processes as they unfold. As such, this study examined the occurrence of multiple goal orientation profiles in undergraduate writing students and if those goal profiles differed in the average duration students spent engaging in multiple writing processes. A *k*-means cluster analysis ($n = 60$) revealed three student clusters with distinct multiple goal profiles. A one-way MANOVA did not find significant differences in mean keystroke activity times across these profiles, bringing into question the applicability of traditional achievement goal frameworks in writing contexts.
Keywords: Achievement Goal Theory, Keystroke Analysis, Motivation, Writing Analytics

Achievement motivation in writing tasks

Achievement goal theories have been used to research learners' achievement motivation in educational settings (Elliot & Murayama, 2008), resulting in the development of self-report that are used to categorize students within a single achievement goal orientation. Previous research supports the relationship between students' pursuit of these goal orientations and beneficial academic outcomes such as increased academic achievement or content interest (Senko et al., 2011), however renewed attention to the impact of motivation within complex tasks like writing, has prompted researchers to apply these measures in context where measures of achievement are more subjective (Wormington & Linnenbrink-Garcia, 2017).

As such, it is important to expand beyond the current reliance on self-report measures and exclusive goal endorsement (Elliot et al., 2011). In contrast with more objective STEM disciplines, the 'right' answer in writing is often subjective and situated within dynamic cognitive and socio-cultural factors (Graham, 2018). This level of subjectivity, paired with limited understanding of how motivation interacts with students' writing processes may impact the relevance of a highly structured measure like the AGQ-R in writing contexts.

For this reason, achievement goal research must expland to better reflect the impact of less clearly delineated elements such as multiple goal profiles and contextual factors. While past studies examining the role of goal orientations in writing have found relationships between performance goals and increased academic achievement (Senko et al., 2011), as well as mastery goals and beneficial behaviors like revision (Kaplan et al., 2009), researchers investigating the role of achievement goals in writing have also noted the existence of multicollinearity between goal orientations and participant reports noting similar usage of revision strategies across goal profiles, muddying our understanding of how achievement goals impact motivation in writing contexts (Paul et al., 2021). By shifting towards the use of person-centered research methods and granular data channels, researchers may be able to examine individual motivation profiles more closely (Urdan & Kaplan, 2020; Wormington & Linnenbrink-Garcia, 2017).

Theoretical frameworks

Elliot and Murayama's (2008) 2x2 achievement goal questionnaire-revised, (AGQ-R) has been widely used to asess learners' achievement motivation across diverse educational contexts. Within the traditional 2x2 framework, learners are categorized into distinct achievement goal orientations, which Elliot and Murayama separate by both the definition of learners' achievement goals (mastery and performance) as well as the valence of those goals (approach and avoidance), resulting in four distinct goal profiles (2008). Previous research on these achievement goal profiles (i.e., mastery approach [MAP], mastery avoidance [MAV], performance approach [PAP], and performance avoidance [PAV]; see Elliot & Murayama, 2008) has found positively valenced approach goals like MAP and PAP to be linked with desirable student outcomes such as increased academic achievement and content mastery, while negatively valenced avoidance goals are largely viewed as less-beneficial (Elliot & Murayama, 2008).

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Graham's writer(s)-within-community model (WWC) provides a discipline-specific compliment to the achievement goal framework by giving attention to the role that motivation plays in the writing process (2018). Graham describes writing as a complex task that is influenced by both cognitive and sociocultural factors, positing that a writer's motivation or goals for the task are influenced by both internal (i.e., content knowledge) and sociocultural (i.e., community support) factors, which impacts learners' writing processes and behaviors (Camacho et al., 2021). Given the complex nature of writing texts, the WWC model provides important insight into contextual factors specific to writing tasks that may impact the writing process (Graham, 2018).

This study used these theories to interpret writers' achievement goals and writing processes, utilizing advances in analysis methods and fine-grained representations of participants writing processes to highlight the connections between participants' motivation and writing processes.

Current study

This study sought to examine first-year undergraduate writing students' self-reported achievement goals in relation to completing a self-reflective writing task, as well as the relationship between those goals and students' keystroke behaviors during the writing task.

The participants in this study were undergraduate students (n = 60) enrolled in a first-year writing course. Students were asked to *describe in as much detail the step-by-step process of how you complete a formal writing task* for 30 minutes. Students had no requirements (e.g., specified length, structure, etc.) other than to respond to the prompt for the allotted duration and were explicitly told their responses would not be graded.

Prior to the study, participants responded to a series of questionnaires that included Elliot and Murayama's (2008) AGQ-R. The AGQ-R contains four subscales (one for each of the achievement goal profiles) that consist of 3 questions for each subscale, for a total of 12 items. Participants indicated their agreement (from 1 = '*strongly disagree'* to 5 = '*strongly agree'*) to statements to measure their achievement goals in relation to the writing course. Each of the four subscales have also shown high levels of internal consistency (mastery approach [=.84], mastery avoidance [=.88], performance approach [=.92], performance avoidance [=.94]) (Elliot & Murayama, 2008).

Keystrokes were logged using InputLog (Leijten & Van Waes, 2013) to record students' input in Microsoft Word during the writing session (e.g., mouse movements, keystrokes, inter-key intervals, etc.) with its associated timestamp in milliseconds. Keystroke behaviors utilized within this study included the mean total time participants spent pausing, inserting, producing, and deleting text during the writing.

Results

Research question 1: Did undergraduate writing students' self-reported achievement goal endorsements suggest the occurrence of multiple goal profiles?

Given the presence of significant multicollinearity between participants' aggregate scores derived from the 2x2 AGQ-R, a cluster analysis was performed to identify multiple goal orientation profile types across participants.

Hierarchical clustering was applied to participants' raw aggregate scores for each of the achievement goal subscales using Ward's method, with changes in the agglomeration coefficients (AC) and assessment of the resulting visualizations (i.e., elbow technique) used to determine the ideal number of clusters (Wortha et al., 2019). *k*-means clustering was used to compare cluster centers and membership for the 2- and 3-cluster solutions. Given that the 3-cluster solution found large Euclidean distances between the final cluster centers and appropriate sample sizes for each cluster (n > 15), the 3-cluster solution was selected.

The 3-cluster solution was further categorized based on the goal profile labeling procedures outlined in Wormington and Linnenbrink-Garcia's 2017 meta-analysis. Cluster profile labels were based on each cluster's mean aggregate AGQ-R subscale scores (e.g., less than 6 on a 15-point scale indicates low goal endorsement, more than 12 indicates a high goal endorsement, and scores within that range are viewed as moderate goal endorsement), where average mean aggregate scores for each of the four subscales were used to label the 3 clusters.

Research question 2: What multiple achievement goal profiles did students pursue in relation to the writing task?

Cluster 1: High all goals

Students in Cluster 1 (n = 24) were classified as belonging to the *High All Goals* profile, with final cluster centers (see Figure 1) exhibiting high endorsement of all four achievement goal orientations, which suggests these students were highly concerned with both writing task mastery and their ability to appear as competent writers to others. While traditional achievement goal theories may interpret the pursuit of all four goal orientations as

inherently contradictory, Wormington and Linnenbrink-Garcia's meta-analysis found that students within High All Goals profiles displayed high levels of academic achievement, suggesting some benefits of multiple goal pursuit (2017).

Cluster 2: Average all goals

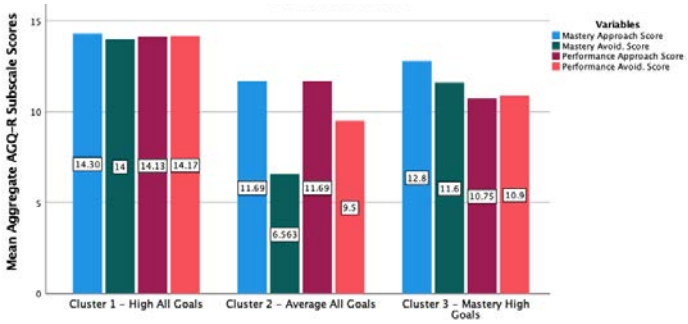
Students in Cluster 2 (n = 16) were classified as belonging to the *Average All Goals* profile, with final cluster centers (see Figure 1) exhibiting average endorsement of all four achievement goal orientations, which suggests these students were also concerned with both writing task mastery and their ability to appear as competent writers to others, but at a more moderate level. Wormington and Linnenbrink-Garcia found this goal profile to be the most prevalent, with students in Average All Goals profiles exhibiting lower scores on measures of engagement and well-being (2017).

Cluster 3: Mastery high goals

Students in Cluster 3 (n = 20) were classified as belonging to the *Mastery High Goals* profile, with final cluster centers (see Figure 1) exhibiting high endorsement of both mastery approach and mastery avoidance goal orientations, which suggests these students were most strongly motivated by an intrinsic desire to master the writing content. While the mastery avoidance cluster center (M = 11.60) fell below the established requisite score, its proximity to the cut off score (12) in addition to the overall high mastery approach score (M = 12.80) suggested Cluster 3 most closely fit the Mastery High goals profile described by Wormington and Linnenbrink-Garcia (2017). Wormington and Linnenbrink-Garcia (2017) found this goal profile to be common and generally associated with higher academic performance outcomes than other goal profiles included within studies of multiple goal orientations.

Figure 1

Final Cluster Centers for 3-Cluster Solution.



Research question 3: Was there a significant difference in students' keystroke behaviors between the resulting goal orientation profiles?

A one-way multivariate analysis of variance (MANOVA) was conducted to determine if participants' mean deletion, insertion, production, and pausing times (ms) captured within the keystroke logs significantly varied between the three established achievement goal profile clusters. Despite variation in keystroke behavior times across the clusters, there were no significant differences in mean keystroke behavior times across the three goal profile clusters (see Table 1).

Table 1

Means, Standard Deviations, and MANOVA Results for Keystroke Activity Times Across Clusters

Keystroke	Cluster 1		Cluster 2		Cluster 3		$F(2, 57)$	
Times (ms)	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*
Deletion	44573.42	22812.62	43197.31	18249.34	44526.85	19065.17	.026	.975
Insertion	142536.67	135310.16	140085.56	117000.28	169006.85	174162.17	.239	.788
Production	4000847.42	135896.80	365366.19	170528.41	339559.25	143882.99	.947	.394
Pausing	1761231.71	113013.01	1733557.38	102386.89	1745347.30	74019.01	.393	.677

Discussion and future directions

Given the presence of multicollinearity between goal profiles, a *k*-means cluster analysis used to answer research question one produced three student clusters, each with a distinct achievement goal endorsement profile. Results of research question two found that all three goal profile clusters exhibited high to moderate endorsement of two or more achievement goals simultaneously, supporting the occurrence of multiple goals and highlighting the complexity of students' writing motivation (Graham, 2018).

The third research question examined relationships between students' achievement goal profiles and writing behaviors measured through keystroke logging. Although the mean keystroke activity time differences across the established goal orientation clusters were not statistically significant, the discrepancy between these findings and the established linkages between achievement goal orientations and academic performance highlights the need for further exploration of achievement goals in writing tasks to include more granular data (i.e., keystroke input).

Through the inclusion of multiple data channels and person-orientated methods like cluster analysis, researchers can develop a deeper understanding of motivation in writing contexts, potentially challenging some of the long-standing assumptions regarding the achievement goal framework and its generalizability across more subjective tasks like writing.

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Exploring Cross-cultural Differences in Student Game Designs for WearableLearning

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Abstract: In this paper, we describe a study exploring cross-cultural differences in the game designs of middle school students from the USA and Argentina. Students created game design artifacts as part of the *WearableLearning* curriculum, which were coded to identify game aspects such as social and physical interactions, technology incorporation, and game characteristics and representations. We describe initial findings on how students' culture is potentially expressed in their game designs and discuss future directions for designing interactive learning environments that engage students in game design activities.

Keywords: learning technologies, game design, constructionism, culture

Introduction

The digital revolution has reshaped education and efforts to improve student learning outcomes. For example, individualized learning technologies have been found to improve learning outcomes and enhance student motivation (Hamada & Hassan, 2016). There is also a growing research focus on the intersections of culture, learning, and technology. Learning takes place in cultural contexts and learners' cultural backgrounds shape their learning habits (Ladson-Billings, 1995). Research on how culture influences learning suggests that instruction and learning environments should be consistent with learners' cultural experiences (Benson et al. 2017). Mohammed and Mohan (2011) argued that deficiencies in cultural awareness in digital learning platforms and instructional design cannot be ignored, given the rapid rise of digital learning. Some interactive learning environments (ILEs) have been expanded to account for the socio-cultural aspects of learners, such as the use of avatars that provide a sense of familiar cultural presence for learners (e.g., Arroyo et al., 2014).

In this paper, we explore how learners' culture is potentially expressed in their game designs within the context of *WearableLearning* (*WL*), a platform for children to learn mathematics by *playing*, *designing*, and *programming* physically active and social educational math games that use mobile phones to support players (Micciolo et al., 2018). *WL*'s accompanying curriculum engages students in the experience of *playing* games, and then later on *designing* and *building* their own games for peers to play. A key part of this process asks students to express game design ideas as drawings and narrations on booklets. These artifacts could mirror learners' cultural values, beliefs, and practices. Understanding the cultural constructs embedded in these designs and artifacts could help us identify ways to better support students' learning, and more broadly, improve the design of ILEs and understand the extent to which learning technologies can be "exported" to other geographies and communities. We present our initial findings on cross-cultural differences in game designs by middle school students from the USA and Argentina and discuss how these findings can be used to benefit the design of ILEs.

Related Work and Theoretical Framework

Our work is driven by key constructs including socio-cultural theory, constructivism, and constructionism.

Socio-cultural theory. Socio-cultural learning theory stresses that learning occurs within a social world and that learners' cognitive development is largely influenced by their surrounding culture, tools, beliefs, and attitudes (Vygotsky, 1978). In the *WL* context, game design artifacts such as written narratives, drawings, and diagrams on rules, physical objects and space, or physicality could mirror aspects of learners' culture, such as their beliefs, values, attitudes, perceptions of time, religion, and material possessions (Hofstede et al., 2005). In a similar vein, Kafai (1996) explored students' game designs and gender differences in them; we continue to build on such research through explorations of cross-cultural differences in the game designs of learners.

Constructivism and constructionism. *Constructivism* posits that learners construct their own knowledge and unique meanings for concepts (Elby, 2000). Related to this is *constructionism*, which states that learners are more deeply involved in their learning if they are constructing something that others will see, critique, and use (Harel & Papert, 1991). Leveraging constructivism and constructionism, *WL* facilitates mathematics and computing learning through learner-constructed math games (Micciolo et al., 2018). Through the *WL* curriculum, learners design and program phone-supported, physically active games, situating themselves within the context

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of a problem- and project-based game-design activity at the same time.

WearableLearning. *WL* is an ILE that enables learners to create and play mobile math games using a visual programming language based on *finite state machines* (FSMs). FSMs are typically used to teach computer behavior, concepts, and logic in terms of actions and reactions through visual FSM diagrams (FSMDs). The *WL* curriculum promotes computational thinking (CT) through game creation and play that integrate math, physical activity, multiplayer games, and programming. Prior work on *WL* has shown that middle school math teachers cultivated a deeper understanding of math concepts as game creators and players (Smith et al., 2020). Kafai and Burke (2015) noted that learning through game creation improves children's understanding of programming and math concepts. Our work expands *WL's* game design and play embodied learning portfolio through the lens of cross-cultural differences. Specifically, this study aims to answer the following research questions (RQs):

RQ1: What differences in *WearableLearning* game designs between students from Argentine schools and US schools exhibit, along the aspects of (a) social and physical interactions, (b) technology incorporation and dependence, (c) game characteristics, and (d) game representations?

RQ2: What do differences in game designs suggest about how students express their culture in their games?

Methodology

To explore cross-cultural differences in the game designs of students from Argentine and US schools, we analyzed *WL* game design artifacts using Ottmar et al.'s (n.d.) game design coding scheme.

Study design. We ran the six-stage *WL* curriculum with middle school students in US and Argentine schools. Students were introduced to the *WL* platform and were asked to create multiplayer games that use math, physical activity, and mobile phones (phones are used for game prompts and game inputs). The full curriculum is available at https://osf.io/yq49e/. In Stage 2 of the curriculum (a curriculum "stage" corresponds to a day), student teams brainstormed their own math games on paper to draw or map out game ideas. In Stage 3, students were given a short lecture on FSMs and then designed FSMDs on paper to represent the behaviors of mobile phones in their game. Students drew "state" boxes that correspond to game screens on the phone and arrows that specified concrete inputs (buttons, text, color sequences) that game players had to enter to move from one game state to the next. We analyzed game design artifacts from these two curriculum stages.

Participants and data collection. We collected data from a total of 172 students. Students from the US school were 21 seventh and eighth graders who attended a week-long game development summer camp. Students from three Argentine private schools were 151 sixth and seventh grade students who participated in our curriculum activities once a week for 6 weeks. In both cases, the activities were the same and each activity lasted for 60-90 minutes each day. The data collected includes the paper-based game ideation (Stage 2) and FSMD (Stages 3) sketches and the games programmed on the *WL* platform (Stages 4 to 6). Our analyses and discussions in this paper will focus on students' paper-based sketches from Stages 2 and 3 (Figure 1).

Analysis. We used a coding rubric designed by the *WL* research team specifically for analyzing game design artifacts produced by students through the *WL* platform and curriculum (full coding rubric available at https://osf.io/yq49e/). We coded for four game aspects: (1) social and physical interactions (*Collaboration, Competition,* and *Physicality Option*); (2) technological descriptors (*Dependence* and *Incorporation*); (3) game characteristics (*Game Descriptors, Progressive Levels,* and *End Goal*); and (4) game representation components (*FSMD Rules, Physical Objects, Physical Space,* and *Timing*). We used Between Subjects t-tests and Chi-Square tests to analyze differences between students from the US school and students from the Argentine schools.

Results and Discussion

We coded for ten game variables. Table 1 shows a subset of the results from coding the (1) *social and physical interactions* (*SP*), (2) *technological descriptors* (*TD*), (3) *game characteristics* (*GC*), and (4) *game representation components* (*GR*) from students' game design artifacts. We include only the four game variables with statistically significant results due to space constraints (full set of results available at https://osf.io/yq49e/): *Competition Between Teams* is the extent to which a game engages player teams in competition, *Technology Incorporation* indicates whether or not the designed game uses any form of technology (e.g., iPad, computers) within the gameplay, *End Goal* refers to the presence of an end goal for players or teams to win or finish the game, and *Timing* refers to expressions of time within the game (e.g., waiting time for turns). We found that the game designs of students from the US school depicted significantly more *competition* between teams than the game designs of students from the Argentine schools. Conversely, US students' game designs depicted less *collaboration* than Argentine students' game designs. These results suggest an expression of practices from the cultures of students' contexts: the Argentine students may be expressing the collectivist nature of Latin culture and the US students expressing the individualist culture of the US (Triandis & Gelfand, 2012). Game designs of the US students also

Figure 1
Examples of game design (left) and FSM diagram (right) sketches produced by Argentine students.

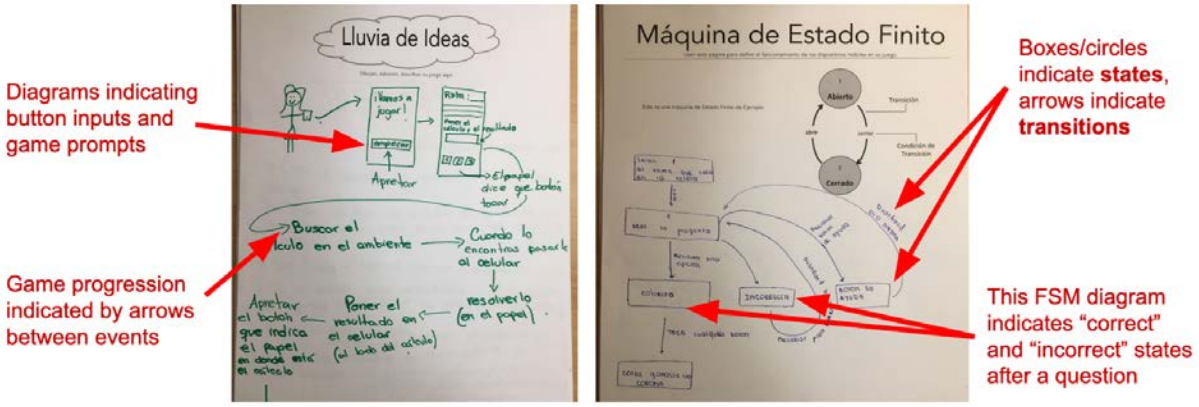

Table 1
*Count and % occurrence (in parentheses) for game variables coded for US (n=7) and Argentina (ARG) (n=41) games. (Chi-Square tests: * indicates significant difference, $p<0.05$; $^{+}$ indicates significant difference, $p<0.1$)*

Game Variables Coded	US-Stage 2	US-Stage 3	ARG-Stage 2	ARG-Stage 3
(*SP*) Competition Between Teams	3 (42.9%)*	3 (42.9%)	5 (12.2%)*	8 (19.5%)
(*TD*) Technology Incorporation	7 (100%)$^{+}$	5 (71.4%)	28 (68.3%)$^{+}$	22 (53.7%)
(*GC*) End Goal	5 (71.4%)$^{+}$	2 (28.6%)	15 (36.6%)$^{+}$	14 (34.1%)
(*GR*) FSMD: Timing		7 (100%)*		20 (48.8%)*

incorporated more technology than Argentine students' game designs. Reports (Auxier et al., 2020; Ravalli & Paoloni, 2016) indicate that children in the US and Argentina have access to technology at an early age, so early technology access does not explain the differences in technology incorporation in games. This, however, points to the need to better and more deeply understand our students' contexts. For example, we did not have data on students' use of technology outside of school settings.

In terms of game representations, all game designs of the US students had *timing* components compared to about half of the games from the Argentine students. The expression of timing in game designs may be related to the students' perception of time: Latin cultures tend to be flexible in their use of time, whereas US culture perceives time in a more rigid manner (White et al., 2011). With regard to *end goals*, in Stage 2 of the curriculum, there were more game designs by US students that had specific end goals for their games compared with Argentine students' game designs. These expressions of end goals dropped in Stage 3 in the game designs of both US and Argentine students. We suspect, however, that this drop had less to do with cultural factors, but rather the students' ability to translate from one design representation to another. Stage 2 required students to informally draw and sketch out their game design ideas on paper; Stage 3 required them to create a more formal representation of their game design sketches through FSMDs (also on paper). It is possible that when translating from one representation to another, students could have found that certain end goals they initially sketched out or conceptualized were difficult to formally represent in FSMDs. This hypothesis merits further exploration with bigger populations of students to better understand how expressions of game factors such as specifications of end goals are represented in game designs and potentially relates to students' cultures.

Conclusions, Limitations, and Future Work

Our results show that the game designs by students from a US school exhibited more technology incorporation, competition, specific end goals, and timing. Game designs by students from Argentine schools exhibited more collaboration, relatively consistent expression of game end goals, and less timing components. Aligning these with prior work on individualist and collectivist cultures, our work points to initial insights on how the culture of students' contexts (i.e., a US school and the three Argentine schools) could potentially influence how learners construct game design artifacts, specifically game designs constructed through the *WL* curriculum. This study could serve as a jump-off point for further research on exploring how ILEs and curricula supports, sustains, or hinders learners from expressing their cultural beliefs, attitudes, values, and practices in the artifacts they design and construct. Future work could address limitations in our study. For example, we used the geographic locations of the participating schools as a proxy for culture. This ignores the unique, multifaceted sociocultural identities

of the students themselves and does not account for how the cultural backgrounds of each student could contribute to and shape the game design artifacts that they co-constructed with their peers. Interviews or focus-group activities with the students could enable the collection and analysis of more nuanced data to more deeply understand the kinds of cultural expressions that students bring into the constructions of game artifacts. Furthermore, this can provide insights for designing curricula and ILEs (such as *WL*) that engage students in creative design and construction activities for learning that are also grounded in the students' needs and values. Additionally, our analyses are based primarily on our coding rubric, and this study is the first time it has been used on design artifacts beyond ones collected from the US. In future work, we aim to further explore and understand the extent to which our coding rubric can be used to encapsulate the nuanced characteristics of game design artifacts created by learners, especially across different cultures and contexts.

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How Embodiment Helps Students Explain Their Ideas within an MR Environment and Content Interviews

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Abstract: In this paper, we explored young children's embodied representation of states of matter after engaging in a mixed-reality environment where students explored states of matter by acting as particles (Danish et al., 2020). To examine how embodiment may play a role in helping students' explanations, we analyzed students' performance in assessments to explore how embodiment helps young children represent their ideas and found they were able to use a combination of talk and embodiment to provide more detailed explanations. Then we further explored how students formed these conceptual understandings in the MR environment and applied interaction analysis to analyze how embodiment played a role in the process. The results showed that gestures students used in the post-assessment emerged through their collective embodiment in the classroom.

Introduction

Embodiment has been viewed as a crucial part of cognition and learning (Abrahamson & Lindgren, 2014), prompting scholars to explore how to use embodiment to support students' learning (Danish et al., 2020). Previous studies demonstrate how engaging with conceptual ideas through movement improves students' target content understanding. Embodied motion and gesture have also been shown to serve an important role in students' communication and knowledge construction (Broaders, et la., 2007). As the role of embodiment in learning and knowing continues to be studied, there remains little scholarship exploring the role of embodiment in assessment in addition to instruction.

Many studies use multiple choice questions or content-focused measures of learning after embodied activities that reflect traditional beliefs about learning and do not keep pace with our current understanding of the repertoires of embodied expression children utilize during learning. Novices, in particular, might have ideas about target science content that they cannot show in the traditional assessment context. Therefore, there is a need to incorporate embodiment into assessments that measure students' learning after engaging in embodied learning activities. Previous research also suggests that embodiment offers an alternative way for elementary students to explain their understanding of concepts that they're less familiar with (Salehet al., 2015). This suggests that embodiment can offer a broader picture of what concepts students understand and how deeply they understand them. However, questions remain about how to reliably draw out students' embodied understandings in an assessment context. Therefore, in this paper, we focus on students learning states of matter within the Science through Technology Enhanced Play (STEP) environment as a case study for how the body can play a role in supporting sensemaking across learning and assessment. In prior studies, we found that students were able to understand complex science concepts such as the particulate nature of matter while engaging in the STEP environment (Danish et al., 2020). In this study, we designed two forms of instruments to assess young children's understanding of states of matter: a multiple-choice test and an individual interview. In the interview, we encouraged students to use their bodies to show how particles behave in different states of matter. We also provided manipulatives for student's opportunities to "act out" ideas. We then explored the following two questions: 1) How did embodied prompts help students to represent their ideas in an assessment context? 2) How did students form a conceptual understanding of particles' behavior and connection to macro-level state within the STEP environment?

Design

This study was built in the Science through Technology Enhanced Play (STEP) environment (Danish et al., 2020), a MR environment that uses Kinect cameras to track students' movement and map them to digital avatars. As students move in the space, the simulation shows their movement as particles interacting and changing into solid, liquid, and gaseous states on a shared screen in front of the classroom. The learning targets were (a) understanding and demonstrating particle behaviors in three states of matter and (b) depicting the connections between microscopic and macroscopic representations of matter. While students moved to represent particles moving,

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STEP depicted particle speed, distance, attraction, and particle trajectory according to real-world physics, enabling students to discover these underlying rules through their collective movement.

Method

Participants and Data source

Twenty-two students from a first and second-grade mixed-age classroom in a mid-western elementary school in the U.S. participated in this study. Students participated in a 7-session STEP activity; each session included 30 minutes of activity in the STEP environment and 30 minutes of supplemental activities without the STEP software in another classroom. Students participated in multiple-choice pre-tests and then one-on-one interviews the week before the project started, and the multiple-choice post-test was followed by individual post-interviews after the class engaged with all STEP activities. The interview included 26 questions, and during the interview, students were encouraged to use body movements to demonstrate particle behavior. All classroom activities and interviews were video recorded for analysis.

Data analysis

We applied a paired t-test to examine students' overall understanding of particle behavior We coded the pre- and post-interviews with a coding scheme used in previous iterations of STEP (Danish et al., 2020). Three research assistants coded the interviews and achieve 81% agreement on coding. We also looked into the interview data to find how embodiment helped them to demonstrate their understanding of the particle's behavior. All authors re-watched students' interviews videos and focused on students' verbal and embodied responses in the videos to explore how they articulated their ideas in the interviews. Based on our review of the interviews, we found that students used gestures in the post-assessment to supplement their demonstration of understanding, especially for challenging ideas such as micro-macro connection. Then we went back to the classroom videos and applied interaction analysis (IA, Jordan & Henderson, 1995) to see how concepts explored in students' interviews were developed through their in-classroom activities.

Findings

We ran a paired t-test on students' performance on the multiple-choice test and found there was a significant improvement from the pre-test score (M = 5.5) to post score (M = 11.2), t = -8.72, p <.01, which showed that students' overall understanding of the target content improved after they engaged within the STEP environment.

To answer our question: "How did embodied prompts help students to represent their ideas in an assessment context?" We focused on two sets of interview questions related to the challenging multiple-choice questions: 1) questions that encouraged students to use their body to act like particles and 2) questions that asked them about the micro-macro connection. We found that more students were able to answer the interview questions in post-interviews accurately when encouraged to use their body to represent particles' movement. For example, 57% of students were able to describe at least one characteristics of particles in Question 4 "Let us pretend you are particles in that water, can you act out with your body how particles are moving in the water?". Then for questions 12-15, which covered micro-macro connections, we found thirteen of the twenty-one students (61%) were able to elaborate on the mechanisms of particles' behavior. This was quite a difference compared to the 2 students who were able to answer the multiple-choice question covering similar content correctly. This suggests that students benefited from using their bodies to explain their understanding.

We present an example of a student gesturing to answer the question about particles moving in water. These questions asked how particles behave when there is a macro-level change (Table 1). Lily explained that with a macro-level change, the liquid would turn to gas (line 2). Then in the next question, she described changes in the distance between particles and the speed of particles with gestures (Line 4). She mentioned that "they will go farther apart, and go faster and have more energy," while pulling her hands far apart horizontally to show the increasing distance between particles in liquid as they get more energy. Then she used another gesture to demonstrate the speed of particles by making her hands into fists and moving them quickly in the air (Table 1, Figure b). Then she used the same gesture to describe the distance between particles as far apart. In her responses, her gestures were consistent with demonstrating certain characteristics of the particles' behavior (e.g. distance). In addition, she was also able to describe the changes in particles' speed, which is the concept she failed to answer in the multiple-choice test. On looking across the interviews, we found that this pattern of gestures and embodiment supporting more elaborate descriptions was consistent across the interviews analyzed. Therefore, the interview helped students to demonstrate ideas by allowing students to use gestures to represent ideas.

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Table 1

Lily gesturing to demonstrate particle behaviors to answer question 12 to 14.

Turn	Verbal	Embodiment
1 Author 2	if the plate is really hot, what will happen to liquid water? [Q12]	
2 Lily	It turn to gas. [MMC1, macro change]	Student used gesture to show the distance between particles (figure a). a
3 Author 2	So, if the plate is really hot, what will happen to the particles in the water [Q13]	
4 Lily	They will go farther apart, and go faster and have more energy [MMC4, Distance and Speed]	And then she used gesture to show particles will go "faster" (figure b) b
5 Author 2	More energy. Okay, so why do you think the particles will do that? [Q14]	
6 Lily	Um.. Because gas has more energy and it goes apart.	When students talk about the particles go part, she used the gesture in previous answer (a) again to show the distance between particles.

RQ 2 How does students' understanding of particles behavior form in classroom activity?

To answer our second research question, we analyzed how students' embodiment helped them to form their conceptual understanding in classroom activity. We focused on how students' understanding of 1) characteristics of particle behavior (e.g. distance), and 2) micro-macro connection, were constructed during class activity. We identified two classroom activities on 1) students exploring particles behavior in a tank, and 2) students explore particles with changes of temperature when the concepts we outlined above were discussed.

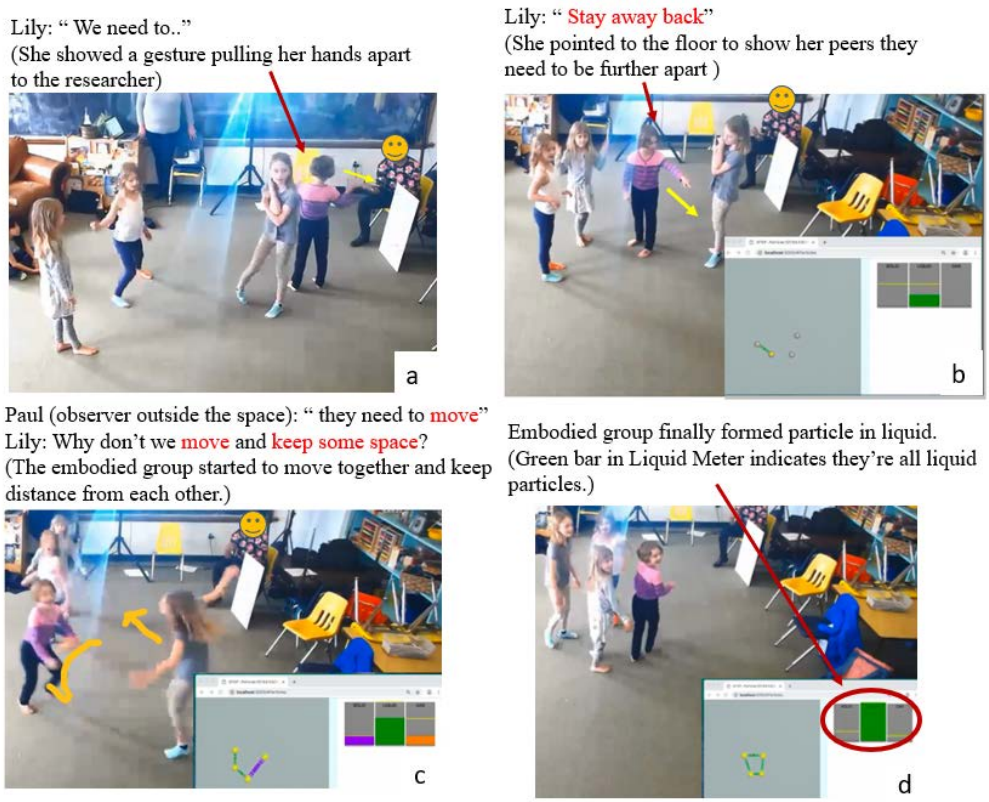
Exploring characteristics of particles in a tank

Our Day 3 activity focused on helping students to understand particle speed and distance in three states of matter. The physical positions of students were projected as particles on the shared screen and they needed to move collectively to form different states of matter. We present a segment of Lily's group collectively exploring how liquid particles move in Figure 1.

Lily's group went into the space with a goal to form liquid. They started moving freely in the space, and tried different motions (e.g., running, standing still) that would trigger the state meter in the simulation to indicate that they had achieved liquid state. Even though they were recognized as particles, there was no certain state shown in the state meter. So, the researcher in the space asked them what they needed to do to make liquid. Lily looked at the screen and used a gesture that pulling her hands far apart, indicating her group should be farther apart (Figure 1a). With encouragement from the researcher, Lily went back to the tracking area, pointed to the floor, and told her peers to stay away (Figure 1b). Here, Lily suggested the team to work collectively to adjust their relative *distance* between particles. Even though they moved away from each other, they were not recognized as liquid particles in STEP simulation. At this moment, Paul, an observer pointed out that the embodied group was not moving. Then the entire group started to move around without maintaining their distance from one another leading to no particular state of matter depicted by the state meter. Then Lily suggested, "why don't we move around and still keep some distance" (Figure 1c). At this moment, Lily was suggesting her team collectively adjust their *distance and speed*. In response, the embodied group walked in one direction to keep relatively the same speed and amount of space, and the team was recognized as liquid particles by the state meter (Figure 1d). In summary, this episode showed that students' understanding of liquid particles was formed through their collective embodiment. In post-assessment, when students were asked to demonstrate liquid particles, we also see a similarity between the gesture that Lily used here to represent particles' distance in the classroom and interview.

Figure 1

Lily's group exploring how liquid particles move.



Summary and Significance

In this study, we explored the role of embodiment in an assessment context contrasted with a more traditional multiple-choice assessment, and how students formed the conceptual understanding in classroom activities. We found that the individual interviews offered students opportunities to articulate their ideas with more detail through talk, gesture, and motion. Students frequently used gestures in the post-interview to demonstrate their understanding of particles' behavior. Then we analyzed classroom data to understand how young children made sense of the content when they embodied particles in the MR environment. By showing links between Lily's interview answer and her actions during classroom activity, we show how to construct embodied assessment questions that map to classroom learning. This suggests that, especially when students have learned concepts in an embodied learning context, assessments that capitalize on these embodied resources may provide greater insights into their emergent understanding of the concepts than traditional measures.

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Focused Self-Explanations Lead to the Best Learning Outcomes in a Digital Learning Game

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Abstract: Prompted self-explanation, in which learners are induced to explain how they have solved problems, is a powerful instructional technique. Self-explanation can be prompted within learning technology by asking learners to construct their own self-explanations or select explanations from a menu. The menu-based approach has led to the best learning outcomes in the relatively few cases it has been studied in the context of digital learning games, contrary to some self-explanation theory. In a classroom study of 214 5th and 6th graders, in which the students played a digital learning game, we compared three forms of prompted self-explanation: menu-based, scaffolded, and focused (i.e., open-ended text entry, but with a focused prompt). Students in the focused condition learned more than students in the menu-based condition at delayed posttest, with no other learning differences between the conditions. This suggests that focused self-explanations may be especially beneficial for retention and deeper knowledge.

Introduction

Prompted self-explanation is used to promote learning by encouraging learners to self-explain what they are studying or how they have solved a problem (Wylie & Chi, 2014). As an instructional strategy, prompted self-explanation has proven to be one of the most robust and effective learning science principles (Pashler et al., 2007). Different forms of prompted self-explanation have been shown to be effective in a variety of studies with educational technology. Wylie and Chi (2014) cast the various forms of prompted self-explanation that have been used in learning technology along a continuum between what we describe as *unconstrained* and *highly constrained* self-explanations. Unconstrained self-explanations allow learners to freely create their own explanations, while presenting the highest cognitive challenge to learners (i.e., *open-ended self-explanations*). Highly constrained self-explanations, on the other hand, present the learner with a small set of options to choose from to self-explain and thus create the least cognitive challenge for learners (i.e., *menu-based self-explanations*). Between the two extremes are three other types of prompted self-explanation: *focused self-explanations*, which are constructive but focused in a specific way, such as prompting learners to identify relationships between mental models; *scaffolded self-explanations*, which provide support and/or feedback as learners construct explanations or fill in blanks of an explanation sentence; and *resource-based self-explanations*, in which explanations are selected by learners with the support of a resource, such as a glossary.

According to Chi and Wylie's (2014) Interactive-Constructive-Active-Passive (ICAP) framework for cognitive engagement, open-ended and focused self-explanations are constructive because the student must generate their own content. Scaffolded, resource-based, and menu-based self-explanations are active, because the student must actively select or manipulate information provided to them. The ICAP framework predicts that students should learn more from more cognitively engaging tasks, meaning constructive self-explanations should be more beneficial than active self-explanations. Only a limited number of studies have directly compared different types of self-explanation prompts. Evidence across these studies suggests that focused self-explanations may be the best, because they are constructive, yet direct students to ideas and explanations better than open-ended prompts, thus reducing cognitive load (Wylie & Chi, 2014) .

Self-Explanation in Digital Learning Games

Digital learning games are an interesting and important platform for exploring self-explanation, as they are now widespread in education, with a growing research base supporting their efficacy (Mayer, 2019). Despite contentions that prompted self-explanation within a digital learning game could disrupt game flow and induce extraneous cognitive processing (Adams & Clark, 2014), prompted self-explanation has been shown to support learning within games. For instance, Hsu and Tsai (2011) found that prompting learners to explain their errors from a menu of choices led to better learning gains than not prompting error explanations. However, not all studies have led to benefits of prompted self-explanations in digital learning games. For instance, Adams and Clark (2014) found no learning differences between two game conditions: menu-based self-explanation with explanatory feedback and a control condition with neither self-explanation nor explanatory feedback.

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We know of only one study that directly compared menu-based and open-ended self-explanations in learning games, and in that study Johnson and Mayer (2010) showed that menu-based self-explanations led to better transfer than open-ended self-explanations. While Johnson and Mayer argued that menu-based prompts likely led to better learning because they were less disruptive to game flow, Wylie and Chi (2014) argue that the open-ended prompts of the study may not have had the focus to direct students' attention in a game environment.

In light of the competing predictions that less disruptive self-explanations are best (Johnson & Mayer, 2010) and that more constructive self-explanations are best (Chi & Wylie, 2014), we decided to conduct a study with our learning game *Decimal Point* (McLaren et al., 2017) to investigate this issue. We hypothesized that constructive explanations could lead to deeper learning within a game context without disruption to game flow, provided that they are sufficiently focused.

A Self-Explanation Study with the *Decimal Point* Learning Game

Decimal Point is a single-player, non-competitive learning game based on an amusement park metaphor (McLaren et al., 2017). It is designed to help middle-school students practice their decimal knowledge. The student plays a variety of *mini-games* targeted at common decimal misconceptions within theme areas. Students make their way through the entire amusement park playing all of the mini-games in sequence. An example mini-game is "Rocket Science," which challenges the student to fill the gas of a rocket ship by choosing fuel canisters labeled with decimal numbers (e.g., 9.222, 9.3, 9.43, 9.2111) in the order from largest to smallest. If they make mistakes as they choose canisters, they are prompted to correct their solution by dragging and dropping the canisters into the correct order. The student continues playing the game until they correctly order the canisters. After correctly solving two problems within each mini-game, students are prompted to answer a self-explanation question, according to one of three different conditions and self-explanation formats.

The original version of the game employed a menu-based self-explanation approach and produced better learning outcomes compared to a non-game control (McLaren et al., 2017). In the current study we compared three forms of self-explanation to test competing hypotheses about the benefits of more constrained, active self-explanations (Johnson & Mayer, 2010) and less constrained, constructive self-explanations (Wylie & Chi, 2014) in digital learning games.

- *Menu-based self-explanations*: Students were presented with 3 or 4 explanation menu options, with the correct option being a conceptual description of the problem solution. We consider this form to be highly constrained and active according to the ICAP framework.
- *Scaffolded self-explanations*: Students were prompted to complete a fill-in-the-blank sentence, using a word bank of 4 or 5 words/phrases that could be inserted into the sentence. We consider scaffolded self-explanations to be moderately constrained and active according to the ICAP framework.
- *Focused self-explanation*: Students responded to focused self-explanation prompts about specific problems by filling in an open-text field. To assure that students would expend at least minimal effort, we required that their self-explanations contained at least four words with at least one of the words being from a relevant list (including common misspellings) that would legitimately be found in a correct explanation. We consider this form to be minimally constrained and constructive according to ICAP.

Across all conditions, students could not proceed to the next mini-game until they provided a correct self-explanation or, in the focused condition, an explanation that met the length and relevance requirements. The question prompts were written to align content across all three conditions. Our rationale for choosing these three prompted self-explanation approaches was to directly compare different levels of cognitive engagement (constructive and active), while also including the original menu-based approach used in previous versions of the game. Our research questions for the study were:

RQ1. Which form of prompted self-explanation – menu-based, scaffolded, or focused – leads to the best learning outcomes in the context of the Decimal Point learning game? Although prior results with self-explanation in digital learning games supported using menu-based prompts to avoid disrupting game flow (Johnson & Mayer, 2010), the theories proposed by other researchers suggest that constructive prompts are better than active prompts if they are sufficiently focused (Wylie & Chi, 2014; Chi & Wylie, 2014). Therefore, we predicted that focused prompts would be best.

RQ2. Which form of prompted self-explanation – menu-based, scaffolded, or focused – leads to the least enjoyment in the context of the Decimal Point learning game? This is an important question because one wouldn't want to lose the enjoyment aspect of game-based learning, given that engagement has been shown to explain the learning benefits of a game compared to the non-game equivalent (Richey et al., 2021). As less constrained prompts are likely to be more disruptive to game flow, we hypothesized that the order of enjoyment would be: menu-based self-explanation more enjoyable than scaffolded, which

would, in turn, be more enjoyable than focused.

Method and Materials

Four schools, 1 rural, 2 suburban, and 1 urban, with a total of 357 5th and 6th grade students participated in the study during regular class time. One hundred and forty-three (143) students were dropped due to (a) failing to complete part or all of the learning materials or any tests and (b) having participated in a similar study the previous year. (Note that the relatively high attrition rate was due, at least in part, to running the study during the COVID-19 period.) Of the remaining 214 students, 75 were in the menu-based condition (mean age: 11.6; girls: 39; boys: 35; 1 did not respond), 72 were in the scaffolded condition (mean age: 11.6; girls: 44; boys: 28), and 67 were in the focused condition (mean age: 11.6; girls: 31; boys: 36)

During 45-to-55-minute class periods for up to a full week, students worked on the Internet-based materials at their own pace to complete a decimal pretest, the game intervention according to condition (i.e., They played all of the mini-games, with two problems per mini-game, followed by a prompted self-explanation, according to condition), an immediate posttest, and a questionnaire. One week after the posttest, a delayed posttest was taken during one class period. Each test consisted of 43 items, designed to probe for decimal misconceptions and conceptual understanding, with 52 points possible across these items. We used three isomorphic test forms that were positionally counterbalanced across conditions. The questionnaire included 3 items each from the mastery, meaning, and challenge subscales of the Player Experience Inventory (PXI). We also included 3 items targeting affective engagement and 3 items targeting behavioral/cognitive engagement. Finally, we included 5 items adapted from an enjoyment subscale, the Achievement Emotions Questionnaire.

Results

RQ1. Which form of prompted self-explanation -- menu-based, scaffolded, or focused -- leads to the best learning outcomes in the context of the Decimal Point learning game?

A one-way analysis of variance (ANOVA) showed there were no differences in pretest performance based on condition, $F(2, 211) = 1.90$, $p = .15$, $\eta^2_p = .018$ An ANCOVA revealed a significant effect of condition on delayed posttest when controlling for pretest, $F(3, 210) = 3.08$, $p = .048$, $\eta^2_p = .028$. Pairwise comparisons with Bonferroni corrections indicated that the focused condition performed significantly better than the menu-based condition, $p = .042$. There were no significant differences in performance between the focused and scaffolded conditions, $p = .76$, or between the menu-based and scaffolded conditions, $p = .55$. There was no significant effect at immediate posttest, also when controlling for pretest, $F(3,210) = 2.25$, $p = .11$, $\eta^2_p = .021$. Thus, our hypothesis that focused self-explanations would lead to the best learning outcome was confirmed (at least with respect to the focused versus menu-based comparison).

To better understand the different conditions' effects on students' learning processes, we also analyzed time spent and errors made. An ANOVA indicated a significant condition effect on time, $F(2, 211) = 13.27$, $p < .001$, $\eta^2_p = .11$. Pairwise comparisons with Bonferroni corrections revealed that the menu-based condition took significantly less time than the scaffolded condition, $p < .001$, and the focused condition, $p = .001$, but there was no significant difference in time between the scaffolded and focused conditions, $p = .88$. There was no significant condition effect on the number of errors during gameplay, $F(2, 211) = 0.72$, $p = .49$, $\eta^2_p = .007$.

Table 1. The mean and standard deviation of different learning and game play metrics by condition.

	Menu-based (n = 75)	Scaffolded (n = 72)	Focused (n = 67)
Pretest	26.01 (10.47)	24.63 (10.03)	27.96 (9.69)
Posttest	30.12 (9.58)	30.58 (9.88)	33.69 (9.33)
Delayed posttest	30.55 (10.29)	30.97 (10.23)	34.81 (9.88)
Time (minutes)	62.65 (24.68)	83.76 (27.56)	79.12 (26.09)
Errors	75.07 (50.52)	73.22 (46.94)	65.63 (49.67)

RQ2. Which form of prompted self-explanation -- menu-based, scaffolded, or focused -- leads to the least enjoyment in the context of the Decimal Point learning game?

We applied a series of ANOVAs to assess the impact of condition on each of the factors analyzed in the questionnaire: player mastery, player meaning, player challenge, affective engagement, behavioral/cognitive engagement, and enjoyment. There was a significant effect of condition on player mastery, $F(2, 211) = 4.15$, $p = .017$, $\eta^2_p = .038$. Pairwise comparisons with Bonferroni corrections revealed that the focused condition led to significantly greater feelings of mastery than the menu-based condition, $p = .014$. There were no significant

differences in mastery between students in the focused condition and the scaffolded condition, $p = .19$, or between students in the scaffolded and menu-based conditions, $p = .96$. There was no significant effect of condition on any other questionnaire measure, $p = .16$, indicating that students' reported experiences of engagement, enjoyment, meaning, and challenge did not differ based on self-explanation condition.

Discussion and Conclusions

The central finding of this study is that focused self-explanations led to better learning outcomes than menu-based self-explanations in the context of a digital learning game. Although this is consistent with prior research comparing focused and menu-based prompts in interactive learning environments, it contrasts with the findings of Johnson and Mayer (2010), in which students playing a learning game attained a better learning outcome using menu-based prompts than students using open-ended self-explanations. An important difference between our study and the Johnson and Mayer study is that they used an open-ended prompt ("Provide an explanation for your answer in the space below"), while we used *focused* prompts that were specific to the values and misconceptions addressed by each problem. While Johnson and Mayer argue that less constrained prompts may be more disruptive to game flow than more constrained prompts, Wylie and Chi (2014) suggest that more constrained, constructive prompts can be beneficial in digital learning environments, including games, provided they are sufficiently focused. Our results appear to support the latter view.

The superior learning benefit of focused self-explanation was on a one-week delayed posttest, suggesting deeper, more conceptual learning. This further suggests that focused self-explanations may be especially beneficial for retention and deeper knowledge, consistent with the ICAP theory (Chi & Wylie, 2014) claim that this type of knowledge is better supported by constructive processes than active processes.

We also found that the learning benefit of focused explanations did not come at the expense of enjoyment. In particular, there were no differences in enjoyment across the three conditions. Thus, the benefits of enjoyment often claimed for digital learning games do not appear to have been undercut with less constrained self-explanations. Even though extra cognitive resources were likely expended by the students in the focused self-explanation condition, they enjoyed playing *Decimal Point* as much as the students in the other conditions and even expressed a greater sense of player mastery.

Determining the best way to infuse instruction into digital learning games, while maintaining the flow and enjoyment that is central to learning games, is an important research direction. While prior research indicated that menu-based self-explanations in games were superior to open-ended self-explanations in a game-based learning context, this study found that focused self-explanations led to a better learning outcome than menu-based self-explanations, suggesting that focused, constructive prompts can be effective in learning games.

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Qualitative Observations of Metacognitive Tendencies of High and Low Foreign Language Anxiety Learners

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Abstract: Despite the ever-growing necessity to speak in a foreign language (FL), it remains a nerve-wracking task for many. Speaking in a FL, a cognitive task, is under the control of a learner's metacognition, and research in mathematics anxiety have pointed to metacognition's role in the possible onset and/or maintenance of negative affect. The link between foreign language anxiety (FLA) and metacognition, however, is currently unclear. To understand this link further, the authors combined the use of novel scenarios and a questionnaire to identify differences in metacognitive thoughts and behaviours between high (HA) and low anxiety (LA) participants. HA participants were found to write less relevant information and be more negative towards themselves, while LA participants mentioned more strategic choices and focused more on the task at hand.

Introduction

Foreign language anxiety (FLA), an affective condition that affects both a learner's desire to engage in speaking activities and their performance (Young, 1991), is a particularly pressing issue in our interconnected global society where many people are required to communication in a FL – English. While potential causes are plenty, such as negative past experiences (MacIntyre & Gardner, 1998) and study-abroad experience (Saito & Iida, 2015), there is also a possibility that a thinking element – a metacognitive element – may play a role in FLA.

Metacognition encompasses both the knowledge people have of themselves as learners, their strategies in a given task, as well as their planning, monitoring, and evaluation strategies (Wenden, 1999). Speaking is a skill that requires complex cognitive processes such as message planning, monitoring of oneself and others, and evaluating communication efficacy (Levelt, 1989), as well as a skill which is also subject to self-efficacy judgements (Wenden, 1999), thus influenced by metacognition. While somewhat dissimilar, mathematics is likewise a subject that requires complex cognitive and metacognitive skills, and in the context of mathematics anxiety, a lack of sufficient metacognitive skills, or an inability to apply them properly may cause or further exacerbate anxiety in the context of mathematics test-taking (Veenman et al., 2000). This same theoretical thread may also apply to FL speaking.

Currently, many studies in FLA rely on self-report questionnaires completed by large samples of learners to draw inferences about the nature of the issue based on statistical models and correlations. While this is often the most ethically sound and generalisable method available, there are obvious limitations. Due to this, there are still many questions unanswered about the cognitive – particularly the metacognitive – element of FLA. In this study, the authors apply a novel approach to answer the following questions:

1. Is there a relationship between metacognition and foreign language anxiety?
2. What metacognitive tendencies do anxious individuals show?

Method

Participants

Participants were 68 students (mean age: approx. 19 years) enrolled in both English major and non-English major courses at a women's university in Western Japan. Of these, high and low anxiety participants were selected for further qualitative analysis (see Results).

Procedure and Materials

The survey study comprised three parts which were administered online over the course of three weeks. In the first week, participants wrote, in free prose, answers to six scenarios each designed to elicit participants' metacognitive knowledge or strategy in a slightly stressful context where English should be used (Table 1). The six components of metacognition chosen were based on Wenden's definitions (Wenden, 1998). In the following two weeks, the Japanese version of two 5-point Likert-type scale questionnaires – the Foreign Language Classroom Anxiety Scale (FLCAS) (Yashima et al., 2009) and a double-back Japanese translation of the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994) – were administered. These self-report

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questionnaires are designed to measure the extent of classroom FLA and awareness of metacognitive capabilities, respectively.

Table 1
Six Novel Scenarios Designed to Elicit Metacognitive Thoughts and Behaviours

Metacognitive component	Scenario
Planning	For your English class, you must give a 5-minute presentation in English about climate change. You have one week to prepare for this presentation. You can use notes, but you cannot read from a script. How would you prepare? List in order what you would do to prepare. Explain and provide details where necessary.
Monitoring	You are travelling in Singapore, a country that uses English, Mandarin Chinese, Malay and Tamil. However, you dropped your purse in a department store. It contains your credit cards, money, and hotel key. You go to the security office to get help. During this conversation, what would you be thinking about when explaining to the security guards?
Evaluation	Imagine you work in an international company. You have just given a presentation in English, but you do not think it went very well. List what aspects of your presentation would be important for you to consider in deciding how good or how poorly you did your presentation. Apart from what you think, how else can you find out how well you did?
Task knowledge	Imagine that you have been invited to participate in an international meeting to discuss university student experiences, in English. List what you would need to do to decide whether to participate. Explain briefly why those would be important in helping you decide.
Strategy knowledge	An international student from Senegal has just joined your course, but she cannot speak Japanese. One of the teachers recommended you look after her during her first few weeks in Japan. You are talking at lunch with the student and some other Japanese friends in English, however the conversation isn't going well and there is some tension. What will you do?
Person knowledge	Describe yourself as an English speaker/learner. What are your strengths and weaknesses? Why are these your strengths and weaknesses? What is important in speaking English?

Analysis

Data-driven thematic analysis was used to identify salient features of the sample's metacognitive behaviours and tendencies (Tsuchiya, 2016). Clauses expressing semantically similar ideas were extracted, then grouped and labelled under headings that captured the main theme. Correlational analysis was conducted on the questionnaire data to examine relationships between FLA and metacognitive awareness to clarify a possible link between these two concepts within the participants.

Results and Discussion

A significant correlation was found between the FCLAS and the MAI (r = -.39, p > .01), indicating a moderate relationship between FLA and metacognitive awareness. To select low and high FLA participants for further comparative qualitative analysis, the first and fourth quartiles (105 and 126, respectively) were calculated. Participants whose FLA score included or fell below 105 were considered "low anxiety" and likewise, those whose FLA score included or exceed 126 were classed as "high anxiety". These will be referred to as the LA (low anxiety) group (n = 17) and HA (high anxiety) group (n = 14, due to non-submissions, this group has fewer members), respectively. Qualitative differences between the two groups' metacognitive knowledge and strategies were identified, and these are outlined below where the percentages are the number of participants who fell under a given thematic category out of a total of 31. The quotations that follow each section begin with the group (HA or LA) and the participant's randomised 4-digit identification number, followed by text translated from Japanese.

Planning

Both groups showed a preference for general planning behaviours: researching necessary information prior to scripting (48%), the creation of a script in Japanese (31%) and subsequent translation into English (42%), and memorisation of the script (35%). Notably, many of the LA group showed further aptness of strategy choice that would make the hypothetical classroom presentation easier for them. They exclusively wrote that they would write the script in English first (8 responses) and would create bullet points/notes (7 of 10) and identify and focus on keywords (3). Members of this group were aware of the need to make the text easier to memorise while also being aware of the week time limit. Finally, only participants in the LA group wrote about strategies for reducing

anxiety during the presentation (2) and considered the needs of the audience (5). The HA group, on the other hand, tended towards more actual planning behaviours such as choosing topic areas (6 of 11) and making summaries (5 of 8) and lacked the same strategic decisions mentioned by the LA group (see example comparison below).

> LA (4103): I will write out the words and phrases I circled from my script on another piece of paper, and use them as presentation notes, in case I get nervous and forget everything.
> HA (2222): First I will write a report and summarise my points from that.

Monitoring

Hypothetical monitoring behaviours common to both groups were making sure they would explain the contents (48%) and features (65%) of the lost item, as well as the places they visited prior to its loss (58%). Like the above, few strategies were salient in the HA group but themes exclusive to this group were: favour confirming possible collection of the item (2 of 3) and the need to prepare themselves for the worst (2 of 3), while giving the reason that it may have been stolen or that the country is not as safe as Japan (example below). In contrast, the LA group mentioned how they would ask advice from the authorities (2 responses) and use gestures and visual aids to facilitate communication (5 of 7; example below). While shared by a small percentage of the HA group participants, use of visual aids (2 of 7) and the awareness of the need for easy communication categories (3 of 5) were occupied largely by LA participants, who, based on the above, seem to be aware of the authoritative listener in this task and the necessity to communicate effectively.

> LA (3509): When going abroad, the most important thing in addition to speaking, is to make sure you convey what you want to convey by using gestures.
> HA (7637): Even if the purse comes back, the contents might not, as Singapore isn't as safe as Japan.

Evaluation

The analysis for the hypothetical evaluation scenario also yielded similar qualities between the two groups: asking the audience directly for feedback (61%), reflecting on their performance by themselves (29%), comparing with others' presentations (13%), and using the evaluative information for further use (13%). Again, the HA group did not indicate any behaviours that were not seen in the LA group, although they did mention evaluation standards such as the need to be understandable from the perspective of the audience for their presentation (3 of 4). Themes occupied by the LA group participants were: the use of video (7 of 9), monitoring audience reactions (2 of 3), and the use of questionnaires (4 of 6). All of these indicate ease around actively engaging with their performance outcomes and the audience. Examples of comparing with others appeared in both groups; however, the tone of the HA group member is far more critical.

> LA (4802): I would look at presentations done by people who did well, compare what they did and why, and then see what I could learn from them.
> HA (9274): I would compare with others and think carefully about what parts were not good.

Task knowledge

Both groups mentioned the requirement of sufficient English (23%) and communication skills (31%) in helping to decide whether to participate in the event, although these were more common amongst those in the LA group (4 of 7 and 7 of 10, respectively). In line with the above results, the LA group were found to include other qualities in addition to the shared qualities. These were: mentioning of specific (4) and general (3 of 5) speaking skills, affect (2 of 3), and their ability to understand English well enough (5 of 6). Both groups responded incorrectly with *how they would prepare* for the event, but the difference here is the LA group's mentioning of linguistic (5 of 7) and vocabulary preparation (2 of 3) in contrast to the HA group's preference to write about specific content (4 of 7) and preparing hypothetical materials for the event (1), which would not likely be necessary. Below is a comparison between how two participants, high and low anxiety, responded in relation to language. The LA participant is more specific and relevant in her submission.

> LA (5252): I need to think about whether I can respond immediately during question time (because thinking and searching up information would hold up the conversation).
> HA (9285): Since I still don't know the right vocabulary, I would prioritise memorising them.

Strategy knowledge

In relation to the participants' strategy knowledge, both groups saw value in mixing English and Japanese in this scenario (13%), where communication breakdown had occurred. They also equally mentioned playing a game to ease tension (16%). In the HA group, one participant mentioned the use of external tools such as using a translator, while others mentioned introducing or talking about Japan (2 of 3; example below). To compare with the LA group, these participants focused more on the hypothetical exchange student in the moment and were more likely to mention asking her questions (4 of 5) and talking about her country (8 of 10; example below), rather than their own. Their responses were found under labels that showed more active group management strategies such as conversation manager, entering the conversation, and providing an alternative topic (total 12 of 18).

> LA (4802): For example, by sharing the differences between our two countries and trying to speak in each other's language, we can teach each other new things and reduce some tension.
> HA (0241): I would ask the exchange student about Japan and if she says something like "I like shrines" we'd talk about that together with the others.

Person knowledge

This section was a set of sub-questions that elicited details of learner beliefs. This yielded a particularly rich set of data which can be summarised as follows: the HA group viewed their *overall* English-speaking skills and self-impression negatively and especially in relation to others, with their most salient strength being compensatory body language. They were particularly harsh about their weaknesses in English grammar and pronunciation. In contrast, the LA participants mentioned *certain aspects* of themselves that they viewed as problematic such as a lack of confidence and symptoms of anxiety, but also noted some positive aspects of their overall impression as well, which was exclusive to this group. They were also more focused on their ability to communicate, both linguistically and with gestures. A comparison between the two participants' negative views of their vocabulary knowledge can be found below. Note the self-blaming tone of the HA participant.

> LA (4103): I can convey necessary information to the listener with a small number of words but I think this is also a weakness. I only use the words I know.
> HA (1395): I don't know any vocabulary at all and because I don't know anything there isn't much I can say, so I end up not being able to speak.

Conclusion

While both groups demonstrated necessary metacognitive skills that were relevant to each scenario, presumably facilitating hypothetical success, subtle differences existed between the LA and HA groups indicating that the LA group chose more effective strategies that matched the scenario more closely and were aware of not only themselves but the other people they would encounter in each scenario. From these results it appears that there is a qualitative difference in the metacognitive competencies of HA and LA learners, and further research should clarify whether there is a casual relationship between these competencies and its direction of influence.

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Insights from Using a Systematic Design Process to Develop Classroom-based Assessment Resources for Measuring Elementary Students' Science and Literacy Proficiencies

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Abstract: The *Framework* and NGSS bring to the forefront the role of language in doing science and in learning from doing science. Yet, most existing science assessments for elementary learners do not integrate or attend to aspects of scientific language and literacy that are essential components of science proficiency. Accordingly, there is a need for high-quality classroom resources capable of providing teachers with information on where students are in the process of developing proficiency in science and scientific-specific literacy. In this paper, we present our design process for developing assessment resources – tasks, rubrics, and teacher support materials – and describe initial insights from using the process to develop resources for elementary grade classrooms. We highlight challenges and opportunities that have emerged from our work attending to the role of literacy assessing multi-dimensional science learning, incorporating equity and inclusion considerations in assessment design, and embracing the affordances of technology.

Introduction

High-quality, classroom-based assessment resources can provide critical information that helps teachers in making informed instructional decisions to further student science learning (Shepard et al., 2018). However, the potential of classroom-based assessments to increase students' opportunities to learn can only be realized if students can access and engage with tasks productively and if accompanying resources provide teachers with insights on students' developing proficiencies. This sets a high bar for knowledge-in-use assessments that aim to measure students' multidimensional proficiencies as articulated in science education frameworks and standards such as the National Research Council's Framework for K-12 Science Education (henceforth *Framework*; NRC, 2012) and the accompanying Next Generation Science Standards in the United States (NGSS Lead States, 2013). The challenge is especially acute when designing assessment resources for early elementary students who are just beginning to develop the cognitive endurance, attention span, physical dexterity, and language and literacy skills they must have to demonstrate what they know and can do (Billman et al., 2021). For example, as young students use and apply their knowledge to understand and explain phenomena, they must learn science-specific ways of talking, reading, and writing to communicate findings and provide explanations (Billman & Pearson, 2018). Unfortunately, most existing science assessments for elementary learners do not integrate or attend to aspects of scientific language and literacy that are essential components of science proficiency. Accordingly, there is a need for classroom resources capable of providing teachers with information on students' developing proficiencies in science and science-specific literacy.

In this paper, we describe how we use the Next Generation Science Assessments for Young Scientists (NGSA-YS) design process to fill the need for equitable, technology-based assessment tasks that integrate science and literacy proficiencies appropriate for elementary students. The NGSA-YS process (Billman et al., 2021) was specifically developed to meet the challenge of measuring students' integrated science and literacy proficiencies by following the argumentative reasoning of evidence centered design (ECD; Mislevy & Haertel, 2006) to create classroom-based assessment tasks that support NGSS teaching and learning. In accordance with the principles of ECD, NGSA-YS is a systematic design and development process that builds from the Next Generation Science Assessment (NGSA) approach (Harris et al., 2019; Harris et al., in press). NGSA-YS aims to result in coherent assessments by unpacking the science and literacy dimensions to be measured, developing evidence statements that describe student performances, and creating tasks that measure specific knowledge and skills, which taken all together form a basis of an argument about what students know. After describing the design process, we highlight challenges and opportunities that have emerged from our work.

Theoretical framework

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Three-dimensional science learning and the integrated role of literacy

The vision of science learning in the *Framework* emphasizes three dimensions – disciplinary core ideas, crosscutting concepts, and science and engineering practices – and the idea of knowledge-in-use where students use and apply the dimensions to explain phenomena and/or design solutions to problems. Importantly, the *Framework* also brings to the forefront the role of language in doing and learning science. For example, students develop proficiency in scientific ways of talking, reading, and writing when they engage in the science and engineering practice of argumentation to construct claims based on evidence or to exchange ideas that advance, improve, and defend explanations. Likewise, applying the crosscutting concept of systems and system models requires students to generate coherent narrative accounts of science phenomena, linking ideas and describing relationships among components in systems. Recent research shows that integrated science and literacy instruction increases student learning in both domains (Billman & Pearson, 2018; Maarouf, 2019). It follows that classroom-based assessment resources should also attend to this integration to best support science instruction.

Equity and inclusion considerations in the design process

The *Framework* makes the call that science education must be for all students. The design of classroom-based, knowledge-in-use assessments must likewise heed that call, ensuring that assessments are inclusive of all students and are equitable in the measure of all students' proficiency (NRC, 2014). Recent guidance for designing knowledge-in-use assessments that attend to and promote inclusion of all learners includes recommendations that tasks use scenarios and phenomena that are likely to have interest or universal relevance for students, explicitly attend to accessibility of language, include scaffolds to make expectations explicit for students, and be accompanied by tools and routines to support teacher enactment (Furtak et al., 2020). This is an emerging area in NGSS-aligned assessment, where researchers are dedicating attention to how assessments can and should support meaningful science learning for a wide range of students.

Affordances of technology for high-quality formative assessment

Technology-delivered assessments can provide unique opportunities for students to demonstrate knowledge-in-use, exhibit emerging literacy proficiency, and can also provide equitable and inclusive ways for students to access and engage with tasks. Related to this last point, technology can provide options for students to use multiple modalities and representations, affording students with diverse abilities and language backgrounds opportunities to demonstrate their proficiencies that are not possible in print-based assessment (Henderson et al., 2021). For teachers, technology can make regular use of formative assessment more feasible by providing support for implementation, data collection, interpretation, and instructional next steps (Zhai et al., 2020).

The NGSA-YS design process

The NGSA-YS design process consists of four iterative steps (Figure 1). Each step includes activities that achieve coherence across the science and literacy proficiencies underlying an NGSS performance expectation (PE), that incorporate guidance for equity and inclusion, and tend to the design of technology-based affordances.

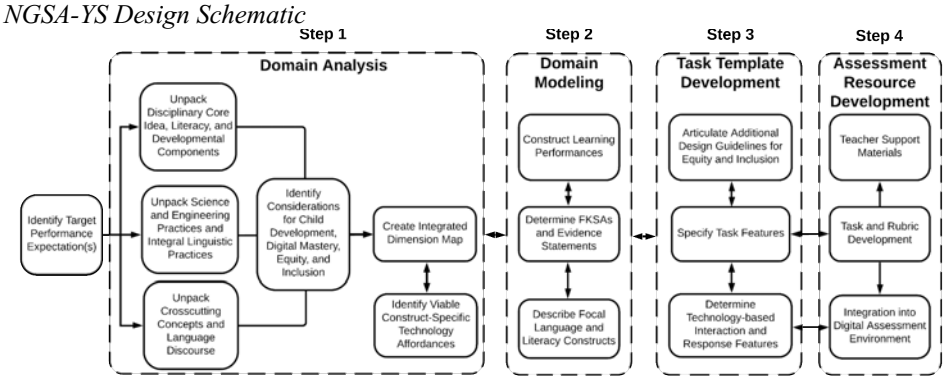
The first step is a purposeful analysis of the domain covered by a PE or PE bundle. In this step, we identify the focal components of each dimension including the science-specific language and aspects of literacy required to demonstrate proficiency as well as the aspects of language and literacy that may inhibit students' ability to demonstrate proficiency. Information obtained through the domain analysis is brought back together in an *integrated dimension map* (IDM) that illustrates relationships between each aspect of the three dimensions of the NGSS called out in the PE along with key elements of science-specific language and literacy. The IDM helps identify ways in which the three dimensions can work together to define proficiency and lays the groundwork for specifying the knowledge, skills, and abilities that will be measured. Alongside our IDMs, we set forth an identification of viable technology affordances specific to the constructs articulated in the mapping.

The second step, domain modeling, uses the IDM to articulate and refine the multiple sub-performances (referred to as learning performances) that students need to demonstrate to meet a PE or PE bundle. A single learning performance is crafted as a knowledge-in-use statement that is smaller in scope and covers a designated area of an IDM. Multiple learning performances are needed to fully cover the conceptual terrain of a PE. Learning performances are a keystone in the process of developing tasks that assess for building toward a PE.

The design goal of **the third step** is to develop task templates – detailed design tools that guide the creation of families of tasks and rubrics. Task templates articulate information about how the task is presented to the student, what content is covered in the task, options for how students can respond, and preliminary scoring guidelines. Templates also bring attention to language and literacy features, to equity and inclusion considerations, and to intended technology interactions such as how students will interact with any digital components as part of the task activities or response modes.

The final step involves operationalizing the assessment argument and specifications from the task template to develop tasks, scoring rubrics, associated digital assessment environments, and teacher resources. In general, each task consists of a set of prompts tied together by a common, developmentally appropriate scenario that establishes a relevant phenomenon or context for student problem solving aligned to the associated learning performance. The prompts embedded within the task ensure that there are opportunities for students to demonstrate integrated proficiency with the dimensions of the learning performance and with science-specific language and literacy. Rubrics target the science and science-specific literacy aspects of student responses that should be scored and show how they relate to proficiency with the learning performance. To complement the assessment tasks and rubrics, we develop materials to support teachers' use of the assessments and their facility with implementing formative assessment practices in the midst of science instruction. A key resource is a practice guide to support administration of the tasks, scoring and interpretation of student responses, and decision-making for instructional next steps.

Figure 1
NGSA-YS Design Schematic



Challenges and opportunities in using the NGSA-YS process

Our use of the NGSA-YS process revealed new challenges in addressing the needs of teachers and students. It also revealed new opportunities to push the assessment development field forward in attending to literacy and equity within multi-dimensional science assessment design while realizing the affordances of technology.

All students, especially in the early grades, benefit from opportunities to practice and develop a broad range of language and literacy skills in the context of engaging with the NGSS. In our work, we recognize that these opportunities must also extend to classroom-based assessment. Consequently, it is important in assessment design to identify measurable components of language and literacy proficiency that are essential elements of the target science performance. One challenge we wrestled with was determining the degree to which students can express their understandings with everyday language while recognizing that science has domain-specific words, some that are essential for engaging with an idea or concept, but which students are unlikely to encounter outside of the classroom (Osborne et al., 2016). For example, "push and pull" is sometimes sufficient for expressing ideas about forces, but the domain-specific use of "forces" can include additional meanings. We have found, too, that it is of value to identify general language and literacy proficiency targets. For example, student proficiency with writing within an organizational structure can be targeted (e.g., students' ability to describe the steps in an investigation). This adds new challenges in unpacking an NGSS PE, but also improves the instructional supportiveness of the assessment in both science and language arts domains.

Equity is interwoven throughout our work using the NGSA-YS process. In attempting to follow the emerging guidance on equity and inclusion, we have wrestled with early grade students' lived experiences and developmental profiles in relationship to expectations put forth in the NGSS. For example, providing students with different options when developing and using models without neglecting the conventions and expectations in the design and format of visual representations in the scientific community. Additionally, in identifying phenomena and constructing task scenarios that are relevant to students' lived experiences, we have wrestled with the tension between scenarios that have universal relevance and utility for a wide range of students and those that leverage the specific identities of learners.

As we work to design assessments that will be delivered on a digital platform, we have focused on affordances that fall into two categories: (1) general enhancements applicable to all tasks; and (2) interactive technology-based components directly related to an assessment target. General enhancements include building text-to-speech capabilities to facilitate students' reading of the assessment tasks and speech-to-text capabilities to

assist students in recording their responses in ways that do not require keyboarding skills. Interactive components include design patterns that allow students to express ideas in modalities other than writing and to engage in science practices in ways not possible with paper-based assessments. These might be simulations that students manipulate and annotate, tools that facilitate construction of a model diagram, or drag-and-drop interactives that provide a context-specific opportunity to express concepts and ideas with both words and images. Evaluating when affordances from these two categories are useful in a particular context has raised new questions regarding what elementary students can do within a digital system and what supports they need.

Conclusion

Our use of the NGSA-YS approach has contributed to our understanding of knowledge-in-use assessment design for the early elementary grades by focusing attention on the science-specific language and literacy practices that are integral parts of multi-dimensional science learning. Importantly, considerations of language and literacy inform the tasks, the rubrics, and the teaching resources we develop. New technology affords opportunities for students of wide-ranging proficiency to showcase what they know and can do. These insights fit into an emerging appreciation of the integrated role of science and literacy that push our assessment work forward in designing instructionally beneficial assessments for elementary teachers and their young students.

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International Society of the Learning Sciences

Students' Prior Knowledge of Disease Spread and Prevention

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Abstract: The COVID-19 pandemic has highlighted a need for students to learn about public health issues, including the transmission of disease and methods for the prevention of epidemics. This study presents data from a project focused on developing an emergent systems microworld to help middle school students learn about these topics. The microworld is designed to help students model and test their ideas about how a disease spreads through a population and how an epidemic can be prevented. The paper presents an analysis of students' prior knowledge of disease spread and prevention, which they shared during an activity preceding their exploration of the microworld. We present student ideas in categories of *disease transmission*, *recovery from disease*, and *disease protection strategies*. We describe their ideas and suggest how they may be integrated into the design of the microworld.

The COVID-19 pandemic has highlighted the need for a health-literate society. This means enhancing the public's knowledge of public health issues, including the transmission of disease and methods for the prevention of epidemics. Epidemiology is a branch of science that studies health-related behaviors and outcomes in populations. This includes subjects such as disease causation and transmission, outbreak investigation, and disease surveillance. At present, learning about epidemiology is primarily limited to graduate and undergraduate students. By comparison, few middle school students have access to courses in epidemiology (D'Agostino, 2018). Some scholars have found that developing material on epidemiology for middle school students is challenging (Hlaing, 2014). However, learning about epidemiological topics at a young age is essential for helping students make informed decisions regarding their health and having critical thinking regarding public health policy (Bracken, 2014).

To address this need, we are designing student-centered epidemiology education materials for middle school students. We use NetTango (Horn, Baker, & Wilensky, 2020), a block-based interface to the NetLogo modeling platform (Wilensky, 1999). NetTango blocks allow students to create, test, and debug models of disease spread based on their own ideas. Blocks in NetTango are not general-purpose programming primitives, but rather, are semantic blocks relevant to the modeled phenomenon. The approach engages students in the construction of an agent-based computational model of the spread of disease in the context of an emergent systems microworld (ESM) (Dabholkar, Anton & Wilensky, 2018). Students can develop ideas about disease spread and prevention at the level of a population by exploring individual agent behavior and multi-agent interactions.

Emergent systems microworlds and the value of their application have been investigated by many research studies, including studies that specifically examine the impact on students' understanding of scientific phenomena (Levy and Wilensky, 2009; Wilensky & Reisman, 2006; Wilkerson-Jerde, Gravel, & Macrander, 2015). We are investigating how to integrate students' prior knowledge into the design of the ESM, so that students can construct, test, and revise models that represent their thinking. Our aim is to build a computational modeling environment that very consciously meets students halfway. This means giving students programming blocks that allow them to work with ideas that closely match their intuitions, which in turn requires research into what these intuitions are. The present work investigates student intuitions about the spread of disease and based on these findings, makes recommendations for refinements to the primitive coding blocks in the microworld, so that students can model, test, and debug their thinking.

Theoretical Foundations

This research draws on a constructivist view of knowledge and learning called Knowledge in Pieces (KiP; diSessa,1993). KiP argues that knowledge is a complex system composed of knowledge elements. KiP instruction advocates that learning starts with eliciting students' prior knowledge and develops by reorganizing and refining the learner's knowledge networks. To our constructivist lens, we add the lens of constructionism (Papert, 1980). Constructionism is a theory of pedagogy, which posits that learning happens best through the construction of publicly shareable artifacts. Constructing a publicly shareable artifact helps students learn because they can gain knowledge and skills by creating, reflecting on, and discussing their artifacts. In the case of our project, the learning-by-modeling approach has students use computational models to refine their thinking through the building, testing, and debugging of models.

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Methods

In this paper, we ask "*What intuitions do students have about disease spread and prevention, and how can those be used to inform our microworld design?*" To address these questions, we employed a lab-based case study approach (Yin, 1998) and conducted one-on-one, 1.5-hour recorded interviews through Zoom with middle school students (ages 12-14). During the interview, students were asked questions about the spread and prevention of disease and then invited to model and test their ideas in the microworld shown in Figure 1.

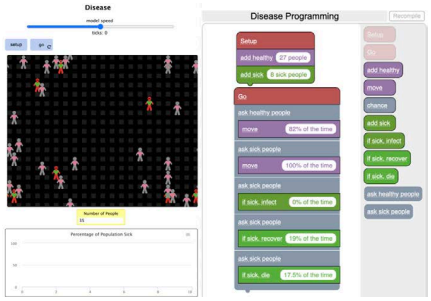

Figure 1. Screenshot of the *Disease Spread* microworld (Martin et al., 2021).

Figure 1 shows the microworld display. The box on the left represents the world, where agents interact with each other. The modeling space on the right of the interface has blocks including "setup," "go," "add healthy," "add sick," "ask healthy people," "ask sick people," "move," "chance," "if sick, infect," "if sick, recover," and "if sick, die." These blocks can be used to model the spread of disease by arranging them in the modeling space. The microworld is agent-based, meaning each agent is asked to behave, at each tick of the clock, according to the blocks assigned to them in the "go" procedure. For example, healthy agents might be asked to move randomly throughout the world and become infected with some probability if they cross paths with an agent who is sick.

The interviewer began the session by sharing their screen and presenting the student with a story about the spread of disease. The story was about Jack, who goes to a party and interacts with Mary, who has been sick. Jack gets sick the next day and then, having recovered, goes to play soccer with his friends. One of the friends gets sick the next day. The interviewer asked open-ended questions and probed for additional information after each explanation offered by the student. After answering the questions, the students were invited to model and test their ideas in the microworld.

This study focuses on interviews with three middle school students: Alex (13), Max (12), and Sam (14). The interviews were recorded and transcribed. A microanalysis (diSessa, Sherin, & Levin, 2016) was conducted to produce a list of the students' initial ideas about the spread and prevention of disease. The audio recording of each student's interview was reviewed, and times were noted during which they revealed their thinking. These episodes were then marked on the transcript, which was then read for evidence of their initial thinking.

Our analysis of the data was driven by the aim of refining the set of coding blocks used in the microworld, and our own intuitions about the appropriate grain size for these blocks. We began by paraphrasing the student explanations, and then looked across students for common ideas. The ideas were organized based on similarities and grouped into the following categories: 1) *disease transmission*, 2) *recovery from disease*, and 3) *disease protection strategies*. These students' ideas can help us get a sense of what intuitions students have about disease spread and prevention and how we might revise the emergent systems microworld by adding new blocks and adding parameters to existing blocks.

Findings

The analysis revealed 11 pre-instructional ideas across the three categories. We propose 6 corresponding revisions to the microworld, which would allow students to model and test these ideas. We present each knowledge category, listing student ideas (with illustrative segments of transcript) and proposed model revisions.

Disease transmission

Pre-instructional ideas belonging to this category emerged when the students explained why Jack took a day to develop symptoms after he played with Mary and transmitted the virus to others even though he had no symptoms. Table 1 organizes students' ideas about *disease transmission* and implications for the design of our ESM.

Table 1. Pre-instructional ideas about *disease transmission* and design implications.

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Transcript	Pre-Instructional Ideas	Implications for Block Design
Sam: …You do not show symptoms right away, it takes time for you to start to feel it.	It takes time to get sick and show symptoms.	Add a "set incubation time" block, to cause a delay between being exposed and getting sick.
Max: Mary sneezed or coughed, the species, the sneeze or cough went into the body of Jack and took time to process and get into his body and get infected. Alex: The virus got on, for example, his hand. And then when he got home, he had to eat and touch the food. That was with his hand. So, he ate the food, so now it is in his stomach.	Agents of disease can transmit through the human mouth and nose when coughing and sneezing. Agents of disease can stay on objects and transfer through touch.	Add "cough," "sneeze," and "touch objects" blocks to the "ask sick people" and "ask healthy people" block sets. The parameters of each block could be varied with respect to probability of infection.
Alex: Maybe even Jack recovered from the virus. He still had something in his body when they were playing. Max: …it's like since he is lying on the bed for like a week, perhaps the disease stops working, but when Jack started to play, they started working again.	Agents of disease can still be in your body even when you are healthy. Viruses would "sleep" in a deactivated body and "wake up" when the body is active again.	Add a "show symptoms" block with a variable probability parameter, to allow agents to be sick with or without showing symptoms.

Disease Recovery

This category of pre-instructional ideas emerged when students explained what disease Jack caught. Table 2 organizes students' ideas about *disease recovery* and implications for the design of our ESM.

Table 2. Pre-instructional ideas about *disease recovery* and design implications

Transcript	Pre-Instructional Ideas	Implications for Block Design
Alex: …When he recovers from the normal flu, he can't affect it to someone else. [...] A flu. You get it once. Because after your body sees the virus, they will get rid of it right away.	A body can gain immunity when it gets used to a disease.	Add an "if recover, gain immunity" block, with an adjustable probability parameter.
Max: Probably COVID. Coronaviruses, however, our body can't identify them, so it takes a process for our body to notice that we are sick and clear the virus.	It takes time for our body to recover from Coronavirus.	Add the blocks "get flu" and "get COVID-19" to pair with the variable probability "if sick, recover" block.

Disease Protection Strategies

This category of pre-instructional ideas emerged when students were asked to explain which kind of protection strategies would be effective in protecting themselves from infection when vaccines are still in short supply. Table 3 organizes students' ideas about *disease protection strategies* and implications for the design of our ESM.

Table 3. Pre-instructional ideas about *disease protection strategies* and design implications

Transcript	Pre-Instructional Ideas	Implications for Block Design

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Sam: I'm kind of staying at home and stuff. [...] I don't think wearing masks works. The virus would stay on the masks. Your mouth touches the masks, then the virus comes into your body. Alex: I think every time you go out, wear masks. Some people wear masks and facial to protect their eyes too. Wash hands often. Sanitize your clothes and shoes when back home.	Stay home more of the time. Wear masks and facial shields. Wash hands. Sanitize personal objects and the environment.	Add "wear masks," "wash hands," "wear facial masks," and "sanitize the environment and belongings" blocks to the "ask sick people" and "ask healthy people" sets of blocks. Each block could have different parameters for probability of infection. It would be possible to display the results of single or multiple disease prevention strategies by stacking or using them separately.

Discussion

Our larger research project aims to develop emergent systems microworlds that intentionally meet students halfway. We approach this by providing students with programming blocks that correspond to their intuitions, which requires investigating what those intuitions are. This study examined students' intuitions about disease spread and prevention. Findings suggest that students have many intuitions about the spread, recovery from, and prevention of disease. Our findings offer insight into what coding blocks a pandemic microworld should have so that students can build, test, and debug models that represent their thinking. We anticipate that adapting blocks to accommodate students' intuitions will help students build models that represent their thinking and allow those without programming experience to use agent-based modeling to learn about complex systems phenomena.

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Investigating Student Learning about Disease Spread and Prevention in the Context of Agent-Based Computational Modeling

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Abstract: COVID-19 has brought increased attention to the importance of health literacy, including understanding of the transmission and prevention of disease. This study presents data from a project aimed at developing a computational modeling microworld to help middle school students learn about these topics. Specifically, the microworld is meant to help students model and test their ideas about how a disease spreads through a population and how an epidemic can be prevented. The paper analyzes one student's knowledge refinement through the building, testing, and debugging of a disease spread and prevention model. We model student refinement of thinking through steps of building initial models and predicting results, testing initial models and making sense of the results, debugging and retesting models, observing final models, and explaining results. Our findings suggest adolescents can learn about strategies for disease prevention through computational modeling.

Introduction

COVID-19 has brought increased attention to the importance of health literacy in society. This involves making the public aware of issues related to public health, such as disease transmission and epidemic prevention. Epidemiology is the study of population-level health-related behaviors and outcomes, including disease causation, transmission, and prevention. Castagno et al. (2020) found that computational models could support the teaching and learning of topics in epidemiology. Their study was limited to undergraduate and graduate students and there is therefore a need to study how adolescents learn about epidemiological topics through computational modeling.

Agent-based computational modeling microworlds are a powerful tool for helping students learn about complex systems phenomena, including the spread of disease (Wilensky & Abrahamson, 2006). The value of their application has been described in many research studies, including studies that specifically describe their impact on students' understanding of scientific phenomena (Levy & Wilensky, 2009; Wilensky & Reisman, 2006, Wilkerson-Jerde, Gravel, & Macrander, 2015). We aim to offer middle school students block-based modeling microworlds, which allow them to represent their ideas in the program code and refine their thinking as they debug their program. We lower the threshold of this type of coding by using NetTango (Horn, Baker, & Wilensky, 2020). NetTango makes the computational power of NetLogo (Wilensky, 1999) accessible to modelers by using a block-based programming language curated to a particular phenomenon. NetTango blocks are not a full programming language, but domain-specific blocks relevant to the modeled phenomenon. This paper examines how our *Disease Spread* microworld can support student learning about agent-level behaviors that can lead to the prevention of an epidemic. Specifically, we show how a middle school student refined his thinking about disease prevention strategies using an agent-based computational microworld.

Theoretical Foundations

Constructionism informed the development of the instructional environment for this study. Constructionism asserts that learning occurs best through the construction and refinement of publicly shareable artifacts (Papert, 1980). Constructionist pedagogy helps students gain knowledge and skills by creating, reflecting on, and discussing these artifacts. In the case of our study, students used a computational agent-based model to articulate their thoughts on disease spread and prevention. They refined their ideas as they tested, debugged and refined their models. The theory of Knowledge in Pieces (KiP; diSessa,1993) informed our analysis of the engagement and refinement of naive knowledge. Knowledge, according to KiP, is a complex system made up of knowledge elements. Learning happens through the reorganization and refinement of the learner's knowledge networks. KiP instruction is constructivist, focusing on eliciting and refining students' prior knowledge.

Methods

This paper draws data from a larger study focused on developing a computational modeling microworld to help students construct an understanding of the spread of disease (Figure 1). The present work investigates the question: "*How does the computational block-based modeling microworld help students move from their initial thinking to their later thinking, with respect to disease prevention strategies?"* In order to address this question, we employed

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a lab-based case study approach (Yin, 1998). We conducted a one-on-one 1.5-hour interview through Zoom with a 12-year-old student we call Max. During the interview, Max was asked questions about the spread and prevention of disease and then invited to model and test his ideas in the microworld (Figure 1).

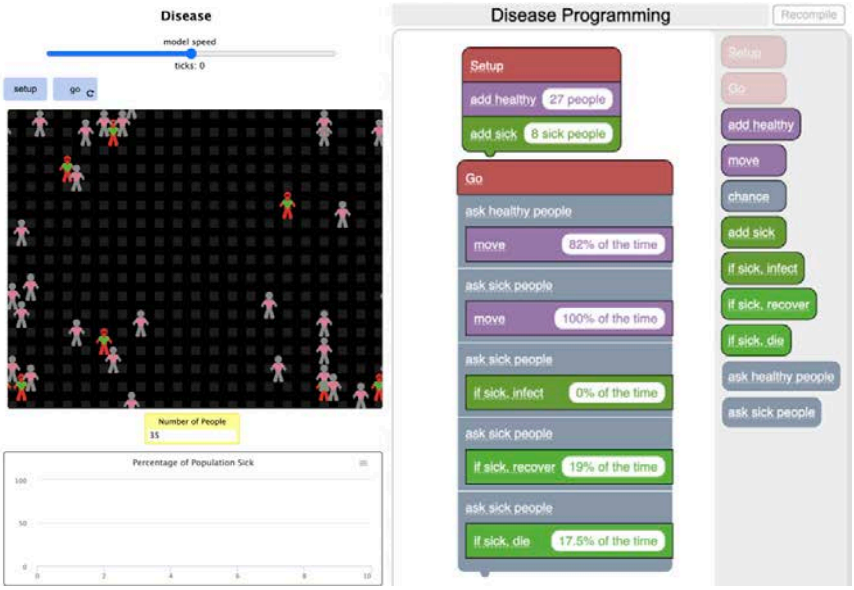

Figure 1: Screenshot of the *Disease Spread* microworld (Martin et al., 2021).

The box on the left side of Figure 1 represents a space where agents interact with each other. The modeling space on the right side of the interface has blocks including "setup," "go," "add sick," "add healthy," "ask healthy people," "ask sick people," "move," "chance," "if sick, infect," "if sick, recover," and "if sick, die." These blocks can be used to model the spread of disease by dragging and arranging them in the modeling space. The microworld is agent-based, meaning each agent is asked to behave, at each tick of the clock, according to the blocks assigned to them in the "go" procedure. For example, healthy agents might be asked to move randomly throughout the world and become infected with some probability if they cross paths with an agent who is sick. Sick agents might be asked to die or recover with some probability.

Max was invited to model and test his ideas in the microworld. Instead of writing text-based programs, he used blocks to build and test models and examine how emergent patterns arose at the system level from simple rules and interactions at the agent level. Specifically, he could build and test a model representing the spread of disease to explore how the individual-level interactions could give rise to a pandemic, and how individuals' different protection behaviors could make an impact on the overall health of the public.

We audio-recorded and transcribed Max's interview. We conducted a microgenetic analysis (diSessa, Sherin, & Levin, 2016) to produce a temporal decomposition of Max's trajectory of thinking with respect to disease prevention and protection strategies. First, we reviewed the recording of Max using the modeling microworld to build models of two different disease prevention strategies. We noted times during which he built, tested, debugged, and made sense of his models. These episodes were marked on the transcript, which was then analyzed to understand his process of knowledge refinement. This process included four steps: 1) building an initial model and predicting its results, 2) testing the initial model and making sense of its results, 3) debugging and retesting the model, and 4) observing the final model and explaining its results. We then tracked the shifts in Max's ideas over the course of these steps in order to understand how engagement in computational modeling helped Max refine his thinking.

Findings

We present an episode from Max's interview to illustrate how he refined his thinking as he refined his models. In the beginning, Max thought the best strategy for preventing a pandemic was for everyone to stay at home. By the end of the interview, in contrast, he had developed a sense that strict quarantine may not be more effective than allowing healthy people to move around with protection (such as masks), while sick people stayed at home most of the time. In this way, he may have developed his thinking and arrived at a more nuanced understanding of disease prevention.

The interviewer wanted to focus Max on two tasks toward the end of the interview and asked: "Could you arrange the blocks or modify the parameters of the blocks to create two situations? The first situation is the case where everyone stays at home, the second situation is the case where only sick people stay at home, but healthy people are free to move with protection." The steps below describe Max's trajectory through the modeling activity, highlighting his shifts in thinking.

The "Everyone stays at home" model

The interviewer asked Max to build a model of a strict quarantine, in which everyone stayed at home.

Step 1: Building the initial model and predicting its results

Max set up the world with 27 healthy people and 8 sick people. He asked healthy people to move with 82% probability and sick people with 100% probability. He set the probability of infection at 0%, the probability of recovery to 19%, and the probability of death to 17.5%.

> Max: …Basically like this. You can't infect anybody. Mmmm. [Max runs the model] Yeah. Nobody is dying. So basically, if they are quarantined, they can't touch each other, so they can't infect each other. Yeah, all the people would like to recover eventually.

He constructed the model to have a high rate of movement and a 0% chance of infection based on his initial assumptions about how strict quarantine would affect the rules of disease spread. Instead of lowering the rate of movement to represent a strict quarantine in which everyone stayed at home, he reduced the infection rate to zero to create a condition in which "no disease may spread among individuals." Even though this model did not accurately depict people's behavior, it was consistent with his prior belief that "strict quarantine would be the most effective way to safeguard the population." Before he tested his model, he predicted that no one would die. His initial thinking was: "Everyone stays at home is the most effective disease prevention strategy."

Step 2: Testing the initial model and making sense of the results

Max ran his model and watched five people die. He said he was surprised by the outcome of the model run. This reaction was evidence that he built this model with the expectation that a strict quarantine would be the most effective disease prevention strategy. He tried to understand what was happening at the agent level that would have caused the aggregate-level outcome, in particular, why five people died even when the infection probability was 0%.

Step 3: Debugging and retesting the model

In response to the interviewer's prompt, Max started debugging the model.

> Max: Hmmm. Oh, yeah, move! Move rate should be 0%. [Max decreased the probability of moving to 0]. I will try to increase this [Max increased the infection probability to 49.8%, then recompiled the code and tested the model].

Max decreased the probability of movement from 100% to 0% and increased the probability of infection from 0% to 45%. These two moves indicate that he debugged his thinking regarding how to use the blocks to represent a strict quarantine and the probability that a disease would actually transmit. His updated model represents a more normative way of modeling a strict quarantine, by more accurately representing the rules governing individual agents and their interactions.

Step 4: Observing and explaining the results

Max tested the effect of his modified parameter and watched as 6 sick people died, even though no one moved in this model. Max appeared to be surprised by this result, saying, "Oh no, more people died." This is evidence that the outcome of the model-run did not match his expectations. It suggests that he expected this modified model to work out differently, producing a result where fewer people died. It is interesting to note that Max did not continue to debug his model and find the cause of the unexpected deaths, which was the 17.5% chance of dying faced by every sick individual, each tick of the clock.

The "Sick people stay at home" model

Next, the interviewer asked Max to model a situation where only sick people were required to stay at home, while healthy people were allowed to move around the world freely, wearing protection such as masks. Max indicated

that he expected this approach to lead to more sick people and deaths ("So basically, healthy people can move 100% of the time so that more people would die"). As in the previous activity, he engaged in steps of model building, testing, debugging, and explaining his observations. He left most of the model from the previous activity intact, changing only the probability of movement for healthy people (increasing it from 0% to 100%). When he ran the model, four people died. He was surprised by this result, as he expected more people to be infected and die. When asked if he thought there were any issues with the parameters left over from his previous model (probability of infection, recovery, and death) he replied, "I don't think so."

His final thinking on the effectiveness of the two disease prevention strategies was "I am not sure now. I mean, the outcomes of healthy people moving around and staying at home is a tie." This is evidence that engaging in the modeling activity played a role in shifting his thinking about the relationship between agent-level interactions and aggregate-level outcomes. While at the start of the activity, Max expressed certainty in his assertion that strict quarantine would be the most effective prevention strategy, after modeling the two approaches, he felt less certain, hinting that there may be more to consider given the two approaches produced similar results. Though this is a small shift in thinking, it is still a shift, and it is possible that further exploration of the model would lead to more debugging of the model, and in turn, refinement of thinking.

Discussion

This study investigated how a middle school student refined his thinking about disease prevention strategies using an agent-based computational microworld. Findings suggest that computational modeling can help students refine their thinking through building models and predicting results, testing models and making sense of the results, debugging and retesting the models, observing models, and explaining results. Our findings offer insight into how adolescents can learn about disease prevention through computational modeling. A high-level goal of our work is to develop microworlds in which students build models using a language they understand. Analyses show that our representations work as expected. Though somewhat abstract, Max was able to build and refine his model based on ideas drawn from his everyday experiences of the phenomenon he was trying to model.

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Evaluating a Framework for Learning Non-routine Problem-Solving in Mathematics

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Abstract: An important goal of mathematics education is supporting students' ability to tackle novel, non-routine problems. However, typical mathematics instruction in U.S. classrooms often places emphasis on rote learning, without exposing students to the process of deriving a formula or alternative solutions. We propose a framework, *Try-See-Tell-Do*, which combines several evidence-based learning strategies to help students develop non-routine problem-solving skills. Following the framework, a student would first *try* a non-routine problem on their own, *see* a worked example solution to the problem, self-explain (*tell*) the solution they saw, and finally practice with two novel non-routine problems (*do*). Through a series of eight think-aloud interviews, where high school students applied the framework to solve combinatorics problems, we found that students could recognize the instructional value of the learning activities. Additionally, we noted students' tendency to rely on memorized formulas and derived actionable insights on improving the framework to reduce this behavior.

Introduction

The ability to solve non-routine problems plays an increasingly important role in modern workplaces (Neubert et al., 2015), where well-defined routines are insufficient. However, in U.S. classrooms, non-routine problems are often viewed as targeting only high-performing students, and even with these students, there is a lack of empirical evidence for which instructional strategy, or combination of strategies, is most effective (Gavaz et al., 2021). Towards addressing this gap, we propose and evaluate an instructional framework, *Try-See-Tell-Do*, intended to develop non-routine problem solving skills by combining several evidence-based learning science techniques: solving a problem on one's own (*try*), seeing a worked example of this same problem (*see*), self-explaining a solution to the problem (*tell*), and finally practicing with related problems (*do*). These activities are based on well-established benefits of attempting to invent a solution to a new problem before receiving instruction on it (Schwartz & Martin, 2004), worked examples as a means of scaffolding (Paas et al., 2003), and self-explanation as a trigger of generative processing that supports deep learning (Chi et al., 1989).

While each component of the proposed framework has strong conceptual and empirical support, these learning science principles have rarely been applied to non-routine problems or in tandem. Thus, our goal in this research is to evaluate the effectiveness of the *Try-See-Tell-Do* framework as a whole. To this end, we formulated the conceptual strategies that students were expected to learn and designed learning activities based on these strategies and the framework pipeline. Then, we conducted think-aloud interview studies to record students' performance and feedback as they tried out the framework. In what follows, we describe each phase of *Try-See-Tell-Do* in greater detail and formulate the primary take-aways from our qualitative analyses.

Conceptualizing how students learn non-routine problem solving

In preparation for developing the *Try-See-Tell-Do* framework, we solved 70 non-routine mathematics problems from the textbook by Johnson & Herr (2011) and consolidated the techniques introduced in the textbook into eight strategies. Four strategies are for "preprocessing," used to create a mental representation of the problem: *Use Smaller Number*, *Specify*, *List Requirements* and *Identify Target Quantities*. Four strategies are "solving" strategies, used to come up with a solution: *List Number Sequence, Solve Smaller Subproblem, Solve Complementary Problem, Create Equations*. For example, the non-routine problem of finding the last digit in the number 2^{57} can be solved with the preprocessing strategy *Use Smaller Number,* followed by the solving strategy *List Number Sequence*. Specifically, one could list the final digits of smaller exponents of $2 – 2^1$ ends in 2, 2^2 ends in 4, 2^3 ends in 8, 2^4 ends in 6, 2^5 ends in 2 – to identify the recurring pattern 2, 4, 8, 6. Such a pattern in turn implies that 2^{57} should end in 2, without needing to directly compute this number.

In a practical setting, students would have the opportunity to experiment with different combinations of preprocessing steps and solving strategies to construct a solution. In the scope of this work, however, we wanted to first evaluate whether the framework pipeline is effective. Therefore, we only had students work with one preprocessing step, *Use Smaller Number*, and one solving strategy, *List Number Sequence*, in our study. We

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selected three problems from Johnson and Herr (2011)'s textbook that have distinct contexts and involve different number sequences, but can all be solved with this combination of preprocessing and solving strategies:

- **Q1**: You and your friends are organizing a tournament, where each person will play one match against each other. There are five players in total - A, B, C, D, E. How many matches will be played in total?
- **Q2**: Alexis, Bart, Chuck, Jerry, Timmy, Kim, and Dariah are all called in to a radio show to get free tickets to a concert. How many possible orders in which their calls could have been received are there?
- **Q3**: In a movie theater, there are ten rows of seats. The first row contains one seat, the second three seats, the third five seats, the fourth seven seats, and so on. How many seats are there in total?

One of the three problems (Q1) was assigned to the *Try, See,* and *Tell* stages, where students could make an attempt at solving (*Try*) before seeing the worked example (*See*) and explaining a solution (*Tell*). The remaining problems (Q2, Q3) played the role of near- and far-transfer practice problems in the *Do* stage, after students had learned from Q1's solution. We selected high school students as our interview participants since they may have had some, but probably limited, experience with combinatorics, which is typically covered in the first year of undergraduate study in the U.S. In this way, the participants were not expected to have prior formal exposure to the problems and would consider them as non-routine.

Methods

We recruited eight high school students (6 males, 2 females, aged 15-18) in the U.S. to participate in our online think-aloud interviews. Participation was completely voluntary and participants were compensated $25 after the interview. First, participants were asked about their math background, including their grade level, classes taken, and general experience with math. Then they were instructed on how the think-aloud process would be conducted, along with a think-aloud demo on a simple math problem, carried out by the interviewer. The interviews each proceeded based on the four stages of our instructional framework. In the *Try* stage, participants were asked to solve a non-routine problem (Q1) on their own. They then went to the *See* stage and saw a worked example solution to the same problem, Q1. To promote interactive learning, we presented each step as a multiple-choice question on a web interface (1). After answering each question, participants would see a feedback message about their correctness. Participants concluded the *See* stage by reviewing the entirety of the worked example solution, before moving to the *Tell* stage. Here, they were asked to treat the interviewer as a novice and tell them how to solve Q1, using either the solution they derived in the *Try* stage or the one they saw in the *See* stage. Next, the *Do* stage presented two more problems (Q2 and Q3) for participants to solve on their own to measure near and far transfer. Finally, we asked participants about their thoughts on the overall framework.

With permission from the participants and their parents, we recorded the interview audio along with the participants' draft work in each stage. Then we transcribed and performed a narrative inquiry among three researchers on the audio data, focusing on participants' self-reported math background, their feedback on each stage, and their evaluation of the overall framework. We also investigated whether the first three stages provided sufficient learning support for participants to tackle the near-transfer problem (Q2) and far-transfer problem (Q3) in the final *Do* stage, as well as any notable difficulties that participants encountered throughout the interview. From this point, we denote each participant with an anonymous ID, ranging from P1 to P8.

Analysis and Results

There were five rising sophomores and three rising juniors who took part in the study. Five participants had taken classes up to Algebra 2 and three up to Advanced Placement Calculus. All participants indicated that they enjoyed learning math because they liked to challenge themselves or because they had a positive learning experience.

Try stage

In this stage, participants solved the problem Q1 on their own. Five participants were familiar with the underlying combinatorial formula of the problem and were quick to point out the correct answer, "5 choose 2," which equals to 10. The remaining three did not mention any connection to combinatorics, likely because they were not exposed to this field. Among them, one arrived at the correct answer by listing out all the 10 matches. The other two attempted to visualize the problem by drawing the tournament layout in a graph; however, these participants incorrectly considered "A vs B" and "B vs A" as different matches, leading to an overestimation. When asked about the rationale for their chosen approach, participants either mentioned that they had seen a similar problem or that they felt the visualization and enumeration approach was the most natural.

See stage

In this stage, participants reviewed a worked example of the *List Number Sequence* strategy for Q1, accompanied by seven multiple-choice questions. The first question asked about whether it's better to consider all the participating teams at once, or start with a smaller number of teams. The expected answer is the latter, which reflects the *Use Smaller Number* preprocessing strategy, but seven out of eight participants selected the former, which aligns with their approach in the *Try* stage. P6 noted that both options could lead to the correct answer, so the question text should be clearer about why one option is preferred over another. After this point, all participants picked up on the spirit of the solution and were able to correctly answer subsequent questions. When asked about their preference, five participants preferred their original approach (applying the combinatorial formula), on the grounds that the worked example took longer to carry out than their original solution and may not work for more complicated problems. At the same time, they acknowledged that this bottom-up approach could be helpful to beginner students who have no knowledge of combinatorics – as P4 stated, "*It shouldn't be set as the be-all-end-all thinking process as people obviously process thoughts differently, but it's a great baseline to start off the process if people have no idea how to think of problems like this*." The remaining three participants were more welcoming of the worked example, noting that seeing the explanations helped them better understand the solution; P2 further compared this process to their online learning experience: "*Khan Academy shows the steps but doesn't force you to work through it, so this is more helpful*."

Tell stage

In this stage, participants were asked to teach a novice about solving Q1, using either their original solution in the *Try* stage or the worked example in the *See* stage. Five participants taught with their original solution because they were more comfortable with it (P1, P3) or because they believed it is more effective and generalizable (P6, P7, P8). The remaining three chose to explain the worked example, rather than their original combinatorial approach. When asked about their rationale for switching, P5 indicated that the worked example presented a new approach to them, so they'd like to teach it to understand it better. Likewise, P4 considered seeing the fine-grained worked example a new experience -- "*it shows you a process of how to teach others to think, it's a very streamlined process and very natural, but I wouldn't have thought of it before.*" When reflecting on their experience, all participants indicated that this *Tell* stage is the most helpful in the framework. P5 was very familiar with the combinatorial formula solution; thus, having to explain the solution to a novice forced them to think about why the formula works and delve more into the underlying principles. P2 also made a reference to the inductive process "*starting small, building big in a systematic way,*" which they found particularly useful.

Do stage

The first problem (Q2) in this stage was solved successfully by four out of eight participants (P5, P6, P7, P8). These participants were able to immediately point out the answer, which is 7! = 5040, as the problem context is naturally how permutation is defined. Notably, one participant, P2, realized that the problem is related to a combinatorial formula but could not recall the formula -- "*I just can't remember what I actually did with this problem because we had something like this before as well*." The remaining participants either proposed an incorrect answer (7 x 7 = 49) after some trial-and-error or gave up without a solution. The second *Do* problem (Q3) observed more success, where six participants (P2, P4, P5, P6, P7, P8) arrived at the correct answer but did not start from smaller cases, instead considering the whole problem setting. However, participant P5, after mentioning the general formula, also attempted a second solution that followed the *List Number Sequence* strategy from the *See* stage; P5 was the only participant that did so. The remaining two participants failed because they either made a calculation mistake or could not recall an appropriate formula.

When asked about whether the previous stages (*Try*, *See*, *Tell*) helped with their performance on the *Do* stage, P2 noted that these stages helped orient their thoughts and have a clear direction of what to do. The remaining participants indicated that the previous stages had little effect on them, either because they had already seen all three problems given in the interview (P5, P6, P7, P8), or because they didn't apply the strategy in the *See* stage to solve subsequent problems (P1, P3, P4). However, some participants felt that they could have learned from the previous stages if given more time to digest the problem and solution content: "*now that I'm thinking about it, it helped me just now realize that I could minimize the number*" (P1).

Discussion and Conclusion

This work explores a general framework for training high school students in solving non-routine problems. While the framework did not yield clear learning benefits as measured by performance on the practice problems, it reveals important insights into students' problem-solving behaviors and suggests potential future avenues.

Our first observation is that all participants had a strong tendency to appeal to formulas during their problem solving. When these attempts failed, they would then resort to solving the problem by brute force (i.e.,

list all possible configurations) and would give up if this approach was not fruitful. This behavior occurred most frequently in Q2, where there are too many configurations to manually enumerate. Consistent with our findings, Stigler et al. (2010) has reported that, when facing a novel problem that requires flexibility, U.S. students tend to apply memorized procedures or formulas incorrectly rather than develop new solutions.

To combat this issue, we devised the *Try-See-Tell-Do* framework to highlight a general strategy for discovering a solution to a problem, without relying on rote memorization. We hypothesized that the *See* stage, with its detailed worked example, would clarify the conceptual workflow for students, and that subsequent stages would reinforce this workflow through self-explanation, near-transfer and far-transfer practice. Our interview results showed that participants did find the worked example useful, especially for less experienced students, which is consistent with research showing worked examples are most beneficial for novices (Paas et al., 2003). However, most participants were not able to capture the underlying heuristic and apply them to new problems. On the other hand, the *Tell* stage was positively received by all participants, who indicated that it was a novel and helpful experience. Although students thinking an approach is helpful and actually *showing* it is helpful through actual use are two different outcomes, this finding does at least point to past research that shows self-explanation following a worked example is a powerful and robust mechanism to support learning (Chi et al., 1989). For our next experiment, we plan to improve the *See* stage with an interactive visualization of the worked example, which can be effective at maintaining engagement (Liang & Sedig, 2010), while also highlight the core take-aways. As observed from past studies on problem-solving (Arslan & Yazgan, 2015; Nguyen et al., 2020), the visualization approach aligns well with how students tend to explore the solution space when attempting novel problems

Finally, we remark that our interviews were conducted on a small sample of students who had either solid or excellent backgrounds in mathematics. To promote broader applicability, additional evaluation of the *Try-See-Tell-Do* framework is needed, especially with lower-performing students, for whom the multi-layered instructional support may be more beneficial. Nevertheless, we have uncovered students' reliance on formula application as a central issue in problem solving and identified room for improvement in the implementation of our learning strategies. We envision that, through iterative refinement, the framework can be deployed as a digital learning platform with support for personalized feedback to promote non-routine problem-solving skills at scale.

Endnotes

(1) A demo of the worked example prototype is available at: https://bit.ly/3cb25ov.

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Responses of rural Chinese teachers to workshops on culturally relevant constructivist pedagogy

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Abstract: We analyzed the impact of two workshops that introduce Knowledge Integration and Culturally Relevant Pedagogy to rural Chinese science teachers. The workshops emphasized connecting science lessons to local, culturally-relevant contexts. Teachers developed written lesson plans to localize their instruction and implemented their plans in classrooms. We used inductive coding to identify five levels of localization in the lesson plans. We captured the creative plans that teachers generated in three classroom case studies. The workshops revealed ways to support rural Chinese teachers to connect complex science topics to culturally-relevant local examples and identified areas for improvement.

Introduction

Science education researchers and practitioners have long emphasized constructivist perspectives, including eliciting students' prior knowledge and related experiences to scaffold learning (Vygotsky, 1978; Linn & Eylon, 2011). In 2001, the Ministry of Education (MOE) in China embarked on a series of education reforms to shift from an exam-oriented to a student-centric and constructivist education system (MOE, 2001). Consistent with this shift we studied how teachers in a middle school in central rural China responded to two constructivist workshops. We investigated how teachers planned and enacted their lesson plans.

In China, rural areas include villages where people mainly engage in agricultural activities and rural towns that evolved from villages and function as educational, cultural, and economic centers (National Bureau of Statistics, 2008). Rural areas often preserve more traditional cultural practices, compared to urban areas (Oakes, 2013). Rural teachers in China rarely adopt constructivist teaching (Sang et al., 2009; Zhang & Liu, 2014) because they are socialized into norms of science teaching that reinforce exam results (Wu, 2016). And, teachers lack constructivist teaching professional development compatible with rural contexts (Rao & Ye, 2016).

Rural contexts offer a rich environment for learning science as students make scientific inquiries in family settings, community events, natural surroundings, and the agricultural activities in their lives (Avery & Kassam, 2011). Although social constructivists demonstrate that science is impacted by cultural values (Bingle & Gaskell, 1994), in school science classrooms where western science dominates, local practices and knowledge are seldom acknowledged. Researchers have begun to bridge the gap between local experiences and school science (Bang & Medin, 2010), and place-based education approaches (Bartholomaeus, 2006).

We investigated rural teachers' lesson plans and implementation of localized science learning contexts to answer the following research questions: 1) What kinds of localized learning contexts do rural Chinese teachers create? 2) What are the challenges of building localized contexts into science lessons?

Methods

Workshops and Participants

The two-day workshops were held in January 2021 and June 2021. The first workshop introduced the concepts of constructivist teaching and Knowledge Integration (KI) pedagogy. The KI pedagogy emphasizes that students develop multiple, varied ideas about the same scientific phenomena across their many experiences at school, at home, and when interacting with the natural world. By eliciting students' ideas, providing opportunities for students to discover more ideas, encouraging students to distinguish among these ideas, and asking students to reflect on their ideas, teachers help students develop a coherent account of the phenomena (Linn & Eylon, 2011). The second workshop introduced Culturally Relevant Pedagogy (CRP). By supporting learners to draw on their cultural identities and reflect on social inequalities, teachers can build identity as a science learner (Ladson-Billings, 1995). At the end of the second workshop teachers drew on KI and CRP to write a lesson plan that created a learning context to introduce a new concept to their students.

Participants were 20 science teachers who attended both workshops: 8 physics, 8 chemistry, and 4 biology teachers. All 20 teachers are rural residents who grew up in the area and have taught grade 7, 8, or 9 at the school for 4 to 40 years (M = 22.2 years, SD = 8.58). Three case studies involved teachers who consented to

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classroom observations and interviews. After observing each 45-min class, the first author interviewed the teacher and two to three students, asking, "How do you feel about this class?"

Data sources and analysis

The 20 teachers' written lesson plans, written in Mandarin, were analyzed. The first author used inductive coding (Thomas, 2006) to create categories for the localized contexts. The lesson plans were then translated into English. The case study observations were in Mandarin Chinese and the interviews were in local rural dialect Chinese. They were translated into Mandarin, coded, and translated into English.

Results

Each teacher made a detailed lesson plan and 18 of the 20 teachers included creative and relevant local contexts. Teachers were eager to incorporate local contexts in science teaching. Using inductive coding, 5 levels of localizations emerged in the teacher's written lesson plans (see Table 1).

Table 1

Levels of Localized Context Examples Generated by the Teachers

Score	Levels and Criteria	Examples
1	No context building	● I don't think giving examples is helpful in my classroom. It will weaken my teaching efficiency.
2	Irrelevant: Building contexts that are irrelevant to learning objectives	● I will play some music, videos, or pictures that are relevant to learning content to help students get into the learning status. ● When I teach *infectious diseases*, I will introduce a story about a Pacific Island in our biology history.
3	Partial Link: Teachers build contexts that have one of the characteristics: 1) relevant to learning objectives; 2) familiar to students; 3) shared within community culture; 4) have critique of inequities.	● When I teach *salt metathesis reactions*, I don't want students to just memorize the equation. I often introduce it with changing dancing partners while dancing in a ballroom. [In rural China, ballroom dancing is not common, especially among students.] ● I often use our real life events as my example. While I introduce the concept of solutions, I will ask students to predict the reason why the water in swimming pools is blue. [In rural China, swimming pools are not common]
4	Full Link: Students included **one link** between two characteristics listed above.	● When I teach *buoyancy*, there is a very widely used experiment in the textbook: we will ask students to wear plastic disposable gloves and then put their hands into a water tank. Many teachers will just describe to students about how they might feel, but I will ask students to share their feelings (e.g. the gloves will cling to their hands), and predict the reason. ● When I teach *voltage*, the concept is very difficult to understand. The textbook says that "electric current is the result of electric charges moving in a certain direction", but I think students are often confused by "Why charges move in a certain direction?", then I will show them a video about the formation of stream/water flow, and make analogies among flows, current, water pressure, and voltage.
5	Complex Link: Teachers provided **two links**	● When teaching *levers in simple machines*, I will prepare some really hard pieces of chalk and invite two male students to squash them. I can imagine that they will use all their strength to squash the chalk. After that, I will take my pliers, and ask them to try this tool which will easily squash the chalk. ● When I teach *purify*, I will introduce the concept with our Chinese slang "A speck of mouse dung spoils a whole pot of porridge". ● When I teach *Metamorphosis in amphibians*, I will use the story in our traditional fairytale 'The Tadpoles Look For Their Mommy' and ask students to predict the reason why tadpoles cannot recognize their mom.

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The level of implementation of localization did not depend on the science course taught or years of teaching experience. Two of the three CRP features were detected: creating contexts relevant to learning objectives and creating contexts that are interactive, familiar to students, and shared by the community. The lesson plans did not include critiques.

The teachers of each case study reported that their students became excited and engaged when they realized that they were using local knowledge in science. The cases were scored from Level 3 to Level 5.

Case 1 Combustion and Spring Lantern Festival (Level 5)

Teacher Ku is a chemistry teacher with 20 years of experience who was teaching 48 9th grade students about combustion. Ku showed a photo of the Spring Lantern Festival and asked students to rank the most important part of the lantern to keep it lit without burning. Students discussed in groups for 10 minutes and then shared their predictions. Many students raised their hands. Student A mentioned that the vent at the top of the lantern is important because otherwise the light will go out really fast. Student B shared making lanterns by using a special coating inside the paper to concentrate the heat to the center and reduce the chances of the paper burning. Student C's group believed that the material of the candle wick is crucial. After the whole class shared, Ku played a video introducing the functions of different parts in a lantern and asked students to revise their thinking based on the video. During the interview, Ku reported the lesson was a success because "everyone was participating and they also analyzed the combustion conditions by themselves". Student C was surprised that the creative lantern designs aligned with science ideas and described feeling like a "practitioner scientist". Student D didn't speak to the whole class, but drew on prior knowledge during group discussion, saying, "They are discussing the purpose of the vent. Some say it's left for our hand to light the candle, but I remembered that I covered the vent one time because I didn't want the wind to blow it off, but the fire went out immediately. I shared the story with them, and we started to talk about how this vent can be useful."

Teacher Ku's lesson followed the localized KI pattern: eliciting students' prior knowledge; helping students discover new ideas by comparing their experiences and by watching the video. Students spontaneously engaged in distinguishing ideas by comparing their first-hand experiences. Teacher Ku added a distinguishing activity where students ranked the elements of the lantern that controlled combustion. Students then reflected by reconsidering their rankings and explaining their reasoning.

Case 2 Phase Change and Laundry (Level 5)

Teacher Zeng, a physics teacher with 10 years' experience, was teaching 49 8th grade students about phase change. Teacher Zeng introduced the topic by lecturing about the heat transfer process and the changes of states for 20 minutes. Then Zeng showed a picture of laundry hanging in the rural courtyard in the summer (dryers are not common in rural areas) and asked students to predict the phase changes. Several students quickly answered loudly "evaporate!". Then Zeng discovered new ideas by asking if they ever used special methods to make the clothes dry faster. After 10 seconds, Student E said, "Yes, they usually dry faster on sunny days than on cloudy days." Zeng distinguished ideas by asking, "Based on what you've learned so far, can you predict the reasons why they dry faster on sunny days?" Student E then said, "Because of sunlight." Student F said, "Because it's warmer when the sun comes out." Zeng then asked, "What has this to do with the phase change?" Student E answered, "They need heat when they evaporate. The warm sunlight hastens this process." Zeng nodded his head and then asked for more answers. Student G raised hand and said, "They will dry faster if hung in the open courtyard than in the balcony, than indoors." Teacher asked for her reasoning. She said, "Because there is more wind in the open spaces. They can take away moisture." Student H said, "Expand the clothes instead of squeezing them together." Zeng tried to help her reflect on ideas and predict the reasons why her way is faster. Student H said with hesitation, "Maybe because I expose more moisture?" Teacher Zeng agreed with her and added more details, "you increase the surface contacting air, so the water can evaporate faster."

Teacher Zeng implemented the KI pattern while drawing on the students' local knowledge. During the interview, Zeng reported that students were engaged, especially the female students, remarking that in rural families, laundry is always the "women's business." Student G reported already knowing about phase change and learning the names of the phases and the mechanism of heat transfer. Student H reported that laundry methods that seemed like tricks, actually followed real science. Teacher Zeng selected relevant local experiences and was able to recognize female students for their scientific observations.

Case 3 Force and Pressure and Walking/Skiing in Snow (Level 3)

Teacher Zhang, a physics teacher with 28 years of experience, was teaching 46 8th grade students about "force and pressure." Zhang asked students to think about the differences between walking in the snow and walking in the snow with skis. When asked to share ideas, no student raised their hand. Teacher Zhang showed a picture of

a kid skiing and one kid walking in snow. He asked for observations. After 5 minutes there were no hands raised so the lecture continued. During the interview, Zhang said that the example achieved some level of success because students had time to think about the real-life example. However, Student I showed a slight disagreement: "I don't understand why the boy uses skis. How could he move?" Student J was also confused by the details in the picture, "I saw that the ski in the TV is a very large single board, why does this boy use two separate narrow boards? Does this have any difference with the single board?"

Although Teacher Zhang incorporated an example, since the school is located in central-southern China, few rural students have used skis. Students might have seen skiers on TV or the Internet but they didn't have first-hand experiences and were not able to take advantage of the example.

Conclusion and Discussion

These results illustrate the effectiveness of two workshops using KI and CRP to support rural teachers to localize their science instruction. In spite of years of experience with teacher-centered, western science dominated, exam-oriented instruction, many teachers were able to identify relevant local cultural practices and empower students to connect them to scientific phenomena. Some teachers selected textbook examples that were not familiar to their students and gained insight into the limitations of this approach. A few interpreted their students inability to interpret the examples as a weakness or underestimated the ability of their students to come up with examples. The workshops can be improved by increasing opportunities for teachers to collaboratively connect science to local examples. By enabling teachers to report on the successes in the case studies, teachers can enable others to recognize the strengths of rural students.

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Detecting Cherry-Picked Evidence in Texts: Challenges for Undergraduate Students

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Abstract: Authors of digital documents often seek to mislead readers by presenting *cherry-picked evidence*—e.g., a single study supporting a claim when most studies support a different claim. We report results of two experiments to examine whether undergraduate students adjust their epistemic judgments to account for cherry-picked evidence when they read multiple texts with conflicting claims. In Study 1, students adjusted their epistemic judgments when cherry picking was explicitly indicated with warnings called out in texts. In Study 2, however, with a different topic and four conditions that manipulated different degrees to which cherry picking of evidence was explicit, students did not adjust their epistemic judgments, even when evidence was blatantly cherry picked. In addition, very few students mentioned cherry picked evidence in explaining the grounds for their judgments, even when cherry picking was explicit but without such warnings in Study 1. These suggest that most students attend little to whether evidence is cherry picked, except the condition in which authors call out warnings of cherry-picking in texts.

Introduction

Citizens must often weigh information from multiple sources of information to make judgments on issues such as which medicine they should take for a health condition; much of the available information is unvetted and inaccurate. One way to attempt to determine which information to believe is to scrutinize the evidence presented for claims (Duncan et al., 2018). However, sources may intentionally or inadvertently mislead readers who seek to scrutinize evidence by presenting cherry-picked evidence; that is, they may selectively choose one or two studies that support a position, although the majority of studies support a different position. Accordingly, people need to develop their reasoning skills to judge whether evidence has been cherry picked and to reduce reliance on cherry-picked evidence. They should instead seek out information about what the larger bodies of evidence support. This is an important competence that can improve success in reasoning about conflicting evidence encountered online. However, researchers have not yet systematically investigated people's competence in recognizing cherry-picked evidence and in adjusting their beliefs in line with whether evidence has been cherry picked. In this paper, we report the results of two studies that investigate these competences.

Texts presenting cherry-picked evidence are pervasive in social media, and laypeople need to be able to recognize when it occurs and to adjust their conclusions accordingly (Levitan, 2017). However, sources who cherry pick evidence rarely make this clear: They may not realize it themselves, or they may conceal the fact that they have cherry picked the evidence that they present. Still, there may be signs that the evidence has been cherry picked. Authors may hint that they searched for evidence before finding any supporting evidence. Authors may betray cherry picking by not referring to what any larger body of evidence demonstrates, or by not giving any reason for choosing the evidence that they have highlighted. Further, authors of other sources of information may point out that an author has cherry picked evidence. They may also explicitly point out what positions are supported by larger bodies of evidence, highlighting possible cherry picking by those who tout unrepresentative studies. To detect such nuances in texts, readers need to be attentive to trying to find out what larger bodies of evidence say, not just what one or two studies say (Duncan et al., 2018). The purpose of the experiments reported in this paper is to explore whether undergraduates are attentive to these issues, and particularly if they are attentive to cherry-picked evidence when forming beliefs on scientific and social scientific issues.

Study 1. Comparison between Implicit and Explicit Signs of Cherry Picking

We conducted the first experiment to examine whether undergraduate students adjust two kinds of epistemic judgments in response to cherry-picked evidence: (1) beliefs about the claim that the cherry-picked evidence supports and (2) beliefs about the trustworthiness of the source that presents cherry-picked evidence. There were two conditions that manipulated how explicit the indicators of cherry-picked evidence were.

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We developed two documents that presented competing claims on the relationships of rewards, motivation, and performance in social science. Document 1, said to be written by a business journalist, presented evidence from a study that supported a pro-reward claim that "rewards increase workers' productivity" (pro-reward position) based on a lab study where 36 groups of business people in two conditions worked on personnel selection tasks with or without monetary rewards. The study supported the use of rewards to increase productivity. Document 2, said to be written by an author of five bestselling books on motivation research, presented an opposing claim that "rewards decrease workers' productivity" (anti-reward position) based on a field study with 87 participants working on 9 varied tasks and a relatively large reward worth several months' wages. The study's conclusion was that the higher monetary rewards led to worse performance in most tasks, except for very simple tasks that did not require much cognitive attention. These documents were based on actual positions taken by researchers and authors on this topic (e.g., Document 2 was based on the work of Pink, 2011).

Method

The design was experimental, with two conditions (**implicit** versus **explicit** expressions of cherry picking) that varied according to the content of the two documents. In the ***implicit*** cherry-picking condition, Document 1 explained the author's position, mentioning that "monetary rewards tell people that they are valued, and that their work is valued," and then introduced the study described above as evidence, after writing, "Here is *a study* that supports this view." The document then concluded, "It is well known rewards are a main motivator of human behavior…...This is *one study* that shows the efficacy of this approach." (All italics in excerpts from documents have been added to this report for emphasis to highlight differences.) Document 2 first explained the author's position, reporting that "*nearly all psychological studies* have shown that monetary rewards and prizes decrease motivation and performance." Then the document introduced the evidence of the study described above after pointing out a problem in other studies that had been conducted because of the relatively small rewards in those studies. In the ***explicit*** cherry-picking condition, Document 1 added one statement to the document that asserted that the author had searched through many studies until finding one study that supported their claim, thus straightforwardly acknowledging cherry picking. Likewise, another statement was added to Document 2 in which the author warns that if readers find documents that supports a pro-reward position, those documents ignore the large majority of studies that support an anti-reward position. Thus, two corresponding documents presented the same evidence in both conditions, but only the explicit condition contained explicit descriptions of cherry picking and warnings about cherry picking. In both conditions, Document 1 said nothing about the broader body of evidence, and Document 2 asserted that most studies support the anti-reward position.

Participants were 151 undergraduate students in an introductory education course at a public university in Japan; 41 were excluded due to technical problems with the online system, leaving 110 participants. Participants were randomly assigned to conditions. All participants first answered a pre-survey in which they rated (a) the degree of their agreement with the pro-reward or anti-reward positions on 7-point Likert scales (1 = strongly disagree and 7 = strongly agree) (*pre-position*). Next they read versions of the two documents that corresponded to their assigned condition. After this, on a post survey using the same Likert scales, they rated (a) their degree of agreement with the pro-reward and anti-reward positions (*post-position*), (b) the trustworthiness of each of the two documents (*post-trustworthiness*), and (c) the strength of evidence that the pro-reward and anti-reward claims were based on (*post-strength*). In addition, they were asked to report their judgment of the relative amount of evidence supporting the two positions (ranging from 1, indicating that all the studies support the anti-reward position, to 7, indicating that all the studies support the pro-reward position) (*post-amount*). Each pair of responses (on the pro- and anti-reward positions for pre-and post-position, post-trustworthiness, and post-strength) was merged into one variable by subtracting the anti-reward rating from the pro-reward rating, so that a larger value indicated a preference for the pro-reward position, document, and evidence.

Results

The results are summarized in Table 1. There was no significant difference in pre-position between the conditions (F (1,108) = 0.19, η^2 = 0.02), with both groups tending to favor the pro-rewards position equivalently. On the post surveys, the means for each variable were significantly different (post-position: F (1, 108) = 7.30, η^2 = 0.06; post-trustworthiness: F (1,108) = 6.33, η^2 = 0.06; post-strength: F (1,108) = 7.54, η^2 = 0.07; and post-amount: F (1,108) = 5.98, η^2 = 0.05). Participants in the explicit condition provided, on average, significantly lower scores on post-position, post-trustworthiness, post-strength, and post-amount for the pro-reward position. That is, the ***explicit*** markers indicating that the pro-rewards author was cherry picking evidence caused participants to lower their relative preference for the pro-reward position. Explicit markers of cherry picking to support the pro-reward position also led the participants to lower their relative trust in the pro-reward source's trustworthiness and to lower relative ratings of strength for the pro-reward source's evidence.

Table 1
Descriptive and ANOVA Statistics for Study 1

Variables	Implicit (n = 62)		Explicit (n = 48)		F (1, 108)	η^2
	M	*SD*	*M*	*SD*		
Pre-position	3.15	2.22	2.96	2.29	0.19 *n.s.*	0.02
Post-position	1.42	2.46	0.17	2.35	7.30 **	0.06
Post-trustworthiness	–0.26	2.18	–1.27	1.98	6.33 *	0.06
Post-strength	0.68	2.09	–0.50	2.41	7.54 **	0.07
Post-amount	4.34	0.75	3.94	0.98	5.98 *	0.05

* $p < .05$, ** $p < .01$

Study 2. Comparison among Different Signs of Cherry Picking

In Study 1, undergraduate students adjusted their epistemic judgments appropriately when (a) the evidence was explicitly cherry picked and (b) the cherry picking was called out by an opponent. Given this finding, we conducted the second experiment to examine how students responded to differing degrees to which the cherry picking was explicit or implicit.

Method

Two fictional documents were developed that presented opposing claims on the effectiveness of a nutritional supplement called Serenade. Document 1 was said to be written by a doctor who had reported research on nutrition problems for 22 years. It argued for the positive effects of Serenade on health and presented as evidence a recent study showing that Serenade had a positive effect on health (pro-Serenade position). In contrast, Document 2, written by a different doctor who had researched on health promotion by health foods for 21 years, presented an opposing claim with different evidence from another recent study that supported the conclusion that Serenade has a harmful effect on health (anti-Serenade position).

There were four experimental conditions, determined by variations in the content in these two documents. In the first condition (***none—no indication of cherry picking***), the two documents were presented as described above. Specifically, both authors reported "a recent study" as evidence. In the second condition (***hint***), the pro-Serenade Document 1 stated, "After some searching of typical recent research reports, I found a study that I would like to share with you." This statement provided a hint of cherry picking, whereas Document 2 just mentioned that the study presented as evidence was "one typical recent study." In the third condition (***explicit***), Document 1 stated, "There have been many typical recent studies done on the health effects of Serenade. I have looked at many of these studies and in my search, I found one that supports its positive effects, which I would like to share with you." This provided a blatant statement of cherry picking. Document 2 was the same as in the ***hint*** condition. In the last condition (***super explicit***), Document 1 included the same blatant statements as in the ***explicit*** condition, but also included as background information emphasizing that the author of Document 1 had searched many recent studies that supported his belief that Serenade has positive health benefits, and finally found one that supports his claim out of many studies that did not but that he did not report. Document 2 was the same as in the ***hint*** and ***explicit*** conditions, except that one statement was added as background information that the author of Document 2 had written the article after reviewing a variety of recent studies.

Participants were 63 undergraduate students in an introductory course of media and education at a private university in Japan. Participants were randomly assigned to the four conditions. Participants first answered a pre-reading survey in which they were asked to rate (a) their degree of agreement with the pro-supplement or anti-supplement positions for the effectiveness on health in general on 7-point Likert scale (1 = strongly disagree; 7 = strongly agree) (*pre-position*). Next students read the assigned two documents, which varied by condition as described above. After this, they completed a post-reading survey in which they rated their degree of agreement with the pro-Serenade and anti-Serenade positions (*post-position*) and the trustworthiness of the two sources (*post-trustworthiness*). In addition, they rated the relative amount of evidence for each position (1 indicated that all the studies supported the anti-Serenade position, and 7 indicated that all the studies supported the pro-Serenade position) (*post-amount*). Participants also provided written explanations for their level of agreement for both the pro-Serenade and anti-Serenade positions. In the analysis, each pair of responses on the pro- and anti-Serenade stances (pre-position, post-position, and post-trustworthiness) was merged into one variable by subtracting the anti-Serenade rating from the pro-Serenade rating, so that a large value indicates a relative preference for the pro-Serenade stances (see Table 2). In addition, student explanations were analyzed to determine whether students commented on cherry picking as part of their explanation of their level of agreement with the pro-Serenade anti-Serenade positions.

Results

The summary of results is shown in Table 2. The only significant difference between conditions was on the variable *amount of evidence* (F (3, 59) = 4.47, η^2 = 0.19), whereas differences on the other variables across condition were not statistically significant (Table 2). Participants' pre-position ratings were statistically equivalent across conditions. Post-reading positions and trustworthiness ratings were also not statistically different across conditions, except that students' judgements of the relative amount of evidence supporting Serenade (versus the amount of evidence opposing Serenade) differed across conditions. Post-hoc multiple comparisons with Bonferroni corrections indicated that students in the super-explicit condition rated the relative amount of evidence in favor of Serenade significantly lower than students in the none and hinted conditions. These indicate that participants in this condition recognized that there was more evidence in favor for the anti-Serenade position in this condition, yet they did not make a corresponding adjustment to their evaluations of the trustworthiness of evidence or of the overall benefits/harms of Serenade. However, the lack of statistically significant differences may result in part from insufficient statistical power.

Table 2

Descriptive and ANOVA Statistics for Study 2

Variable	None (n = 15)	Hinted (n =15)	Explicit (n = 16)	Super Explicit (n = 17)	F (3, 59)	η^2
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*		
Pre-position	1.93 (2.09)	1.93 (1.53)	2.56 (1.63)	2.41 (1.80)	0.53 n.s.	0.03
Post-position	–0.33 (2.19)	–0.67 (1.84)	–0.69 (2.63)	–1.59 (1.77)	1.04 n.s.	0.05
Post-trustworthiness	–0.47 (1.36)	–0.60 (1.96)	–1.44 (2.00)	–0.18 (2.46)	1.19 n.s.	0.06
Post-amount	4.13 (1.06)	4.20 (0.56)	3.69 (0.87)	3.24 (0.83)	4.47 **	0.19

* < .05, ** < .01

In the analysis of students' written explanations for their ratings, only four students mentioned cherry picking of evidence as a problem—two students each from the explicit and super-explicit conditions; there was no statistical difference across conditions). (A fifth student expressed approval of the cherry-picking tactic!) Student explanations were also coded to identify student mentions of larger bodies of evidence favoring one side or the other. There were no such mentions. Combining these results with the results in Table 2, we conclude that students attended very little to the cherry picking of evidence even in the explicit conditions.

Discussion

In two experiments, we examined whether undergraduate students adjust their epistemic judgments in response to cherry-picked evidence when they read multiple texts with conflicting claims. In Study 1, students adjusted their epistemic judgements when cherry picking was explicitly indicated, whereas in Study 2, students did not adjust their judgments (except for ratings of the amount of evidence) when cherry picking was explicitly or super explicitly indicated. Across the two studies, there was one condition in which one source's cherry picking was explicitly criticized by an opponent (Condition 2 in Study 1); this was the only condition in which students adjusted their epistemic judgments in response to cherry picking. This factor may account for the differences across the two studies. Perhaps students are sensitive to the problem of cherry picking only when an opponent explicitly explains that a source as cherry picked evidence that is inconsistent with a much larger body of evidence. Alternatively, the non-significant results for Study 2 may arise from insufficient statistical power; the sample size for Study 2 was much less than that for Study 1. Further research is needed to investigate instructional methods that can help students become more vigilant in noticing cherry-picked evidence and adjusting beliefs accordingly.

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Racism with Antiracists: Examining Sensemaking in a School-University Partnership for Antiracism

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Abstract: In this paper we explore dialogue between members of an RPP who shared a goal of developing an antiracist learning community. We use one area of disagreement that emerged throughout the partnership to depict how antiracist discourses can align with racist narratives. In our analysis we identified three ways in which RPP partners justified focusing on anti-Black biases over a broader definition of racism, including the need: to uproot internalized anti-Black biases; choose how to use limited resources towards antiracist goals; and create conditions that mitigate Black students' behaviors. Each of these justifications reinforced racist ideologies by separating racialized groups, putting them in competition for attention rather than promoting solidarity and collaborative change, centering white people and their thoughts, and promoting a racist/non-racist binary. We conclude with implications for supporting the design of antiracist, transformative learning opportunities for educators.

Eduardo Bonilla-Silva (2020) describes "racism without racists"—or, how white supremacist structures, systems, and practices could persist in a society in which most people disavow racism and would never consent to characterizations of themselves as racist. While "color-blind racism" certainly persists (ibid), the current moment of blatant white supremacist violence (e.g., the recent wave of anti-Asian hate crimes, the January 6 insurrection, etc.) and highly visible resistance (e.g., Black Lives Matter) has spurred many people, including educators, to adopt the label "antiracist," explicitly rejecting racism and race-evasive approaches to change. Antiracist movements are not necessarily free of racism themselves, however. In this paper, we present our analyses of an RPP that actively sought to develop an "antiracist learning community," exploring how we and our partners made sense of antiracist goals through particular narratives and discourses. As we show, racism may be not only present but actually reinforced in discourse that takes up an explicitly antiracist stance. Thus, in this paper, we explore the question: How can ostensibly antiracist discourses support racist ideologies?

Theoretical Background

Race is a social construct, created to differentiate racial groups and to justify white supremacy as a system of racial domination (Solórzano & Yosso, 2001). This system involves racist structures, practices, and outcomes; it also involves sociohistorical narratives that position (American) white ways of thinking, learning, feeling, and being as normal and good while others as obviously and self evidently less than (e.g., Ferguson, 2000; Menchaca & Valencia, 1990; Shah, 2019). Further, racism and antiracism are complex and intersectional. In the words of Lorde (1984), "there is no such thing as a single-issue struggle, because we do not live single-issue lives" (p. 138). Systems of oppression based on race, ethnicity, gender, sexual orientation, language, class, disability, and other socially constructed categories function simultaneously and in concert to produce inequality in schools as elsewhere (Grant & Zweir, 2012). Thus, to be truly antiracist is to fight all forms of hierarchy and recognize all humans as "levelly human" (the Combahee River Collective, as quoted by Kendi, 2019, p. 187). Coordinating this understanding of racism with literature characterizing multicultural, antiracist, and socially just education, we conceptualize antiracist learning communities in schools as contexts that value and respond to the full humanity of each student, particularly each student of color (e.g., Kendi, 2019). Our partnerships with schools have led us to conceptualize *radical belonging* as a way to center the social and academic needs of students of color in a democratically constituted antiracist learning community (Louie, Berland, Pacheco, Roeker, Grant, under review).

Literature Review

As we partner with a school to develop an antiracist learning community—a community that fosters the radical belonging of each of its students, particularly students of color—we understand that "in the attempt to correct so many generations of bad faith and cruelty, when it is operating not only in the classroom but in society, [we] will meet the most fantastic, the most brutal, and the most determined resistance" (Baldwin, 1963). Resistance to

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antiracism takes the form of deliberate violence, now as it did sixty years ago. It also manifests in the unconscious disruption of antiracist projects, even by those who claim antiracist or equity-oriented projects as their own. For example, Louie (2020) found that teachers actively working to create environments that would support *academic belonging* did so in ways that reproduced ability hierarchies. In this and other examples (e.g., Ladson-Billings, 2014), "determined resistance" came in the form of unconscious ideologies that disrupted teachers' conscious intentions. Despite those intentions, teachers did not have the political and ideological clarity (Bartolomé, 1994) to enact antiracist goals, nor were they supported to develop such clarity. In this study, we explore how systemic racism continued to pop-up and "resist" the process of working towards an antiracist learning community throughout the discourse of our partnership.

Methods and Context

This study stems from a partnership between our university and Eastwood Elementary, located in a mid-sized Midwestern city (the names of the school and participants not on the university team are pseudonyms). Eastwood teachers and administrators invited us (pre-pandemic) to support them on their commitment to become an antiracist learning community. Most of Eastwood's students are students of color. The staff is 90% white. We were invited to partner with Eastwood because, despite their efforts towards addressing race-based harm in their school, racism persisted throughout the school: English monolingual students were bullying peers who spoke other languages, Asian American students were being mocked by classmates squinting and stretching their eyes, students with disabilities were being called the R-word, and a white student repeatedly called Black educators the N-word. Moreover, as a Black teacher at the school explained, the school lacked a shared understanding of racism and commitment to antiracism.

Over the course of a year and a half, we met monthly with the school-based leadership team, spent time in classrooms, and facilitated two summer retreats. For the present analysis, we draw on field notes and recordings from the second summer retreat (in 2020) and field notes from debriefing/planning meetings between the University team and Eastwood leadership. The Eastwood principal encouraged all teachers and staff to attend the retreat and invited parents; 21 teachers and staff and four parents participated.

The 2020 retreat ran for 5 days. Our analysis focuses on a topic that emerged repeatedly throughout the retreat, and which stood out to us because of the strong emotions it evoked (for the paper authors as well as other participants) and the ways in which it repeatedly disrupted discussions of other topics. Specifically, our analysis focuses on our discussions about whether our developing antiracist learning community at Eastwood should specifically and exclusively target Black students and families or take a broader lens to the work. Particularly active in these discussions were the principal (Amy, a white woman), the vice principal (Keith, a Black man), the school social worker (Neal, a white man), the district restorative justice coach (Josh, a Black man), the teacher who initiated our partnership (Malik, a Black man), and the mother of an Eastwood student (Che, a Hmong woman). These discussions occurred during debriefing/planning meetings with the Eastwood leadership team as well as during the retreat itself.

Our analysis of the discussions had two phases. In the first phase, we sought to understand the justifications offered by participants for either a) focusing on anti-Blackness or b) defining racism more broadly. To that end, we employed a process of in-vivo coding, constant comparison of coded episodes, and team discussion to identify themes in the justifications for the different perspectives. We present these themes in the findings section. Our second phase was to interpret the themes in terms of how they disrupted or reproduced racist and white supremacist narratives and/or created opportunities for antiracist learning. We offer these interpretations in our discussion section.

We locate ourselves in our analysis as both researchers and co-partners with the Eastwood educators. Not only were all members of this partnership learning together, but each of our contributions to the discussion shaped the shared (or unshared) meanings that were being co-constructed. Our team is racially diverse (including Black, Chicana, Chinese American, and white individuals) and brings different areas of expertise (e.g., learning sciences, and math, science, teacher, and multicultural education) to the work.

Findings

We identify and illustrate each of the themes that emerged in our analysis of participants' (including university team members) justifications for whether the focus of our antiracist school community should be exclusively about the experiences of Black members of the community or more broadly defined, in Table 1.

Table 1

Emergent themes from across participant justifications

Justifications	Themes	Illustrative quotes
For focusing on Black students' and family members' experiences	Theme 1: diluting the mission of our collaboration	Keith (the vice principal) said, "My worry is that if we're not intentional about the work that we're doing, there won't be any change. We're aiming too wide. …"
	Theme 2: Black students experience the most race-based harm	When directly asked whether the partnership should also address the needs of Latinx and Hmong students, Amy (the principal) responded that "...the racism at our school happens more blatantly and disproportionately to Black students and staff."
	Theme 3: white teachers' biases are uniquely anti-Black	Malik (the teacher whose call to action had initially launched the partnership) said, "I think that the teachers at Eastwood feel more comfortable with other races than they do with Black students. They talk about them climbing up the walls…They talk about them like they're animals!"
For taking a broader perspective on antiracism	Theme 4: Latina/o/x and Hmong students experience significant harm at Eastwood	Che (a Hmong mother of an Eastwood student) told the group that she did not feel welcome at Eastwood. She elaborated: "I have to sacrifice my culture to teach my kids to make it in this school. … My kids aren't seeing themselves represented…[The assumption is] since I'm Asian American … I don't really need anything because I'm smart."
	Theme 5: competing for resources distracts from whiteness	Josh argued that " If we focus on one group, that is separating and further marginalizing…Focusing on individual groups causes tension and makes others feel invisible...

Discussion

By publicly acknowledging race-based harm and calling for work to combat it, participants positioned themselves discursively as critically conscious antiracists. However, we argue that the narratives embedded in some of these concerns ultimately reinforce white supremacy. In particular, we see three ways in which the explicit justifications for exclusively focusing on Black students and anti-Black sentiment implicitly align with the maintenance of white supremacy. We believe our Eastwood partners had good intentions, but racism persisted in and through them—a phenomenon that becomes clear when contextualizing and historicizing their justifications within the systems of oppression upon which the United States is built.

- *Erasing Latina/o/x and Hmong students and families*: elevating the experiences of Black students and family members to the exclusion of all others devalued Latina/o/x and Hmong students and their families, dismissing their school experiences as unimportant and ultimately rendering them invisible.
- *Obscuring Black students' full humanity*: emphasizing behavior reduces (anti)racism to externally visible outcomes that can be measured, observed, and compared, rather than nuanced experiences that can be shared, understood, and improved. That is, by making Black students' behavior hyper-visible, participants made students' capacities and needs as learners, knowers, and thinkers invisible.
- *Undermining efforts to build interracial solidarity*: by making it seem as though the school had to make a choice between *either* addressing harm to Black students and families *or* addressing policies and practices steeped in white supremacy more broadly, antiracism was framed as a limited resource for which marginalized individuals must compete.
- *Centering white people*: while engaging white individuals in confronting their internalized racial biases and white privilege is valuable, emphasizing the internalized racism of white educators at Eastwood served to center the thoughts of white people without attending to the experiences of students of color—the very individuals and experiences that motivated our collaboration. Further, focusing on individuals' internal biases does not move to transformation of practice, so it does not have a clear impact on the experiences of the students of color.

In summary, while each individual in our partnership was there to disrupt racism in Eastwood, we see ways in which the discussions in which we engaged unintentionally reinforced white supremacy.

How could the RPP have built a shared understanding and collective commitment?

Members of both the university and Eastwood portions of our partnership experienced one another's positions as racist—as harming students of color—and this racist/non-racist binary that implicitly emerged in our discussions eroded collective trust in the partnership. Indeed, toward the end of the debrief about the first day of the retreat, Keith said: "I've been disheartened by the conversation today. Last summer we were making a lot of progress. I don't think right now there is respect for our ideas … It felt to me like the conversation wasn't a dialogue, [Eastwood] was attacked." And, this was not resolved. At the end of the retreat, the partnership did not have a shared vision for our joint antiracist work. Instead, the contradictory views of the focus of our partnership remained throughout the summer retreat, repeatedly coming up and disrupting other discussions. Learning theories (pick your flavor, they agree on this point!) tells us that deep conceptual change takes time, and willingness to be wrong. We had neither and we now wonder about strategies for resolving such fundamental disagreements hidden by superficially similar discourse but based on very different ideological underpinnings.

One possible strategy for moving forward could have been to collaboratively unpack the different justifications for the exclusive focus on Black students and to co-construct a new vision that brought the implications of the different positions into alignment. Another possibility could have been using Eastwood educators' interest in focusing on Black students to motivate a careful exploration of the cultural wealth (Yosso, 2005) that different Black students and their communities have. The goal of this work would have been to acknowledge the diversity within the label "Black students," and using that nuance to motivate antiracist pedagogical and curricular practices that make space for the diverse ideas, experiences, and cultural practices of Latina/o/x and Hmong Eastwood students as well. Regardless of the specific strategy we took, we would need to focus on building the "politicized trust" (Vakil et al., 2016, p. 199) that could have enabled us to identify ways in which we were using words differently and the implications of those differences.

This analysis returns us to a question Carl Grant (a member of the University team) repeatedly asked throughout our partnership: "Can you create an antiracist school in a racist school system?". While this study does not answer this question, it suggests that time and politicized trust are necessary for taking the first steps of envisioning what that antiracist school community could even look like.

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International Society of the Learning Sciences

Revisiting revoice: An inductive method for capturing revoice in classroom discussions

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Abstract: Within the scholarly field of academically productive classroom dialogue, several elusive, yet rich and potent discourse moves have received special attention. However, their rarity and complexity also poses significant challenges to meeting interrater reliability thresholds, and they are often omitted from quantitative research efforts. We propose a different approach for coding that circumvents these issues, called DECCA. In this presentation, we showcase this methodology by focusing on teacher revoice. We demonstrate how it is possible to deconstruct this complex phenomenon into smaller and simpler elements. We then code each turn in the corpus for the existence or absence of each element (which we term Dialogue Elements, DEs). Adding a post-coding, pre-analysis stage allows us to extract turns which contain the specific combination of DEs relevant for revoice and distinguish it from similar teacher dialogue facilitation moves. Theoretical and practical implications are discussed.

Introduction

In academically productive dialog (APD hereafter), teachers engage their students with open ended, authentic questions or tasks, encourage them to share their ideas and thinking processes, to build on each other's contributions, to (critically) explore alternative viewpoints and to use external knowledge sources to evaluate them (Asterhan & Schwarz, 2016; Howe & Abedin, 2013; Howe & Mercer, 2017; Kim & Wilkinson, 2019). This form of classroom dialogue has been identified as beneficial for learning and scholars of dialogic teaching and learning have identified the foundations and characteristics of classroom talk that promotes student learning and cognitive development (Resnick, Asterhan & Clarke, 2015; 2018).

Expert teacher facilitation has been proven crucial for APD in classrooms (e.g., Pauli & Reuser, 2015; van der Pol, 2010; Webb, 2009) and research has documented how specific dialogue moves can stimulate (or stymie) intellective student engagement. One teacher facilitation move that stands out in terms of the scholarly attention it has received is "revoice" (Michaels & O'Connor, 2015; O'Connor & Michaels, 2019; 1993; 1996). Revoice occurs when a teacher reiterates a particular student contribution in her own words, while acknowledging the student's ownership of the original contribution, elaborating on its content, and finally asking for the same student's confirmation on her inferences. The phenomenology and affordances of revoice have been documented extensively (e.g., Alozie et al., 2009; Ferris, 2014; Fitzgerald & Palincsar, 2019; Glenn et al., 1999; Hmelo-Silver & Barrows, 2006; Kwon et al., 2008). Yet, despite this attention in conceptual, descriptive, and qualitative research, revoice has been largely absent from quantitative research efforts on APD.

A possible reason for this absence is that revoice is a collateral victim of common top-down coding practices, while adhering to strict standards of scientific measurement. Quantitative research on dialogue requires the systematic categorization of selected characteristics, that is: coding (Hennessy et al., 2020; Shaffer & Ruis, 2020). Yet, when attempting to capture a phenomenon such as revoice with a standalone, dedicated coding category, coders encounter two challenges: First, "true" revoice is not a common speech event in classroom discourse (Enyedy et al., 2008; Inan, 2014). When a particular feature is rare, reliability thresholds for the coding category that intends to capture it cannot be met. Second, revoice is a high-inference construct that is a particular composite of different speech moves and can serve multiple purposes. The more multi-faceted the phenomenon is, the less likely it is for the judges to agree.

Some tools give only ambiguous information on this front (see Thurlings & den Brok's 2017 review) whereas others deal with rare and nuanced dialogic constructs by either omitting them from analysis, or by clustering them together in more inclusive categories (Chiu, 2015). Either way, the intended aim of providing a comprehensive and sensitive account of classroom dialogue, is sacrificed at the altar of interrater reliability, and analysis is limited to common and/or coarser dialogue features.

Instead of searching for higher-order discourse constructs (such as revoice) in a top-down manner, we suggest adopting a bottom-up approach according to which we first code for a small and reliable set of basic dialogue elements (DEs). The DEs were systematically identified by comparing seven renowned and well used coding schemes for quality of classroom discourse. This is then followed by a post-coding phase, in which we search for co-occurrences of particular combinations of these elements that represent higher order, compound discourse constructs (such as revoice). In a recent paper (Authors, under review), we presented the reliability and validity of this approach which we call Dialogue Elements to Compound Constructs Approach (DECCA).

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In the current work, we explore whether this small but (hopefully) pivotal change in common coding procedures will enable the systematic identification of instances of revoicing in classroom discourse, while still maintaining scientific rigor in its measurement, and thus its inclusion in quantitative research. This approach to coding has an added benefit, since it also captures approximations of revoice, that can be of particular interest to researchers looking into emerging processes and implementation efforts of new practices. Whereas in traditional coding tools the turns that fail to meet the full requisite list of the full construct are left uncoded.

Method

Data was collected from a pedagogical development effort aiming to encourage APD in upper elementary Hebrew Language Arts lessons. Over the course of 1.5 school years (2018-March 2020, start of the Covid 19 Pandemic) 18 classroom discussion recordings were collected from seven teachers (4 teachers experienced in APD and 3 teachers who were novices). Each transcript involved the teacher and her students (20 - 34 per class) and was collected by a research team member. Students without active parental consent were seated outside of the scope of the camera and their answers were not transcribed. Four lessons were collected from the veteran teachers in the first year of the project (4) and additional two lessons from each of the seven teachers (14) were collected in the second year (18 lessons total, approx. 45 min each). The lessons, conducted in whole classroom format, were video- and audio taped and then, transcribed (parsing on level of speech turn). Each dialogue protocol was then coded with DECCA (nine DE coding categories in all, each turn coded for the existence of one or more of the 9).

Revoice deconstructed

The facilitation move of Revoice can be deconstructed into several components (O'Connor & Michaels, 1993). The teacher gives the original speaker ownership of the content. (in DECCA, the DE Refer). Another component is 'retroactive contextualization' (Lemke, 1990): A combination of repeating the student's contribution (DE Repetition), while elaborating on its meaning (DE Elaborate). Finally, the teacher gives the student a chance to affirm or deny her inferences, captured with DEs Invitation and Evaluation. Interrater reliability for these five DEs ranges from $\kappa = 0.7$ to $\kappa = 0.85$. Then, we extracted only turns with specific combinations of these five DECCA elements. Finally, we compared those turns to search for similarities and differences among them and common constructs from the APD literature.

Results

Teacher revoicing

Results confirmed the rarity of Revoice moves in classroom discourse: Out of the total of 7,405 conversational turns coded, only nine received all five DEs that make up Revoice. Only seven of these were identified as instances of "true" Revoice, all occurring in three of the four veteran teachers' lessons.

Due to shortage of space, we will only discuss one example in depth. The students and teacher had just read the story 'Fly, eagle, fly!' a tale about a farmer who finds an eagle nestling and raises it with the rest of his chickens, on the ground, until a friend comes and convinces the eagle to fly. The question under discussion was about the sort of change that occurred in the story. The student speaking in this example is Nicolay (all names were changed to protect the identity of our participants), for whom Hebrew is the second language, his mother tongue is Russian.

> Nicolay: In the beginning the eagle. Then a chicken. Then an eagle again.
> Teacher (Meital): So, what are you trying to say?
> Nicolay: He (the eagle) changed the behavior in his life.
> Teacher (Meital): He tried to change a behavior. Great, Nicolay! So, I'm writing [writes on the whiteboard] 'change of behavior'. The farmer, Nicolay says (to the class), and tell me if I understood you (to Nicolay), tried to change the eagle and turn him into a (chicken).

In the fourth and final turn in the transcript the teacher's utterance begins with a word-by-word repetition of the student's answer, therefore, the DE Repetition will be marked with 1. Next, the coders indicate the DE Refer here because the teacher refers the idea to Nicolay by using his name (and writing it on the board next to his contribution). The DE Evaluation is present also as a standalone since the teacher gives Nicolay explicit positive evaluation (that's great!) as well as implicit positive evaluation (by putting his response up on the whiteboard).

Throughout her response, and by inserting few key words into her repetition, the teacher manages to elaborate and elevate Nicolay's answer. For example, she adds the word 'tries' before the phrase 'changed the behavior' that Nicolay used, thereby stressing the rigorous and not necessarily successful process this entails.

She also adds the words 'The farmer' to clarify Nicolay's utterance (instead of 'he') and again repeats the word 'tries', this time to describe the actions of the farmer character. Finally, she invites Nicolay's evaluation on her interpretation, asking him to correct her if he does not agree with her interpretation. Therefore, the coders will mark 1 for the Invitation DE and Evaluation DE. To sum, this turn of speech by the teacher contains a combination of five specific building blocks that we have pre-defined as crucial to the revoice construct.

Reoccurring combinations, signs of emerging practice

Using DECCA enabled the distinction among actual Revoice, and cases of Revoice approximations. For example, the revoice move starts with the teacher noticing and repeating a student contribution (O'Connor & Michaels, 2019) and then broadcasting it to the rest of the class (Michaels & O'Connor, 1996). When it stops there, it is a simple Repeat move. Another recurring example is Reformulate, a combination of the DEs 'elaboration' and 'repetition'. The difference with Repetition is that the teacher in addition elevates the student's response (for example, by highlighting its contribution to the topic, adding exact and discipline specific terms and concepts to it, and so on). Another, but less common, compound construct is Reframe, formed by the combination of the DEs Elaboration, Refer and Repetition. The main difference from Reformulate is that in this construct, the teacher explicitly credits the idea to the original speaker. Yet, it is not a full Revoice, as the teacher does not ask the student to indicate whether this is what he or she meant.

Teacher Repetition. The excerpt is taken from the first lesson of Meital the teacher, and her classroom discussion of the story 'fly eagle fly', introduced earlier.

> Teacher (Meital): So what does that mean? What are you actually telling us?
> Nitzan: (I'm saying) that it's pretty hard to adjust to a different environment.
> Teacher (Meital): It is hard to adjust to a new environment.

Other than changing the word 'different' to the word 'new', the teacher repeats her student's contribution word by word.

Teacher Reformulating. Students and teachers discussed how they felt while reading another story, 'The king who did not know how to cry', and shared things they found interesting or important. This story tells about a good king who never cried because his life is so good he never had a reason to be sad or stressed. His advisors to help him cry because it is his only wish. Yet only as an old man when he sees a couple with a young child and cries tears of happiness which fill a whole lake.

> Ronen: What was pretty (interesting) is that the small counselor tried to kill the doctor, but the king did not agree to (do) that.
> Teacher (Liati): The king did not agree. They said (in the story) that he was very good, and he did not agree to give out punishments.

In the example, the teacher performs a reformulating move, by adding reasoning and thus modeling justification practices.

Teacher Reframing. The example shown here was taken from a lesson discussing the story 'Generous deed'. In this story, four students bully a handicapped boy, Carosi, during recess time, and in his fury, he throws an ink bottle at them, but misses and hits the teacher who just walked in, instead. The teacher investigates who threw the bottle, and another student, Garone, takes the blame so Carosi will not be punished. The teacher immediately knows Garone is not the culprit, after Garone whispers something in his ear, the teacher forgives the bullies.

> Revital: They told him sorry and he forgave and that was very touching (because) he could have said no for what they did to him.
> Teacher (Dalit): You understood that the child forgave (them) and that was touching to you that this was the end of the story.

By applying the reframing move the teacher is creating an alignment of Revital's contribution with the way she interpreted the text. The teacher manages to perform this affirmative move, despite the mistake in Revital's understanding of the narrative, as the bullies never apologized to Carosi in the story, and did not ask his forgiveness, the teacher was the one who forgave them.

Discussion

This paper uses the construct of revoice to showcase how a slightly altered coding procedure paves way to *both* keep the inter-rater reliability indices at acceptable levels *and* still be able to capture compound and less frequent

dialogue moves. Moreover, using the same DEs we have been able to distinguish revoice from close approximations moves, closely related yet qualitatively different teacher moves (Repeat, Reformulate, Reframe). For the sake of simplicity, this paper has only focused on the 5 dialogue elements that in combination create the compound construct of Revoice. DECCA currently includes only nine DEs yet is able to distinguish among 52 qualitatively different coding categories, taken from renowned, existing coding frameworks.

One challenge that should be further explored in future research is the finding that out of the nine cases that were deductively identified with DECCA as "Revoice", in two of these, a teacher had acknowledged the student's ownership of the repeated content, but she then evaluated it herself (instead of inviting the student's evaluation) and she did not elaborate on it but, instead, invited the original speaker to do so. Although this is indeed a compound and potentially valuable teacher facilitation move, it is not a classic instance of Revoice, at least not as described in the literature. Future research on larger data sets will show whether these instances were particular to this study's setting, and if not, whether these subtle differences will prove to be important vis-a-vis their impact on student learning and other correlates.

In any case, we believe that the advantages of the DECCA framework outweigh its limitations and hope it will prove to be an important first step toward creating a bridge between the richness and validity afforded in qualitative research methods, and consistency and reliability offered by quantitative research methods.

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Design of personalized instruction using learner data

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Abstract: With the development of advanced technologies, teachers can overcome the limitations of traditional teaching and learning practices by giving personalized instruction. Although personalized instruction can be enhanced with online dashboards showing learning progress and achievements, teachers should develop competencies in how to use the dashboards to design personalized instruction. This study explored how teachers (n = 20) designed personalized instruction using learner data. The think-aloud method is used to explore how teachers create a lesson plan using learner data such as prior knowledge, learning motivation, participation, and so forth. This study found that in-depth learner diagnosis and repetitive design activities play crucial roles in personalized instructional design. Furthermore, the instructional design process had a significant effect on the design outputs and lesson plans. This study has significant implications for teacher education, revealing challenges that teachers encounter in designing personalized instruction with learner data.

Introduction

With the development of information and communications technology, data on learner characteristics, the learning process, and results are collected and analyzed quickly, which creates an environment for designing personalized instruction. Personalized instruction refers to a class that provides an optimized learning experience by tailoring learning activities and resources to the characteristics and needs of individual learners or groups of learners. Previous studies have reported that personalized instruction has a positive effect on learners' academic achievements (Smale-Jacobes et al., 2019; Tomlinson et al., 2003) and makes learning more attractive to learners (Subban, 2006). It was also reported that it could effectively support the learning of underachievers who have been excluded from traditional instruction (Patrick et al., 2013).

However, providing teachers with learner data does not make them better at designing personalized instruction. (Lai & Schildkamp, 2013). The reasons why teachers might avoid using given data include workload, ethical issues, lack of competency, and difficulties in finding meaningful information from the data. To effectively support personalized instructional design using learner data, it is necessary to deeply understand how teachers use data for instructional design. In this study, we explore the personalized instructional design process using learner data by applying the think-aloud method and examine the influence of the process on the personalized instructional design output (i.e., lesson plans). The research questions are:

First, how do teachers design personalized instruction using learner data?

Second, how does the instructional design using learner's data influence the quality of lesson plans?

Personalized instructional design using learner data

It is important to understand individual learners' characteristics and their needs in order to design personalized instruction more effectively. The personalized instructional design uses the learner's data to accurately diagnose the educational needs of learners. The starting point for learner diagnosis is generating questions in order to answer with data, such as whether the students are well-understood and whether there are students who have not completed learning activities (Wise & Jung, 2019). Next, it is necessary to identify the data related to the questions and to understand the structure and content of the data (Mandinach & Gummer, 2016). The final step for diagnosis is interpreting the data. The process of finding meaning in data is a process of discovering educational value by understanding data in an integrated way and connecting it with context (Herodotou et al., 2017).

Diagnostic results from learner data can be used to design activities for the entire class, specific learner clusters, and individual learners. First, teachers can design the whole class activity by modifying the contents and tasks of the textbook according to the characteristics of the entire class. Next, the activity for a specific group of learners can be specifically designed for those whose characteristics are very low or high and who are diagnosed as requiring differentiated treatment. Wise and Jung (2019) referred to this as "scaffolding" for the target cluster. Finally, learning activities or instructional strategies can be designed for individual learners by utilizing adaptive digital resources (Pane et al., 2015; Patrick et al., 2013). This strategy will allow individual learners to learn along a personalized learning path (Pane et al., 2015; Patrick et al., 2013).

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Research methods

Participants

A total of 20 elementary school teachers (17 females, 3 males) participated in the study. They had worked for over five years and were interested in using data and personalized instruction. The average teaching experience of participants was 9.6 years (SD = 4.37); three teachers (15%) had a master's degree, and 15 teachers (75%) had education and research experiences related to data use or personalized instruction.

Research process

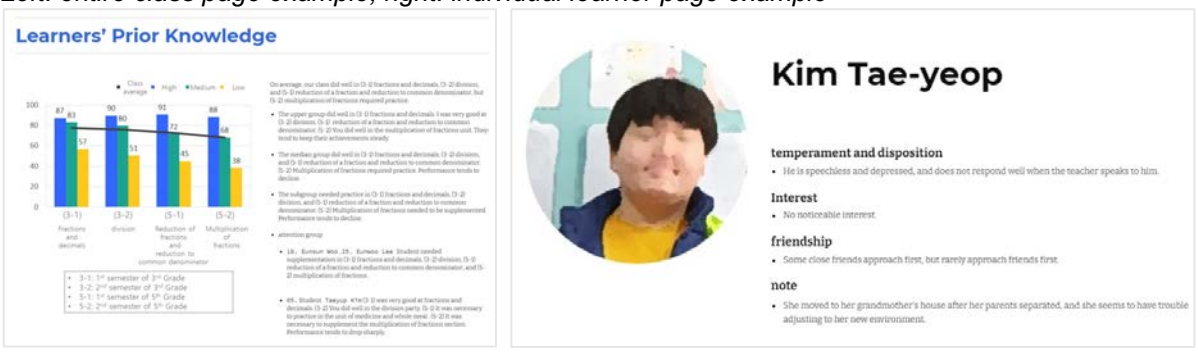
To explore how teachers use learner data to design personalized instruction, the think-aloud method was used in a laboratory context. First, participants practiced the think-aloud method and the research tools. Second, participants were asked to design a personalized instruction session using learner data for 60 minutes and write a lesson plan. Last, an interview was conducted to investigate their perceptions of the instructional design process and outputs.

Data collection

This study collected data using the video conference tool, Zoom, because of the COVID-19 pandemic. All tasks were performed on an online webpage, and the whole process was recorded. Participants were asked to create a lesson plan by designing a personalized instruction that teaches "the division of fractions" in a 6th grade math class using the given learner data and considering the design context (e.g., school characteristics, classroom environment). Participants carried out the think-aloud method for 60 minutes while designing the instruction. For personalized instructional design, the learner data, including learner characteristics, prior knowledge level, mathematics learning motivation, comprehension, participation, and learner cluster information, were provided to the participants. The learner data were presented in raw data, graph, and text formats throughout the class page and individual learner pages (See Figure 1). The goal of designing a lesson that reflects the characteristics and needs of the learner was also presented, along with the context. Furthermore, we collected the lesson plans written by participants. Teachers were asked to fill out a lesson plan form that could describe the lesson's objectives and instructional procedures, and they could modify the form if necessary. They were asked about what types of learner data were mainly referenced in the interview, what was considered in order to design a personalized instruction, and whether there were any difficulties in the design process.

Figure 1

Left: entire class page example, right: individual learner page example



Data analysis

A total of 1,056 analysis units were generated by segmenting the video of the instructional design process video into 1-minute increments. The video was coded according to the coding scheme: (1) learner diagnosis; (2) instructional design (personalized design, traditional design, monitoring and revision); and (3) searching for information related to the lesson. When it was difficult to code with video, interview data was used to supplement it. The inter-rater reliability (Cohen's Kappa) ranged from 0.80 to 0.99. We calculated the ratio of time for each category of the coding scheme and then used it for statistical analysis.

The instructional design outputs were evaluated with a rubric developed based on previous research (Shin, 2021). To understand and evaluate the lesson plan accurately, we conducted an interview with a teacher. The

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rubric consisted of (1) personalized learning plans, (2) competency-based learning, (3) continuous assessment, (4) learner-directed activities, and (5) using technologies for personalization. Using the rubric, two researchers independently evaluated the lesson plans, scoring 1 to 3 points for each category. The possible total score ranged from 1 to 3. The inter-rater reliability (Cohen's Kappa) ranged from 0.88 to 0.95.

To analyze the process of instructional design, we conducted a descriptive statistical analysis and a chronologically ordered representations of discourse and tool-related activity (CORDTRA) analysis. Two researchers classified the teachers' design patterns into two types based on learner diagnosis-instructional design activity. Furthermore, an independent sample t-test was performed to compare the differences between process types. An independent sample t-test was conducted to check whether there was a significant difference in the quality of design outputs between process types.

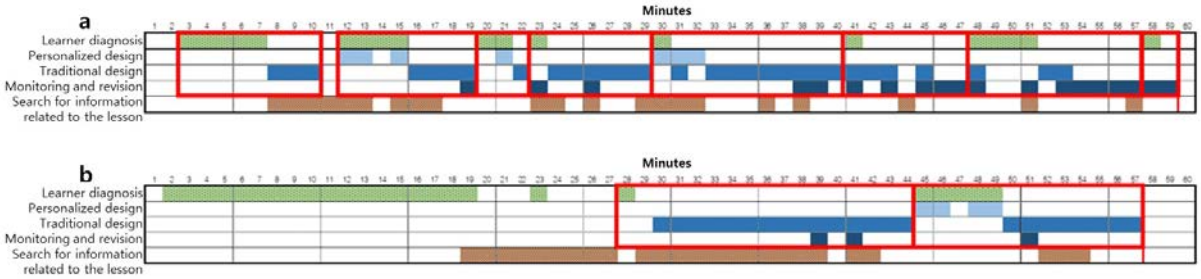
Results

The process of personalized instructional design using learner data

The learner diagnosis activity occurred for 31.54% (*SD* = 11.58%) of the total design time on average among the personalized instructional design activities using learner data. Instructional design activities accounted for 55.91% (*SD* = 16.26%) of design time on average. Among the instructional design activities, the most frequent activity was the traditional design activity (*M* = 59.37%, *SD* = 12.27%)—followed by the personalized design activity (*M* = 17.07%, *SD* = 10.73%) and the monitoring and revision activity (*M* = 9.49%, *SD* = 8.36%). The search for information related to the lesson activity took up 31.59% (*SD* = 13.63%) of the total design time on average.

Using the CORDTRA diagram, learner diagnosis and instructional design patterns were explored to derive design process types (See Figure 2). According to how often learner diagnosis and instructional design patterns were observed, the process types of personalized instructional design using learner data were divided into two types. The first type was the iterative design type. In this type, learner diagnosis and instructional design patterns occurred repeatedly throughout the design process. The second type was the linear design type, in which the pattern of repeating learner diagnosis and instructional design seldom occurred. This pattern was found less in the linear type (*M* = 2.10, *SD* = .99) and in the iterative design type (*M* = 6.20, *SD* = 1.87).

Figure 2
a. iterative design type, b. linear design type



An independent sample t-test was carried out to check whether there is a difference in the ratio of design activities according to the process types. First, a significant difference was found between the iterative design and the linear design type in the learner diagnosis activity ($t(18) = 2.30$, $p = .034$). Teachers of the iterative design type (*M* = 36.91%, *SD* = 9.83%) spent more time diagnosing learners than the teachers of the linear design type (*M* = 26.16%, *SD* = 11.06%). Next, a significant difference was found in the personalized design activities, which is a sub-activity of the instructional design activity (t (15.56) = 3.19, $p = .006$). The iterative design type (*M* = 23.36%, *SD* = 10.41%) had a higher ratio of personalized design activity than the linear design type (*M* = 10.79%, *SD* = 6.84%). No statistically significant difference was found in other design activities.

The influence of instructional design process on the quality of lesson plans

An independent sample t-test was conducted to investigate whether there was a difference in the quality of the lesson plan between the iterative design type and the linear design type. Consequently, there was a significant difference according to the process types (t (18) = 2.72, $p = .014$). The lesson plans designed by teachers of the iterative design type (*M* = 13.10, *SD* = 2.64) were qualitatively better than those designed by teachers of the linear design type (*M* = 10.00, *SD* = 2.45).

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Discussion

This study explored the process of personalized instructional design using learner data. It was desirable to repeatedly conduct learner diagnosis and instructional design in the design process for personalized instruction. The teachers of the iterative design type created higher quality lesson plans than those of the linear design type. The former tended to interpret more learner data and design more personalized activities than the latter. This means that the checking and interpretation of learner data must be continued in the instructional design process to develop a personalized lesson plan.

Even if teachers use data to diagnose learners well, they will not be able to successfully design personalized instruction without appropriate educational support. Therefore, it means that abilities beyond data literacy are required for teachers (Mandinach & Gummer, 2015). However, many teachers do not adapt instructions according to the learners' abilities and have difficulties in designing personalized instructions (Al-Lawati & Hunsaker 2007; Latz et al., 2009); time and experience do not naturally increase the ability to design personalized instruction (Tomlinson, 1995). It is necessary to support teachers so that the learner's diagnosis results can be well-connected to the personalized instructional design. For example, prompts can be inserted in the learning analytics-based dashboard so that teachers can interpret data well in considering pedagogy or context, or data requiring attention for interpretation can be displayed with data from various sources. In future research, it is necessary to specifically develop a tool or instructional model that supports the teacher's personalized instructional design using learner data.

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Multilevel Connected Teacher Learning for STEM curriculum innovation

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Abstract: This study investigates how differences in teachers' learning outcomes may be related to the Architecture for Learning (AfL) at multiple levels of the education ecosystem available to the teachers as well as their own individual characteristics. The MultiLevel MultiScale framework was adopted for the analysis of the AfL available to ten teachers in five schools participating in a University-School Partnership programme targeting pedagogical and curriculum innovation in STEM. The study found that the AfL available to teachers varies across schools and within the same school in terms of exposure intensity and their foci of interaction. Teachers may also have different learning foci depending on their experiences and types of leadership roles. The findings have implications for customization of teacher learning for teachers at different career stages and in different school settings.

Introduction

Evolving social demands on education calls for changes in educational practice, often in the form of curriculum or pedagogical innovation. This in turn puts pressure on teacher professional learning. Yet, we notice there are variations in teachers' learning outcomes even when they have engaged in the same kind of professional learning communities. Evidence shows that within the same project network, there can be variations in terms of teacher learning across schools (Horn & Kane, 2015) as well as across teachers within the same school (Horn, 2005; Horn & Little, 2010). These observations can be explained by an ecological perspective on learning—that teacher learning depends on their intentional learning orientation in relation to their personal characteristics, and their interactions with their professional context (Opfer and Pedder, 2011). Affordances that support teacher learning within their professional context are associated with the architectures for learning (AfL) (Law, et al., 2015; Stein & Coburn, 2008; Wenger, 1998) available to them. In this study, we investigate how different AfL could influence teachers' learning outcomes, as well as whether and how these outcomes depend on teachers' personal characteristics through a set of comparative case studies of teachers taking part in a design-based innovation network (Fishman, et al., 2013) of schools in Hong Kong focusing on the promotion of self-directed learning pedagogy and curriculum integration in STEM related subjects. Two main research questions are explored:

(1) What AfL at network, school and teacher levels were available to different teachers within the same innovation network within their respective professional contexts, which may vary across schools, as well as across roles within the same school?
(2) Whether and how the AfL available to teachers could affect their learning outcomes?

Conceptual framework

This study adopts the MultiLevel MultiScale (MLMS) model (Law, et al., 2015) as an analytical framework. This model posits that within an education ecosystem, learning takes place at student, teacher, school, network, and system levels (Law, et al., 2016). Such learning is influenced by interactions across these levels (thus multilevel), as well as interactions across entities within the same level that may or may not belong to the same organizational unit (e.g., interactions among teachers in different schools, thus the term multiscale to capture the different spheres of influence). This model can guide the examination of learning conditions and learning outcomes at multiple levels in the context of educational innovations. To identify the conditions for learning at different levels of the ecosystem, we adopt the construct of architectures for learning (AfL) (Stein & Coburn, 2008; Wenger, 1998). According to Law, et al. (2015), AfL comprises four key components: (a) organizational structures (e.g., teacher design teams), (b) interaction mechanisms (e.g. co-teaching), (c) reification artifacts such as guidelines and resources, and (d) technology to facilitate actions and interactions within the ecosystem. Guided by the AfL construct, the MLMS model examines learning conditions at different levels by looking at organizational structures of learning environments and differentiating learning interaction mechanisms within and across organizational units (e.g. school as an organizational unit) (Law, et al., 2015). The MLMS model regards reification artifacts and technology as boundary objects (Stein & Coburn, 2008) for embodying ideas and shaping focus in negotiations (Wenger, 1998) travelling across multiple communities of practice.

Research Design

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Research context

This study adopted multiple case studies (Yin, 2003) as its methodological approach, with an individual teacher as a unit of analysis. The research context was in the second phase of a series of funded university-school partnership projects formulated as design-based implementation research (Fishman, et al., 2013). The projects aimed at promoting self-directed learning in Science education in the first phase (2014-2017) and STEM education in the second (2017-2019), which was in response to the STEM education initiative in Hong Kong (EDB, 2016a). In the second phase, the network consisted of experienced and novice teachers from existing and newly joined schools in the network. Schools were expected to design and implement two school-based STEM curriculum units in the first year. The network shared two key design principles for STEM curriculum innovation: (i) self-directed learning (SDL) (Hew, et al., 2016; Knowles, 1975) as the pedagogy of choice, and (ii) interdisciplinary integration as the preferred model of school-based STEM curriculum design. Interdisciplinary STEM units should contain intended learning outcomes related to learning elements from STEM related subjects (EDB, 2016a). Scientific investigation and engineering design process were introduced to teachers as forms of disciplinary practice that teachers could use to model their design of STEM curriculum units around authentic problems/scenarios that provide SDL learning experiences involving different disciplinary elements for learners to engage in.

Sampling, Data source and analysis

This study focused on teacher learning in the first year of phase 2 in the STEM innovation project series. Of the 32 participating schools in that year, we selected 10 teachers from the five schools for which the first author of this paper served as the project consultant. The backgrounds of these teachers are shown in Table 1.

The analysis was guided by the four key components of AfL at different levels. Transcriptions of year-end principal and teacher interviews were coded based on the AfL framework. The investigation of the AfL components for individuals and their practices were supplemented and triangulated by other data sources, including audio records of co-planning meetings, transcriptions of debriefing meetings after lesson observations, teachers' project participation data, and individual school reports. These records facilitated the examination of the focus of interactions in different kinds of AfL experienced by individual teachers. Advances in teachers' practices were analyzed based on the SDL processes (Hew, et al., 2016) and the interdisciplinary elements in STEM (EDB, 2016a). Checklist matrices and contrast tables (Miles, et al., 2020) were constructed respectively for exploring and comparing the teachers' practices as well as the key AfL subcomponents they experienced.

Table 1

Case schools and teachers selected from the second phase of the partnership project

Sector	Secondary school sector				Primary school sector					
Schools	A		D		X		Y		Z	
Teachers	A1	A2	D1	D2	X1	X2	Y1	Y2	Z1	Z2
Teacher's network experience	2	1	2	0	1	0	2	0	0	0

Findings and discussion

Different sets of architectures for learning (AfL) among teachers

To answer the first question about the AfL experienced by individual teachers, we identified and summarized in Table 2 key AfL subcomponents under each of the four AfL components at the network, school and teacher levels experienced by each teacher. The results show that even teacher implementers working within the same school experienced different distribution profiles of AfL. Teachers' participation at the network level interaction mechanisms such as *workshops* and *open class* differed due to school level implementation strategies. There were also differences in AfL sub-components in relation to organizational structures at the school level such as the *laboratory technical team* and *e-learning team*. Only some teachers (A1, D1, X1 and Y1) had access to interaction mechanisms (discussing or reporting) to inform the school administration or the principal about the project progress because of their leadership roles in their schools. There were other self-initiated interaction mechanisms such as *co-teaching* arrangement in school A and emerging *internal COLO ((*COplanning, Lesson Observation & debriefing) *cycles* for improving STEM lessons among teachers in schools A, X and Z. Wenger's (1998) duality of the designed and emergent learning architectures was observed. Such duality can exist when learners are given autonomy to co-design their learning environments.

Variations among teachers because of different sets of learning foci

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For the second research question, the study found that the AfL available to teachers can affect their learning by shaping their contextual learning focus. Three major types of foci were classified with reference to working foci in the school environment for evaluating school performance (EDB, 2016b): (i) learning and teaching (L&T); (ii) management and organization (M&O); and (iii) technical issues (Tech). As shown in Table 2, all teachers were exposed to AfL with an L&T focus. However, only teachers with certain types of leadership roles, such as being a project coordinator or an e-learning team coordinator, would be involved in AfL with contextual learning focus on M&O. Different profiles of AfL with different contextual learning foci explains why even teachers in the same school could demonstrate different intentional learning orientations. For example, A1, with an additional focus on M&O, could orient his learning also at the leadership level, thinking about how to create conditions for teacher learning such as co-teaching and lesson study as well as scaling up cross-subject collaboration, while A2 was only concerned with his own improvement of pedagogical innovation and new understanding of STEM education in the post interview. Similar patterns were found in the comparison between X1 and X2, and between D1 and D2.

Table 2

Architecture for learning and contextual foci of interactions experienced by teachers

Level	AfL subcomponents	A1	A2	D1	D2	X1	X2	Y1	Y2	Z1	Z2
Network level *cross unit*	*-Monthly PD workshops*	58%	25%	17%	8%	83%	75%	58%	75%	33%	58%
	-Other Open classroom		L&T	L&T		L&T			L&T		L&T
School level *within unit/ cross unit*	Lab Technical team	Tech	Tech	Tech	Tech						
	E-learning team	M&O	Tech					Tech	Tech	Tech	Tech
	Cross-curricular team			M&O				M&O			
	School admin/principal	M&O		M&O		M&O		M&O			
Teacher level *within unit/ cross unit*	**Project team**	**Cross-subject project team**						**Single-subject project team**			
	-Organizing the partnership with the uni	M&O		M&O		M&O					
	-Team monitoring	M&O		M&O		M&O		M&O			
	-First COLO cycle	L&T	L&T	L&T		L&T	L&T	L&T	L&T	L&T	L&T
	-Second COLO cycle	L&T	L&T	L&T	L&T	L&T		L&T	L&T	L&T	L&T
	-Own Open classroom	L&T	L&T	L&T	L&T	L&T		L&T	L&T	L&T	L&T
	-LO for non-project staff	L&T	L&T	L&T	L&T	L&T	L&T			L&T	L&T
	-Internal COLO cycle	L&T	L&T			L&T	L&T			L&T	L&T
	-Co-teaching	L&T	L&T								
	e-learning platform	L&T	L&T	L&T	L&T	L&T	L&T	L&T	L&T	L&T	L&T
	LDS					L&T	L&T	L&T	L&T		

Note: L&T= Learning & Teaching; M&O = Management & Organization; Tech = Technical issues; CO = Coplan; LO= Lesson Observation; COLO= COplanning, Lesson Observation & debriefing

Variations among teachers because of innovation experience and their roles

Individual characteristics like types of leadership roles and prior innovation experience affect learning orientation (Opfer & Pedder, 2011) as well as the impact of AfL on teacher learning outcomes. As mentioned, experienced teachers, A1, D1 and X1, with leadership roles in a cross-subject project team had to take on additional M&O related learning foci. These teachers were able to demonstrate their learning outcomes in facilitating professional development of their colleagues and sustaining cross-subject collaboration. Another experienced teacher Y1 was with M&O related foci, but in a single-subject project team and not given any leadership role for steering cross-subject collaboration in the project. She showed her learning outcomes mainly in terms of designing integrated STEM curriculum units instead. Compared with experienced project teachers, the impact of contextual learning focus of L&T on novice teachers' learning outcomes is more obvious in terms of SDL pedagogical innovation. Particularly, learning trajectories of novice teachers from new network schools were more salient in terms of SDL pedagogical innovation. The two novice teachers, Z1 and Z2, from a new network school demonstrated the biggest changes in their classroom practices. In the first COLO cycle, Z1, Z2 and their other team members learned how

not to follow the canned approach in textbooks and let students plan for their investigation as informed by the operational framework of the SDL processes. However, in this first cycle, school Z teachers did not give opportunities for students to revise their methods of investigation. Students were given to accepting a pre-set conclusion irrespective of their results. Compared with the other four schools with experienced teachers, the SDL opportunity provided to students and the extent of STEM integration in school Z was the least. In the second cycle, they improved the SDL opportunities and STEM integration for students. They brought in practices of engineering design process and let students plan, create, evaluate, analyze data, and revise their prototypes. Students were able to exercise more self-direction with greater use of e-learning platform. The *inexperience* of Z1 and Z2 amplified the impact of the L&T focused AfL on their improvement of SDL practices.

Conclusion and implications

This study shows that AfL available to different teachers within the same innovation network may vary across schools, as well as across roles within the same school. The AfL available to teachers can affect teacher learning outcomes by shaping intentional learning orientations. The influence of AfL on learning outcomes is complicated by individual characteristics like types of leadership roles and innovation experience. This could have implications for personalized designs for teacher learning in innovation networks customized for experienced and novice teachers in different school contexts to advance the sustainability and scalability of curriculum and pedagogical innovations. The present study is limited in scope not only in terms of the number of teachers and schools involved, but also that it is limited to the study of only one innovation network with a focus on STEM innovation. Further research is needed to develop more nuanced understanding of how teacher learning is influenced by the interactions between AfL at different levels and the teachers' individual characteristics.

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Mathematics Teachers' Interpretations of Students' Perceptions of the Classroom Learning Environment: Opportunities for Inquiry and Insight into Pedagogical Commitments

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Abstract: This paper reports on a study of nine middle-grades mathematics teachers' interpretations of a novel representation of practice that featured students' perceptions of the classroom learning environment for a given lesson. Based on a sequential qualitative analysis of interview data, we found that teachers' interpretations of students' perceptions (1) tended to open opportunities for future inquiry about instructional decisions and (2) provided insight into teachers' current pedagogical commitments, specifically their current instructional visions and views of the students' capabilities. Implications for professional learning are discussed.

Introduction

In ambitious and equitable mathematics teaching, instructional decisions are centrally shaped by students' current understandings and experiences in the classroom (Franke et al., 2007). Representations of practice, such as student work samples, video-records of instruction, and narratives about teaching play a critical role in providing teachers with windows into students' current reasoning, and in prompting analysis of the relationship between instructional decisions and the understandings students develop (e.g., Ball & Cohen, 1999; Kazemi & Franke, 2004). In this study, we explore teachers' interpretations of a novel representation of practice intended to support generative inquiry: brief, student-facing surveys that elicit *students' perceptions of key aspects of the mathematics classroom learning environment* that research suggests matter for students' learning and mathematical identities (Jackson et al. in press). Specifically, we examine how nine middle-grades mathematics teachers' interpretations of their students' perceptions opened, and, in some cases, closed opportunities for future inquiry into instruction (Little, 2002). Furthermore, we explore how a focus on students' perceptions of the classroom learning environment provides insight into teachers' pedagogical commitments (Erickson, 2011), which is especially valuable for professional development design and facilitation.

Theoretical concepts

Although constructing and investigating representations of practice appears to be necessary to engaging in analysis of teaching, doing so does not guarantee generative inquiry (Horn, 2020). An important distinction concerns whether teachers' interpretations open or close teachers' opportunities for future inquiry about instructional decisions (Little, 2002). *Openings* are characterized by teachers posing questions (van Es & Sherin, 2021) or offering tentative or multiple, possibly "conflicting" explanations of an observation's meaning (Mason, 2011). Conversely, *closings* are characterized by "explaining away" evidence that could have otherwise been used to raise important questions (p. 40). Once an opening has been established, another critical distinction concerns whether and how teachers investigate relationships among the three vertices of the instructional triangle: teacher, students, and content (e.g., mathematics). "The extent to which [teachers consider] issues of teaching, students, and mathematics as independent or interdependent aspects of instruction" distinguishes the potential of teacher inquiry to support the development of ambitious teaching (Horn, 2020, p. 329).

While the surveys were designed to enable inquiry into instruction, how they function is an empirical question. This is because making sense of a representation of practice is necessarily an interpretive act (Coburn & Turner, 2012). On the basis of existing literature, we conjectured that mathematics teachers' *pedagogical commitments* (Erickson, 2011), including their *instructional visions* (Munter et al., 2015) and their *perspectives on their students' current capabilities* (e.g., Horn, 2007; Jackson et al., 2017), would shape how they interpreted students' perceptions of the classroom learning environment.

Methods

This study was guided by the following research questions: (1) How, if at all, do teachers' interpretations of students' perceptions of the classroom learning environment open or close possibilities for inquiry? (2) How do

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teachers' interpretations provide insight into their current pedagogical commitments?

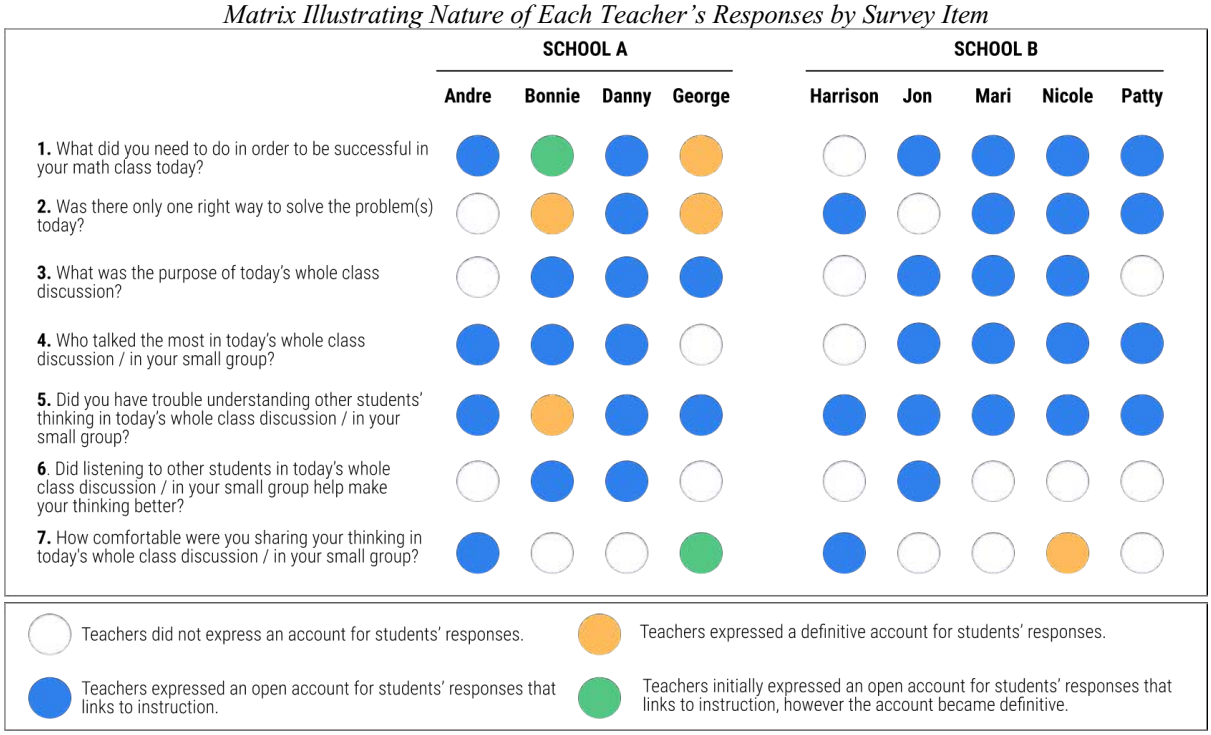
In the 2017-2018 and 2018-2019 school years, the first two authors and other members of the research team spent extensive time in nine middle-grades mathematics teachers' classrooms (located in two schools in one district) to understand the value and challenges of using the surveys in instructional improvement efforts. The primary data source for this analysis is one approximately 45-minute interview with each of the teachers, in which the teacher made sense of students' survey responses from a lesson they had either taught that day or the prior day. Secondary data sources include another 45-minute introductory interview, in which we directly asked about teachers' current pedagogical commitments, and field notes from classroom observations. Analysis took place in four phases: (1) an inductive, descriptive analysis of the sensemaking interviews in which we iteratively developed a coding scheme to characterize each teacher's interpretations of students' responses; (2) a finer-grained analysis of teachers' interpretations, in which we applied codes for whether teachers interpretations of students' responses to each item opened and/or closed opportunities for future inquiry (see Figure 1); (3) an analysis of how pedagogical commitments were expressed in teachers' interpretations; and (4) triangulation of the pedagogical commitments made visible in the sensemaking interviews with additional data sources.

Teachers' interpretations of students' perceptions of the learning environment

Figure 1 provides an overview of our assessments of each teacher's interpretation of students' responses to each of the survey items, in terms of opening or closing opportunities for future inquiry.

Figure 1

Matrix Illustrating Nature of Each Teacher's Responses by Survey Item



As illustrated in Figure 1, overall, teachers' interpretations of their students' perceptions of the classroom learning environment tended to open opportunities for future inquiry into issues of instruction. However, there were seven instances in which teachers provided definitive accounts that "explained away" students' responses to the survey item, and ultimately closed possibilities for future inquiry. Regardless of whether teachers' interpretations opened or closed possibilities for future inquiry, their interpretations provided insight into their then-current pedagogical commitments. To substantiate these claims, given space limitations, we briefly discuss three teachers' interpretations (Mari, Jon, and George), who represent a range of pedagogical commitments.

Mari, a second-year teacher, gave the survey to a class of sixth graders after their discussion of a number talk focused on whole-number division. As evidenced in Figure 1, Mari's interpretations consistently provided openings for future inquiry. For example, in response to Item 5 (see Figure 2a), in which eight students indicated they had trouble understanding their group members' explanations, and 14 chose no, Mari reflected on her role in supporting students to understand one another's ideas: "When kids explain themselves and I see that someone

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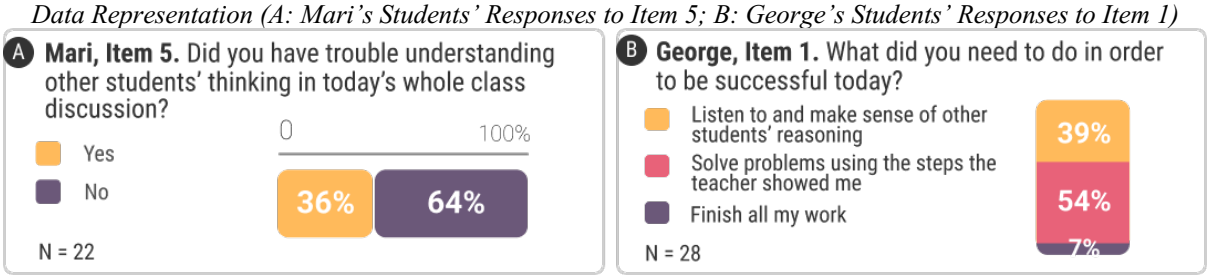
doesn't understand I really try to be like, 'Can someone else explain?' or, 'You might need to say it louder,' so they know that they have to understand each other." She also commented on the importance of the classroom environment in relation to students' willingness to share ideas: "I don't think [discussion] would work if they didn't feel safe." In Mari's interpretations, we consistently found evidence of her commitment to a *dialogic vision of instruction* (Munter et al., 2015). For example, she voiced her intent to use discourse to support students' understanding ("they have to understand each other"). Further, her interpretations suggested that she was actively considering her role in supporting students' understanding of one another's ideas ("I really try to be like: 'Can someone else explain?'"). Mari's interpretations were consistent with how she described her commitments in interviews and what we observed in her classroom instruction.

Figure 2

Data Representation (A: Mari's Students' Responses to Item 5; B: George's Students' Responses to Item 1)



Jon was in his first year of teaching in a general education setting after 16 years as a paraeducator. He administered the survey to a class of eighth graders after discussion of a task focused on factoring polynomials. Like Mari, Jon's interpretations consistently provided openings for future inquiry into instruction. Different from Mari, Jon's interpretations provided insight into how his instructional vision was in *transition*, reflecting both aspects of direct and dialogic visions. For example, when interpreting students' responses to item 2, "Was there only one right way to solve the problems today?" Jon was intrigued by the fact that half said yes and half said no. Jon indicated that he was focused on providing students steps to follow in his lesson on factoring polynomials ("I'm looking at the overall picture of there's only one way to factor polynomials"). However, he also said, "That would be interesting to hear [students'] thoughts and if they come up with a different way." Indications of Jon's transitioning instructional vision was consistent with what he expressed in interviews and classroom observations. Jon's responses also highlighted his view that students' perspectives are reasonable and worth learning from.

George had been teaching mathematics for 15 years and gave the survey to a class of eighth graders after a discussion of common errors on a recent end-of-unit assessment. As shown in Figure 1, different from Mari and Jon, George's interpretations of students' perceptions both *opened* and *closed* opportunities for inquiry into instruction. We found that, overall, his interpretations reflected a deficit perspective of his students' capabilities. Further, while he indicated that he aspired to a dialogic vision of instruction, his assumptions about his students resulted in him enacting a direct vision of instruction. For example, consider George's interpretation of students' responses to Item 1, "What did you need to do in order to be successful today?" (see Figure 2b). George focused on the students who chose "solve problems using the steps the teacher showed me" (15 students) and "finish all my work" (two students): "…it's what they're accustomed to. Whenever we give them work that they have to talk to each other and reason things out, it takes them so long to do it … they get so easily distracted." He next identified a few students in the class who he suggested would engage in reasoning, and then characterized "the rest of them": "they want to be spoon-fed." He elaborated: "That's what I'm trying to get away from, but maybe I'll do it next year, because it didn't happen this year." Different from Mari and Jon, George's interpretation closed off possibilities for future inquiry into instruction. From George's perspective, the students' responses reflected their current dispositions and traits – students who "want to be spoon-fed" and the few exceptions who "try to figure it out." Here, George also indicated that in response to these perceived traits of the students, he enacted a pedagogy of direct instruction, which was consistent with what he shared in his introductory interview.

Discussion and conclusion

In this paper, we reported on an exploration of teachers' interpretations of a novel representation of practice that features *students' perceptions of key aspects of the mathematics classroom learning environment*. It is rare to bring students' perceptions to bear in making sense of instruction in professional learning, yet this exploratory study suggests the potential value in doing so (alongside evidence of student reasoning) for two reasons. First, we found that, overall, these teachers tended to interpret their students' perceptions in ways that opened possibilities for future inquiry into instruction. Second, teachers' interpretations of their students' perceptions often provided

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insight into their then-current pedagogical commitments, specifically their instructional aspirations and perspectives of their students' capabilities. Teachers' pedagogical commitments shape what teachers do in their classrooms and how they engage in professional learning; however, their commitments often remain out of view in professional learning (Horn, 2020). The incorporation of students' perceptions of the classroom learning environment could help surface and make instructional aspirations and views of students explicit objects of inquiry in professional learning. That said, interpreting a representation of practice can result in the reification of unproductive commitments regarding teaching and students (Little, 2003). This could very well be the case with George. Cases like George's suggest the importance of supporting professional development facilitators to learn how to respond productively to the insights gained into teachers' commitments.

A limitation of this analysis is that the sensemaking interviews took place with researchers, outside of a formal professional learning context. Future research will involve investigations of the use of surveys in professional learning, including when and how to introduce the tool, given teachers' current commitments and goals, and how to respond to a range of interpretations in ways that are supportive to teachers as learners. Of course, teachers' commitments do not develop in a vacuum; they are shaped, in part, by the discourses that circulate about teaching and students in the workplace, administrative expectations, and norms of interaction (Little, 2003). We will therefore also attend to features of the organizational context that undoubtedly shape how teachers interpret students' perceptions.

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Applying Deweyan Perspective of Inquiry to Teaching Experimentation Using Simulation

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Abstract: We investigated whether and how learning of experimental inquiry can be facilitated with computer simulations. As a theoretical framework, we built upon Dewey's concept of the continuum of inquiry and identified three types of requisite knowledge that provide support for, and evolve with, experimental inquiry. Preliminary findings from two teachers' classrooms indicate that teacher framing styles identified in the classroom discourse may be a factor in explaining contrasting student experimentation behaviors.

Introduction

The current vision for science education calls for engaging students in science practices so that they can learn how to *do* science, not just learn the end products of science, thereby being able to understand how scientific knowledge is developed (National Research Council [NRC], 2012). The pivotal role that experimentation has played for the development of scientific knowledge, especially in physical sciences, is well described in the philosophy of science (Hempel, 1966). Hence, an important aspect of physical science learning has to do with experimental inquiry, which is carried out by asking an investigative question, making hypotheses, collecting, and analyzing data, formulating explanations and conclusions based on evidence, and communicating findings (NRC, 1996).

As the emphasis on learning scientific content through science practices has grown in recent years (NRC, 2012), the need for reconceptualizing the practice of planning and carrying out investigations has increased (Manz, Lehrer, & Schauble, 2020). We found Dewey's concept (Dewey, 1938) of the *continuum of inquiry* useful in building a theoretical foundation for experimental inquiry. Inquiry process seeks to obtain a warrantable assertion (knowledge *objective*) while building on and making use of knowledge *resources* available. Inquiry is dynamic not just in the trivial sense that the knowledge objective is formulated over time but also in the nontrivial sense that knowledge resources go through concomitant re-examinations and temporal modifications. In turn, the knowledge attained at the conclusion of the inquiry can act as a resource for a new inquiry and will go through its own dynamic update. In this continuum of inquiry, no knowledge, even that of logic, can be absolutely taken for granted; there is only *the self-corrective process of inquiry* whose conclusions approximate the truth *in the long run*. Applied to students' experimental inquiry, this dynamic nature of inquiry requires students to adapt their conceptual and practical resources by constantly responding to new experiences. The resources include, as we discuss below, three types of knowledge: what students understand about the phenomenon under study (science *content*), what students know about how to conduct scientific experiments (*method*, logic of inquiry), and how students interact with the external world entities (*materials*) such as the physical setups with which to create a scientific phenomenon, measurement tools, and software to collect, simulate, or analyze data.

Scientific experimentation can be used to confirm an existing theory in the form of hypothesis testing or to discover patterns in the data while a theory to explain the patterns is yet fully developed (Hacking, 1982). In both cases, especially for the latter, students not only need to reason between their knowledge space and the empirically obtained data space (Klahr & Dunbar, 1986) but also must productively interact with materials to obtain the data so that they can make warrantable conclusions based on the evidence (Miller et al., 2018).

In this study, we focus on scientific experimentation of a physical system based on a computer simulation. Part of interest in employing simulation-based experimentation is to take some cognitive load off from physical experimentation. Especially in a remote-learning situation, computer simulations can be valuable for the purpose of enacting experimental inquiry. Simulations are "dynamic computer models that allow users to explore the implications of manipulating or modifying parameters within them" (Honey & Hilton, 2011, p. 2). Simulations are theory-based models and capture some but not all aspects of reality being experimented. Thus, simulations act as materials through which students can gain access to a theory-laden version of the real physical world. Using the classroom videos and computer log data of two teachers' classrooms, we investigated two research questions: (1) how the teachers framed simulation-based scientific experimentation and (2) how students' experimentation patterns were impacted by the teachers' framing styles.

Theoretical framework: three legs of an experimental inquiry

According to Dewey (1938), the outcome of a competent inquiry is a w*arranted assertion*, i.e., a piece of knowledge. In experimental inquiry, a common form of knowledge to be created would be a data-based answer

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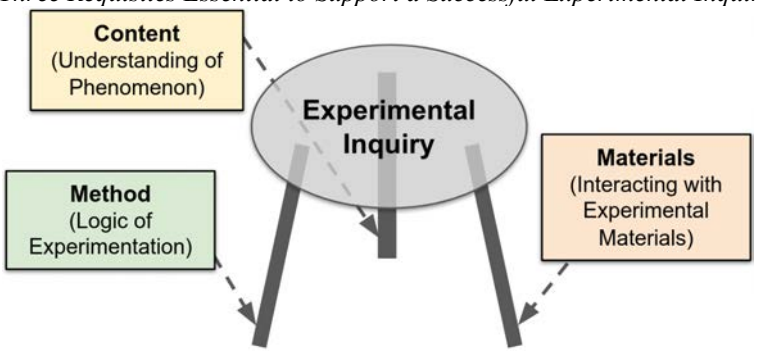
to the question "Does the quantity Y depend on the quantity X, and, if so, how?" We assert that three legs of requisites as shown in Figure 1 are necessary for the completion of a competent experimental inquiry. In describing these three requisites of experimental inquiry, we shall use an example question, "Does the acceleration of the car on a ramp depend on the mass of the car?"

Figure 1

Three Requisites Essential to Support a Successful Experimental Inquiry



1. **Content**: The experimenter's scientific content knowledge of the phenomenon under investigation is a necessary element. Adequate understanding of the main science concepts and their relations is necessary not only for motivating, designing, and understanding an experiment, but also for dynamically steering the experimental inquiry in the productive direction when faced with unexpected outcomes along the way. For the above example question, the experimenter's disciplinary content knowledge must cover the kinematics of the motion (position, velocity, acceleration) and the variables of the setup that affect the motion (mass, friction, gravity, and ramp geometry).
2. **Method**: The experimenter should know how to carry out experiments towards a clearly formulated result without involving confounding variables. This required knowledge is not a type of understanding that applies to a particular experiment or a particular science domain but is *a formal and logical understanding of the practice of experimentation* typically acquired through experiences with epistemic reflections. Namely, it is understanding of scientifically valid experimental strategies to achieve the most unambiguous outcome that can identify or establish causality. For the above example question, the target strategy is control of variables (COV) (Chen & Klahr, 1999; Kuhn, 2000; Schwichow et al., 2016), where all variables (such as friction, ramp angle) are fixed other than one independent variable (mass). COV is an ideal strategy, if available, for deducing the relationship between the dependent variable and the independent variable. While outside the scope of this paper, statistical understanding of data also belongs in this category.
3. **Materials**: This category concerns interacting with the external world. The experimenter should be able to competently interact with equipment, specimen, software, and the general physical setting of the experiment to produce quality data with confidence. In the simulation-based experimentation, simulation itself becomes the material setup. Different from the method, this falls into the category of *an actual doing* of a specific experiment under a specific circumstance and concerns the knowledge necessary to recognize not just how the materials operate and how they can be controlled but also how the phenomenon under study is represented in the material setup and how measurements should be drawn from that setup.

While the three legs of support are formulated as requisite *resources* for an experimental inquiry, their characteristics are also *dynamic*, *a la* Dewey (Dewey, 1938); they are also a *result* of the inquiry in the sense that they change or grow with the inquiry process. They need not, and cannot, be in a perfect state when the inquiry begins. The experimenter's knowledge of phenomenon, method, and materials needs to be only sufficiently settled for the inquiry to begin. In Dewey's words (1938), "In scientific inquiry, the criterion of what is taken to be settled, or to be knowledge, is being *so* settled that it is available as a resource in further inquiry; not being settled in such a way as not to be subject to revision in further inquiry" (p. 8-9). This view of inquiry and knowledge is summarized by what Dewey terms as the *continuum of inquiry*: "It is the convergent and cumulative effect of continued inquiry that defines knowledge in its general meaning" (p. 8). Therefore, any one inquiry process must be viewed as an *open* process spawning further inquiries, not a process closing upon conclusion. All involved knowledge evolves through inquiry. In the symbolism of Figure 1, the inquiry process will transform the *whole* table. It will transform not only the tabletop, representing the *inquiry activity* that occurs to produce the knowledge objective ("Y vs. X"), but also the legs, the *three knowledge requisites* of the inquiry. In a classroom setting where

the experimenter is a student or a group of students, which legs of knowledge will have progressed most prominently through the inquiry may be influenced by how the lesson is structured by the teacher.

The analytical distinction among three types of requisite knowledge is valuable, but we realize that they cannot be cleanly separated in any given situation. Dewey noted (1938), without "the sensitivity to the quality of a *situation as a whole*" (p. 70; emphasis by us), an experimenter cannot avoid "two evils" (p. 70): (1) mindlessly collected data leading to nowhere and (2) prejudiced data collection forced into the predetermined conceptual and theoretical scheme. Thus, it is critical that an experimenter be situated in a holistic mixture of all three requisites. In sum, the continuum of inquiry perspective characterizes inquiry to be *open*, *dynamic*, and *holistic*.

Learning context and methods

This study examined a simulation-based experimentation activity embedded in a four-week, technology-enhanced physics module for high school students. Two participating teachers, Teacher S and Teacher J, taught the physics course to 17 and 27, respectively, ninth grade students in the Northeastern part of the US. Teacher S had 20+ years of teaching experience and held a Ph. D. in microbiology while Teacher J had 10+ years of teaching experience in physics. Teacher S's school was in the moderate to high socio-economic neighborhood while Teacher J's school was in the moderate socio-economic neighborhood. We collected and analyzed videos of the whole class as well as students working in small groups. Among the students, 48% identified as male and 48% as female; 22% had minority backgrounds; 99% spoke English as their first language; 68% used computers regularly for science learning prior to the module. The module addresses physics concepts such as displacement, velocity, and acceleration related to a car's motion on a ramp. Students carry out the sensor-based physical experimentation with a toy car on a ramp and then simulation-based experimentation. The ramp simulation allows students to vary five independent variables such as car mass, ramp angle, distance up the ramp, gravity, and friction. Students investigate how the acceleration of the car depends on one of the independent variables (of their choice).

Table 1

Summary of Different Teacher Framing of the Simulation Experimentation Activity

Three requisites		Teacher S	Teacher J
Content	Address content knowledge of velocity and acceleration	Content as a resource for experimentation	Content as the final goal of experimentation
Materials	Discuss simulation affordances	Emphasized	Emphasized
	Demonstrate how simulation works	Yes, through a student	No
	Encourage exploration	Yes	No
Method	Allow students to select an independent variable	Yes	Yes, but with constraint (by whole class)
	Allow students to experiment with other variables	Encouraged	Discouraged ("Vary only one variable!")
	Characterize the experimentation process and present the goal	- Explore the setup - Select a variable of interest and settle on COV - Take really good data - Obtain trends in data that are trustworthy	- Confirm or learn content knowledge - Use COV - Create community knowledge through each group's contribution

Results and discussions

Table 1 summarizes the major themes emerged from the video analysis. We characterize Teacher S as the supporter of individual experimental inquiry and Teacher J as the orchestrator of the whole class experimental inquiry. Teacher J emphasized the conceptual modeling (i.e., content knowledge) of the ramp system while Teacher S let students explore and experiment freely. Teacher S used content as a resource for carrying out experiments and making measurements and did not go over the content as forcefully or intentionally as Teacher J. While Teacher S's goal for experimentation was to explore the system under study and carry out investigation to collect data that was worthwhile, Teacher J's goal was to create community knowledge based on the contribution from each group. Nonetheless, the affordances of the simulation (e.g., adjustable gravity or perfectly reproducible data) were emphasized by both teachers as the simulation became the main tool of experimental inquiry. Teacher S had a balanced emphasis on all three requisites of content, method, and materials, while Teacher J over-emphasized the content requisite. Students in Teacher S's class were given ample time to get to know the materials with a holistic goal of carrying out the experiment to get "really good data eventually." In

contrast, students in Teacher J's class were urged to experiment only one single independent variable with the simulation so that each student group could contribute to the class wide discussion of the physics content. Surprisingly, in Teacher J's class, nearly half (48 %) of the log data sessions related to simulation usages showed no COV enactment (showing chaotic exploration of the independent variables) despite the fact that the COV was forcibly directed at students. In Teacher S's class, only 30 % showed such a behavior. We postulate that playing as a way of familiarizing with the material such as simulation naturally happens whether the teacher explicitly allows it or not. We further postulate that familiarizing material as a tool for inquiry was critical for students in Teach S's class to make transition from pure play for exploring the tool to productive experimentation for collecting serious data. Indeed, in Teacher S's class, more than half (52 %) of log data sessions showed evidence for "rich" COV enactment: COV behaviors mixed with other variable exploration or showing consecutive COVs with different independent variables. In contrast, only 17 % showed the rich COV in Teacher J's class. The remaining data showed a "strictly regimented" COV behavior (pure single-variable COV with no play), 35 % for Teacher J and 17 % for Teacher S.

While a potential connection between teacher framing and student experimentation patterns exists, it was not possible to tell whether there was any causal relationship between the two due to a small sample size and other student, teacher, and classroom factors that were not considered in this study. What seems to be clear, though, from the Deweyan perspective of inquiry is that Teacher S's framing was more conducive to student learning of an experimental inquiry as a dynamic whole supported by the balance among the three knowledge requisites. On the other hand, Teacher J's framing might have devalued students' engagement with the method and materials legs of inquiry, which diminished their chance to, in Dewey's sense, sensitively and productively interact with the inquiry situation as a whole.

Our results show that it *is* possible to use computer simulation in a productive way to teach important aspects of the experimentation practice. Simulations can be more effective in teaching the experimentation practice such as COV than physical setups thanks to their affordances such as the absence of noise/imperfection in physical data. However, simulations' affordances are also their weaknesses (lack of fidelity to the phenomenon under investigation), thus requiring teachers and curriculum developers to prudently mix physical experimentation with simulation experimentation to maximize student learning. Lastly, this paper focused on experimental inquiry, but the theory outlined in this paper may be applicable to other types of inquiry such as observational inquiry if each requisite knowledge is recharacterized accordingly.

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Considering, Recognizing, and Valuing Culture in Afrikan Contexts

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Abstract: Afrikan countries and cultures create solutions for the needs and conditions of their people, yet their contributions to technological innovations continue to be overlooked. In this paper, we argue that app developers on the Afrikan continent have been accepting educational responsibility by creating mobile applications that specifically meet the needs of the people. From a qualitative research perspective, we conduct a systematic review and cultural studies analyses to explore Afrikan innovations in mobile applications. The findings reveal that mobile developers are 1) building apps that are specific to the Afrikan context and 2) making use of existing apps and appropriating them to the Afrikan context.

Introduction

Promoting diversity, equity, and justice in educational settings cannot be accomplished without considering, recognizing, and valuing culture. Although acknowledged as a crucial component of everything about being human, the concept of culture is often abstract. This difficulty is perhaps what leads to culture, at best being understudied, misunderstood, or at worst being ignored. UNESCO defines culture as "the whole complex of distinctive spiritual, material, intellectual and emotional features that characterize a society or social group, not limited to the arts and letters, and including modes of life, the fundamental rights of the human being, value systems, traditions and beliefs" (UNESCO, 1982). For this paper, considering culture means taking into account the ways of knowing and experiencing of different learners, based on who they are and where they originate. Recognizing culture means being aware of the whole complexities of individuals, where they come from, and how their communities and experience influence their being. Valuing is consideration and recognition put into practice. In the educational context, this can mean valuing different knowledge systems in the way they want to be understood and incorporating the complexities of realities in the design of learning experiences and environments.

Afrikan countries and cultures create solutions for the needs and conditions of their people, yet their contributions to technological innovations continue to be overlooked. Worldwide 2.7 billion people use smartphones (Blair, 2020). Afrika ranks highly as one of the fastest-growing developer communities, as evidenced by contributors to GitHub, a cloud-based repository platform (Kazeem, 2019). From a qualitative research perspective, we conducted a systematic review and cultural studies analyses to explore Afrikan innovations in mobile applications.

At the core of our submission is the notion that culture is a crucial component of one's identity. Our paper explores the ways in which culture manifests in the design of mobile devices, which are common learning devices across educational settings.

Purpose

We explore mobile learning literature to demonstrate how people on the Afrikan continent are considering, recognizing, and valuing culture as they take responsibility for their localized needs by building apps within the African context or appropriating apps to fit the educational needs of their communities. Localization, in this context, means adapting content or a product to a specific locale. In this study, 'environment' is defined as extended reality (XR), which includes virtual reality (VR), augmented reality (AR), mixed reality (MR), and other XR technologies that support and enhance learning and human performance, and to provide users a better immersive experience (Truman, 2019). We refer to standalone products as those things made by man's hand, tools, or systems; products are created manifestations of human thought and ingenuity.

Theoretical framework

> "A theory as it is understood here--does not present a prediction of the results; it only suggests a particular, explicitly defined framework within which the details of a case or the data can be assessed. One must make a clear distinction between a theoretical framework and the particular case being analyzed within it. A theoretical frame presents a general viewpoint and is applicable to a number of cases, whereas the object of a study is a particular case, whose details can only be given a local explanation (Alasuutari, 1996, 376-377)."

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Given Alasuutari's explanation of a theory as a general viewpoint applicable to a number of cases, this research situates itself with The Culture Based Model as a theoretical framework for analyzing culture-based information and communication technologies (ICTs). Specifically, Young's Culture Based Model (2009) proposes that all ICTs are culture-based, but some are more culture-neutral (internationalized) and others more culture-specific (localized). Further, there is a much broader space in which to design. Young situates the design and analysis of technologies from a culture-based context to better understand target audiences and build technologies (Young, 2009, 2008). Similarly, this research seeks to understand the mlearning applications and the culture-based contexts in which they were built, used, or appropriated.

Method

The methodologies used in this study are twofold and represent those mostly cited across interdisciplinary fields for systematic reviews and cultural studies. The entire study is grounded in the qualitative research method of cultural studies that suggest "reality and social life are always and essentially mediated through meanings" (Alasuutari, 1996, p. 35). Next, we conducted a systematic review consistent with the research of Petticrew and Roberts (2006) that proposes the following path to maintain internal validity:

1. clearly defined research questions;
2. the inclusion and exclusion criteria;
3. comprehensive literature review (excluded from this paper)
4. critically appraise the included studies
5. synthesize the studies and assess heterogeneity of study findings

A. Clearly defined research questions ass

Qualitative research questions inform this study. They are defined as:

1. RQ1. Was a product produced, utilized, or appropriated? If so, by whom and for what reason?
2. RQ2. In what cultural context was the product created or used?
3. RQ3. What conditions, problems, or limitations are addressed from the product's creation? What solutions manifested from the product's creation, if any?

B. The inclusion and exclusion criteria

Based on our research questions, we examined only studies that met the inclusion criteria (table 1). We discussed the research bordered on an environment's criteria, process, service, or program. However, we ultimately chose only those focused on a standalone product or environment. Although we had an inclusion criterion, we were uncertain as to what we would find. We expanded on the inclusion and exclusion criteria as we moved past 200 reviewed publications. This is consistent with qualitative research as it is a discovery of knowledge.

Table 1

Inclusion and Exclusion Criterion

Inclusion criteria	Exclusion Criteria
Must reference a product or environment	Articles that only mentioned culture or cultural in the reference list only?
Must be in a peer-reviewed journal between from January 2015 to May 2020	All articles prior to 2015 were excluded as well as books, book chapters, conference proceeding
Must be specific to mobile learning (mlearning)	All other languages
Must include a cultural aspect	Articles from the popular press (magazines, newspapers)
Standalone product or environment	Part of a Commercial suite of products or environments

We searched one of our university's library systems for academic articles using the following keywords: "Mobile learning + culture +Africa," "Mobile learning +Cultural, +Africa" "Mobile learning + international +Africa," and "Mobile learning + localization +Africa." The choice to use a university library system search was informed by the idea that such a system included academic databases such as EBSCO, PsycINFO, Academic Search Premier, ProQuest, Scopus, Google Scholar, JSTOR, PubMed, PsycARTICLES, or Science Direct, etc. The results are presented in Table 2. The search parameters were limited to 2015 to 2020, representing five years from the year our paper was authored.

Table 2
Search Results

Search Term	Results
Mobile learning + culture + Africa	185
Mobile learning +Cultural + Africa	203
Mobile learning + international + Africa	348
Mobile learning + localization + Africa	10
Total number of abstracts	746

Next, we divided up the 746 amongst the three authors. Then, we reviewed manuscripts based on the inclusion and exclusion criteria. We documented our findings on an excel sheet and weekly discussed our progress. For the borderline articles, meaning they may have, for example, developed a temporary web-based tool, we discussed whether those articles should be included or excluded. This was a 3-month process. The comprehensive literature review yielded 746 self-contained articles under the four categories in table 2. A total of 31 articles matched the inclusion criteria; therefore, we reviewed those articles based on the research questions.

Critically appraise the included studies

Critically appraising the information means assessing the original data, and many times this information is limited (Petticrew & Roberts, 2006). We have not altered any findings, results, or conclusions as we did not use these as part of our analysis. Our critical appraisal is finite and specific to the product or environment and needs or conditions.

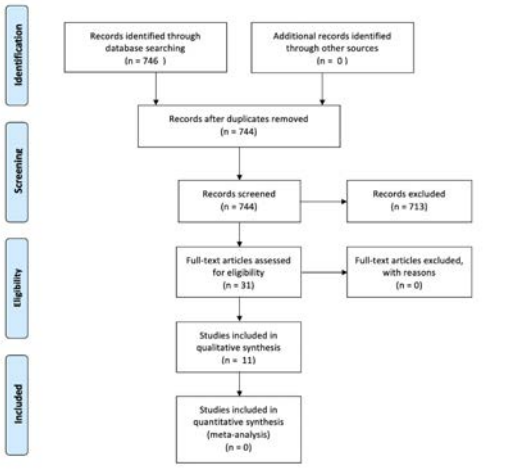
Synthesize the studies and assess heterogeneity of study findings

This review considers "social heterogeneity" that incorporates sociodemographic differences, historical differences, cultural differences, and other differences across the research (Petticrew & Roberts, 2006). These cultural differences may affect the impact and delivery of the review. Specifically, our reviews are aligned with the research questions. This means that only certain information was extracted from the literature per the research questions. Other information like the findings and results are discarded, not because the study is unimportant, but because this study focuses on the cultural context that surrounds the development of the product or environment.

Data sources

The PRISMA (figure 1) flow diagram for the literature review provides an overview of the processes. It goes from the included (inclusion and exclusion criteria), eligibility (initial review of the literature 746), screening (critically appraise the included studies), and identification process (synthesize the studies and assess heterogeneity of study findings (Moher et al., 2009).

Figure 1
PRISMA Flow diagram



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Results

Worldwide 2.7 billion people use smartphones (Blair, 2020). Afrika ranks highly as one of the fastest-growing developer communities, as evidenced by contributors to GitHub, a cloud-based repository platform (Kazeem, 2019). Mobile devices, specifically mobile phones, remain the most widely used technology on the Afrikan continent. Preliminary findings of the research indicate that scholars and app developers are accepting educational responsibility through building technologies in Afrikan cultures in two ways: 1) developing mobile apps that are specific to the context and 2) making use of already existing apps and appropriating them to the Afrikan context. There are a growing number of mobile applications that have been designed by and for Afrikan contexts. Some of these in-house mobile applications remain local to the country and the contexts (e.g., Mixit).

Others continue to use existing Apps such as Whatsapp to fit their educational context. This use is consistent with early thoughts on mLearning that recognised the importance of the mobile phone as a personal device. The importance was not on what was being created by educators for learning, but rather on the apps that were already on the device, which people were using in their everyday life that was not being repurposed for learning.

While there are multiple ongoing software and mobile app development projects around the Afrikan continent, much of these data are not published in academic journals. When it is published, it is through online news outlets, articles, and software development forums. Hence, it is impossible to entirely capture low-key outlets describing how products are produced, utilised, or appropriated.

Significance of the study

Hence if learning sciences research desires to address and disrupt such inequities that are interconnected with diversity, equity, and social justice, as noted in the call, perhaps one of the components is to become more aware of how culture is considered, recognized, and valued in educational settings and in tools for learning. The research in Afrikan contexts is growing, and there is much to learn. Afrikan mobile developers and their localized mobile applications are on the rise. This is significant as the contributions of indigenous cultures to educational technology and beyond is history in the making. As a society with limited human resources, the United States, in particular, will be poised to seek Afrikans to fulfill the growing technological needs and conditions of the present and future generations.

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Adaptation Principles to Foster Engagement and Equity in Project-based Learning

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Abstract: Teachers adapt science curriculum materials in planned and unplanned ways to address a variety of goals. This professional learning design seeks to support 18 elementary science teachers in biweekly professional learning (PL) sessions during COVID 19. They discuss and share their own adaptations for enhancing opportunities for productive disciplinary engagement and equity by collaboratively analyzing one another's teaching artifacts. Findings from transcribed interviews, PLs, and video of teaching are synthesized toward five adaptation principles.

Studies show that science teachers can make use of teacher-facing materials to guide their teaching decisions and the sequence of learning activities. At the same time, teachers make in-the-moment decisions to adapt those materials and learning contexts. Teachers adapt lessons to scaffold student learning, differentiate instruction, and respond to student ideas and questions (Drake & Sherin, 2006). When teachers do not adapt curriculum by responding to students' questions and ideas, they may miss opportunities to foster an equity-centered environment that makes available cultural and linguistic intellectual resources. Similarly, teachers can use in-the-moment feedback from students to make lessons more cognitively engaging for students (Chi, et al., 2018), such as fostering students' shared construction of new ideas. Little is known about how to support teachers to make principled decisions related to project-based learning (PBL) and adaptive practices that move toward goals for equitable practices and productive disciplinary engagement in science.

PBL's student-centered instructional approach presents a framework in which students generate artifacts that can take the form of actions (i.e., short play, social action) or physical objects (i.e., bird feeder, drawn model) to collaborate using disciplinary practices in engaging learning environments. The features of PBL include meaningful driving questions, collaboration, extended projects, orientation to standards-based goals, and community connection. Research suggests that positive results can be traced to fidelity to the PBL features, which is the degree to which teachers support meaningful questions and collaboration, shift to a student-centered approach, and create authentic experiences (Grossman, et al., 2021).

Our collaborative professional learning (PL) design (Swan, et al., 2014) responded to the challenges of maintaining the integrity of PBL during virtual contexts, created by the urgency to adapt instruction. Teachers needed to address the learning goals of the designed PBL units but also adapt the lessons to foster engagement and equitable access, participation, and outcomes for learning. To this end, we welcomed adaptations as part of robust teaching and learning. The PLs were based on co-creation, leveraging, and reflecting on adaptations among communities of teachers and researchers. Hence, our PL design adhered to three commitments: 1) PBL features; 2) positioning teachers as experts; and 3) productive adaptive practices that support equity and engagement. During the PLs, all partners - teachers, researchers, and curriculum designers - shared their knowledge and expertise. The study offers insight into PBL environments and highlights adaptation potential for enhancing engagement and equity.

Theoretical foundations

We build on the theory of principled adaptations (Potvin, et al, 2021), in which the change in lesson enactment from the lesson-as-written deepens the PBL learning trajectory. We use affordance to describe opportunities for action for learning (van Lier, 2008), and how a lesson feature can be adapted for specific purposes in situ. In this view, every PBL feature presents myriad opportunities for learning, and so adaptation is the mobilization of a particular opportunity that can be realized. The context, including aspects of the environment, participants, and teachers' instructional goals, determines the selection of a particular affordance of a feature. For example, a teacher may select

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among affordances of the feature "artifact development." Affordances include the opportunity for informal assessment, making a physical representation of thinking, or support for comparison of ideas across student groups. Teachers can be supported to adapt PBL lessons in ways that are principled, meet learning goals, and ultimately lead to increased engagement of students, including students from groups underrepresented in science.

Student engagement and equity describe processes and outcomes for learning in a PBL classroom. Student engagement is a multidimensional, dynamic interplay among individuals' academic, cognitive, and social involvement in specific activities (Fredricks, et al., 2004). Chi and colleagues' (2018) ICAP framework describes engagement as "*pragmatically based on the absence or presence of overt, observable behaviors, as well as whether the products contain information that went beyond the instructional materials* (p.1791)." According to this framing, other latent forms of engagement may be present, but as teachers can only respond to observable forms of engagement, this definition renders it productive for classroom use. Observed evidence of engagement includes students exhibiting behaviors such as using disciplinary ideas and practices to gather evidence and construct new understandings, productive manipulation of materials, and interaction with others to solve problems.

Equity in PBL classrooms is conceptualized as processes of access, participation, and outcomes of students from groups that are underrepresented in STEM, and advocacy for the inclusion of all students in the classroom (Tzou, et al. 2010). In this manuscript, we focus on the observable behaviors, interactions, and resources in the classroom that support equitable participation and engagement in science practices. For example, evidence of equity might be a teacher providing opportunities for students to utilize home and community resources and interactions where underrepresented students position themselves as knowers and doers of science (Miller, et al, 2021).

This study sought to develop a set of guiding principles that could inform teachers' adaptation of PBL features in ways that enhance equity and engagement of students during COVID-19, with the purpose of extending these supports for adaptation in non-COVID-19 contexts. Figure 1 shows the conjecture map that frames the research study. Within this design-based study we ask: *What principles can guide adaptation of the features of PBL to foster equity-centeredness and student engagement?*

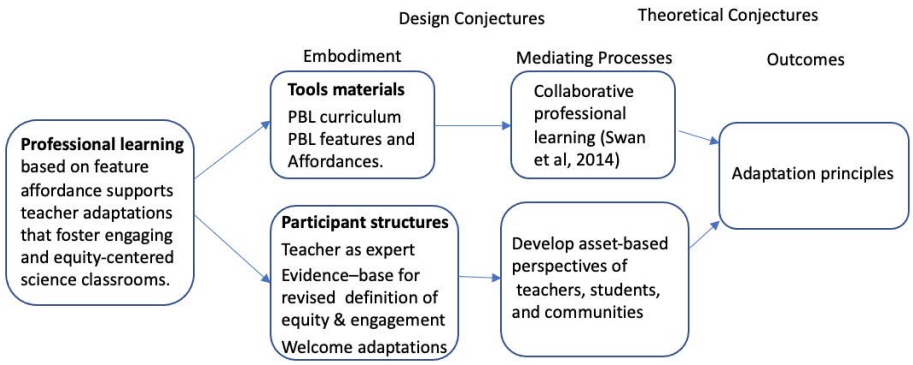

Figure 1
Conjecture Map detailing the mediating processes and outcomes for high-level conjecture

Methodology and data analysis

This research project is in the context of Multiple Literacies in Project-based Learning (ML-PBL; Miller & Krajcik, 2019), a 3rd-5th-grade coherent interdisciplinary curriculum system for meeting the science standards in the USA, designed for face-to-face contexts. Participating teachers (n=18) taught grades 3-5 across two great lakes states and represented schools from a variety of regions, economies, and student demographics. During the study, in 2020-2021, schools shifted among fully virtual, face-to-face, and hybrid formats of instruction. Teachers participated in 14 PLs designed to forward three foundational constructs: 1) Deepening enactment and reflective practices of PBL; 2) Positioning teachers as experts, with collaboration among teachers and researchers as critical agents of learning; and 3) Creation of productive adaptive practices, meaning that researchers encouraged teachers' adaptations (planned, enacted, and reflected on) in the service of collectively realizing goals for learning.

The collected data included transcribed teacher interviews (n= 36), video-taped observations and field notes of classroom teaching (n=154), and transcribed teacher PL sessions (n=14). Teacher interviews were semi-structured

and conducted three times across the school year (beginning, middle and culmination of the academic year). The biweekly, 2 hour, PL meetings, had three parts: 1) Teachers presented artifacts from prior adaptation to interrogate and refine the groups' definition of equity and engagement; 2) They reflected on PBL features and their affordances; 3) They co-planned adaptations that would foster engagement and equity.

ML-PBL adaptation principles were designed through investigation of instances of student productive disciplinary engagement and equity processes, and related lesson events. Coding across data employed thematic analysis using grounded coding (i.e., characterizing instances of criticality, accessing student intellectual resources) and a priori coding (i.e., PBL features, ICAP Framework). After identifying preliminary equity and engagement instances in classroom videos, we generated codes and then looked across classrooms and similar contexts to reach consensus. Next, we characterized the teacher adaptations and related factors that may have contributed to those processes. As some adaptation codes and features became salient for repeated and pronounced associations with equity and engagement, agreed-upon themes were created and then triangulated with the PL transcription and teacher interviews to seek confirmatory and disconformity evidence. In disconfirmatory cases, the team returned to the original example to better understand the event; in confirmatory cases, themes were further supported.

Findings

Findings from the project include five adaptation principles that can be used to enhance equity and engagement: Adapt features to 1) bring in and leverage students' identities and intellectual resources from home; 2) provide student-centered choice; 3) elicit different ideas and diverse perspectives about the same event; 4) make use of different modalities; 5) disrupt the traditional classroom structures. The adaptation principles can guide the adaptation of PBL to support equitable science learning opportunities and student engagement. We expand on the first adaptation principle with evidence from videotaped observations, transcription of PLs, and teacher interviews related to enactment in the science classroom.

Adaptation Principle 1: Adapt features to bring in and leverage students' identities and intellectual resources from home. Using and leveraging students' identities and intellectual resources from home or community is actionable and can be used to guide adaptations. Equity and engagement were associated with instances in which the teacher created investigations that foster students' intellectual and home resources.

Observation video notes

A 5th grade Latine student brought her sister outside their home to investigate shadows. They brought their virtual classroom with them as they figured out how shadows work in their backyard. During the lesson, other students commented in the chat, asking their peer to explore the stretched shape of the shadow.

The lesson called for students to generate questions as they explored shadows as a group in the schoolyard, which was impossible during distance learning. However, the adaptation of including the local place and family corresponded with observable evidence of equity and engagement. Students added new ideas for exploration in the chat, evidence of constructive engagement, and the student and sister from a group traditionally marginalized in STEM, became positioned as experts, adding cultural intellectual resources and family engagement. Related adaptations implemented in a third-grade unit involved a teacher asking students to collect and use home-based recycled material to investigate forces in front of the camera, instead of using teacher-provided identical materials.

Interview transcript

T: "This time I switched it up a little bit. I thought if it's about making toys, we're going to have to use what the kids already have at home.... So, they came up with some really good and interesting ideas. One student made a paper airplane with a face mask that had stretchy bands. ...then he talked about the multiple forces involved. Even though it wasn't following the lesson plans, the students were able to get the science concepts."

In this example, students created new designs and added their thinking to explain the forces involved with motion of the toy, which corresponds to evidence of constructive disciplinary engagement. Additionally, the student in this example is an immigrant from Gambia, and labeled ELL, a member of a group underrepresented in STEM.

Further triangulation confirmed this theme. During one PL, a 4th-grade teacher shared a way she had adapted the Energy unit. She adapted the feature of driving questions to bring in local events and community connections. Later, other teachers tried this idea in their classrooms and corroborated the value of this adaptation.

PL transcribed

"And so we watched the videos of the mills, and we watched the video of the homemade water wheel. And then we have a water wheel in town, that's not too far from my school and I went there and took a video of that water wheel and me. Yeah, so I think they really understand water wheels, they really enjoy it, they understand how the energy transfers from the water to the wheel."

This 4th-grade teacher went on to describe how the adaptation to a place-based context enabled students to draw from experiences in their community from which to build understandings. This practice enables equitable processes for learning by allowing students to use local knowledge. The teacher reported that the class participated in discourse to use the experience in their artifact design, observable evidence for interactive engagement.

Conclusion and Discussion

Teachers, when supported with collaborative professional learning design, can adapt lessons based on feature affordance, and maintain the coherence of the unit and learning trajectory. By focusing on features of PBL and their affordances for student engagement and equity, teachers were able to create principled adaptations that deepened teacher expertise and student learning. Thus, we add to the field's understanding of the benefits of welcoming teacher-driven adaptations that adhere to principles of learning environment design, while elevating the singular expertise that teachers can offer researchers.

This study provided a set of five adaptation principles that can be expanded and further iterated in face-to-face and cross-disciplinary settings. Further research is needed to investigate how principles can be introduced to teachers to promote sustained disciplinary learning on the part of students and promote shifts in practices for teachers. Additionally, teachers in this study were responding to extraordinary circumstances. More research is needed to understand how teachers might develop and utilize principled adaptations in business-as-usual learning contexts. Furthermore, research is needed to investigate whether use of adaptation principles can strengthen the main tenets of PBL and translate to student learning outcomes.

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Crafting Paper Circuits: Gendered Materials for Circuitry Learning

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Abstract: Given the persistent issues of equity in technology-rich fields, this study argues that our choice of tools and materials significantly impacts both what is possible to be learned as well as who participates. This study examined students' learning of basic circuitry concepts through the use of paper circuitry toolkits in art-based activities. The data was collected in a 4-day workshop for middle school students (N=17). Findings showed that arts integration promoted the creation of paper circuits that leads to artistic exploration into STEM engagement. Pre- and post-tests results showed improvement for students by gender. Although the boys outperformed the girls on paper circuits, the girls outperformed the boys on e-textiles which is considered more "feminine" than others. The findings imply the nuances between material property and gendered practice to understand how we can better design tools and materials to rupture stagnant norms around educational practices.

The persistently lopsided gender makeup of the workforce in science, technology, engineering, and math (STEM) in the U.S. (e.g., only 28% of women work in STEM related occupations) suggests that the gender gap in STEM education is still obstinately wide (Corbett, & Hill, 2015). Yet, despite several national initiatives to diversify participation in STEM fields, the underlying culture of computing and engineering education remains relatively stagnant, with curriculum, tools, and materials that continue to emphasize areas historically aligned more closely with male interests than women's (Margolis & Fisher, 2003). Furthermore, these tools and materials seem to be failing today's youth, as they are arriving at college without an understanding of the big ideas important to electronics and computing (Peppler & Glosson, 2013).

Given the persistent issues of equity in technology-rich fields (Prey & Weaver, 2013), this study argues that our choice of tools and materials significantly impacts both what is possible to be learned as well as who participates. For instance, materials and tools such as sewing with textiles are often seen as the domain of females (Beaudry, 2006), whereas actions and materials such as building electronics are often seen as the domain of males. Recent studies focus on ways to resolve lopsided gender participation in STEM fields by addressing the tools we teach with (i.e., pedagogy), what is created with them (i.e., robots vs sculptural artifacts), and what audiences can be formed around their practice (i.e., girls-only robotics clubs) (Sullivan & Bers, 2016). However, little attention is paid to the role of tools and materials as the initial drivers of these outcomes, both in terms of who participates as well as what is learned. The marginal gains in gender representation due to these prior efforts (e.g., Corbett & Hill, 2015) may start to explain a different root cause of this persistent problem.

This study is part of a larger research project that aims to examine students' learning of basic circuitry concepts (i.e., current flow, connection, and polarity) using paper circuitry in art-based activities. From its inception, *Chibitronics*™ provided a new way to learn and create circuits but with the affordances of paper crafting and possibilities for expressive art creations (Qi & Buechley, 2014). The purpose of this study is to explore how this circuitry toolkit impacts learning by gender, and simultaneously, how it presents multiple possibilities of artistic expression for youth. Therefore, in this study, we aim to address the following research questions: *(1) To what extent does the art-based workshop support students' learning of basic circuitry concepts via paper circuits? (2) To what extent do the learning gains vary by the types of toolkits and by gender?*

Social Constructionism: Designing Art-based Learning Activities

In this work, we draw on sociocultural understandings of constructionism in a way that seeks to understand both the social nature of learning and the power of designing and creating artifacts that can be shared and iterated upon. Much of this notion comes from Papert (1980), who in his elaboration of Piaget's constructivist ideas posited that learners construct their own knowledge through their experiences with meaningful tools and artifacts with others.

Studies have shown that arts integration benefits student performance in STEM areas (e.g., Hardiman et al., 2014). Particularly, arts-based activities can serve as effective mediators for learning (e.g., Halverson & Sheridan, 2014) because of their focus on the creation of meaningful artifacts and social interactions with others. From the perspective of constructionism, the creation of art artifacts in a social context not only affords learning as it promotes an internalized mental structure of physical experience, but the learner and the artifact actively can create meaning as the learners make sense of their world (Peppler & Thompson, under review).

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Through the lens of the constructionist approach, we examine art-based activities as cultural practices, along with the related tools and materials which carry historical expectations for what counts as expertise. These expectations evoke *social scripts* that may prompt gendered patterns of participation. According to our prior work (Peppler & Thompson, under review), we found that the intersection of practices created by the tools and materials also created space for the performance of gendered scripts. For example, e-textiles is a science and engineering activity (fields often dominated by men); however, the integration of the sewing materials invited girls to take leadership roles and have more "hands-on" access to the projects than is typically expected or allowed in classroom science activities. Building on our prior work, in this study, we are interested in exploring the performance by gender with the use of paper circuits and examining how the concepts which students learned through paper circuits can possibly be transferred to other types of circuitry toolkits.

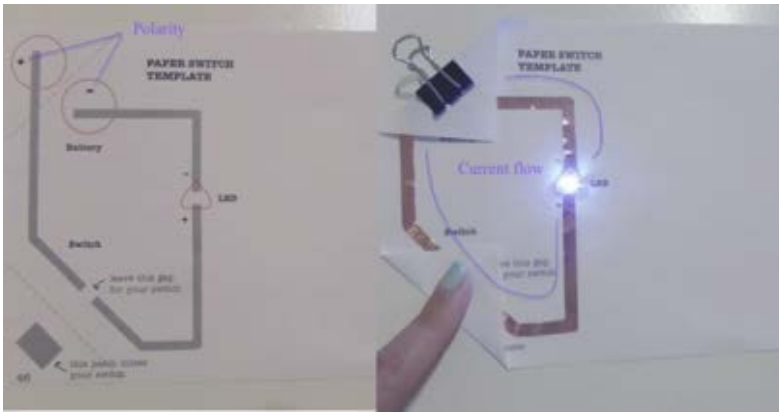
Methods

Setting, Participants, and Workshop

To answer the aforementioned research questions, we measured learning gains of middle school students after participating in a circuitry workshop with *Chibitronics*™ paper circuit toolkits. Building on the previous studies (Peppler & Glosson, 2013), we modified and created a 4-day workshop (90 minutes a day) for a charter class located in Southern California, USA. A total of 17 students (F= 9, M = 7, unidentified = 1) between the ages of 11 and 13 participated in the workshop. Nine out of 17 participants self-identified as White, and the others identified as either Asian, Hispanic, multiracial Asian, or multiracial Hispanic. For each day, we introduced circuitry concepts, such as current flow and polarity using Chibitronics (see Figure 1). Simple daily activities led from learning how to light up one to three LEDs (lights) using a coin battery and finished with one final project by creating a greeting card and a microcontroller board to automatically light up the lights.

Figure 1

Examples of Basic Circuitry on a Paper Circuit



Data Sources and Analysis

At the beginning and end of the workshop, we administered paper-based pre- and post-tests which included circuit diagram questions to assess the concepts of circuitry: current flow, connections, and polarity across three separate electronic toolkits, including e-textiles, breadboards, and paper circuitry. The content of the workshop and the measurement instrument have been refined and improved over previous study implementations. The pre- and post-tests had three sections, one section corresponding to one circuitry or computational toolkit: breadboard, e-textiles, and paper circuits. These sections compared how youth formed working circuits using materials familiar to them (i.e., Chibitronics) against less familiar materials (i.e., e-textile and breadboard). To understand how learning with paper circuits serves as indicators to prepare for future circuitry learning, we analyzed students' learning gains while youth were exposed with less familiar materials (i.e., other circuitry toolkits). These gains can serve as indicators of preparedness for future circuitry learning across settings.

In the pre- and post-tests, students were provided engineering components (e.g., LEDs, battery, microcontroller) as stickers to simulate the functions and draw lines across the components to accomplish the tests. We then developed coding schemes to examine students' competence of basic circuitry concepts from pre- to post-tests. The highest scores of pre- and post-test is 18. The inter-rater reliability of the coding scheme was

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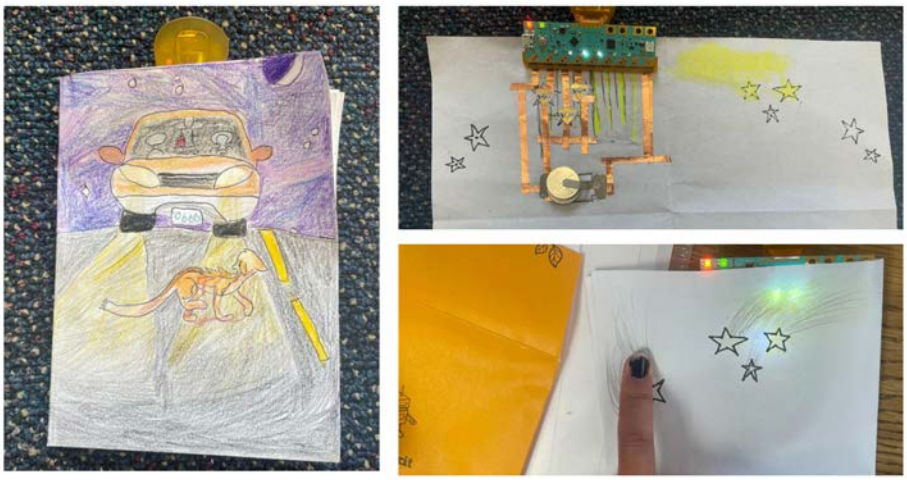
calculated by Cohen's kappa with k =.82. Two researchers scored the pre- and post-tests based on the coding scheme. Building on the coding results, a paired sample t-test and one-way ANOVA were applied to examine the changes and differences between pre- and post-tests by gender and types of toolkits.

Findings

In the workshop, we found that arts integration promoted the creation of paper circuits that leads to artistic exploration into STEM engagement. Figure 2 shows examples of how creating a circuit using copper-colored tape and paper provides additional flexibility and possibility for exploration with aesthetics, color, shape, unexpected uses of circuits, and more. This is a similar pattern found in other toolkits that promote artistic engagement such as e-textiles or playdough circuits (Peppler & Glosson, 2013). In addition to a more artistic output, the process of crafting these types of circuits seem to deepen opportunities for applications of STEM concepts for greater learning. Further, arts integration seems to demonstrate a broader applicability for transfer of circuitry concepts from one set of context and materials to another. With flexible materials that require deep embodied actions, such as pressing down copper tape along its entire trace, circuitry kits like paper circuits create a unique relationship between the materials and the elements that are necessary to build a working circuit. This leaves space for learners to apply parts of that close relationship to other toolkits and potentially learn the new materials more easily.

Figure 2

Examples of Students' Work



The results from pre-test (M = 3.5, SD =6.5) and post-tests (M = 21.4, SD = 11.9) showed significant improvement for both girls and boys on basic circuitry concepts (M =17.94, SD = 11.77), $t(15) = 6.1$, $p < .001$ with a large effect size (d=1.58). The results indicate that all students improved on the circuitry concepts (i.e., current flow, connection, and polarity) from pre- to post-tests. To answer the second research question, we then further examined the differences between gender and types of toolkits.

Building on the findings from the first research question, we examined the differences among three types of toolkits by gender. The results showed that both girls and boys improved significantly on e-textile and paper circuitry (see Table 1 for details). Particularly, girls performed better on the e-textile than breadboard and paper circuitry from pre- to post-tests, whereas boys performed better on the paper circuitry than the other two toolkits. The results of descriptive statistics on gains indicated that boys outperformed the girls on all items except for e-textiles, which are arguably more feminine than the other two toolkits. Interestingly, girls scored the highest on e-textiles among the three toolkits, whereas e-textiles were not introduced in this workshop, and all students did not have prior experience on the toolkits. Paper circuits are considered as gender neutral based on our prior work (Peppler & Thompson, under review). Breadboard was not intuitive for either group based on the results.

Table 1

Paired Sample T-test Results of Learning Gains by Toolkits for Girls and Boys

	Girls				Boys				Girls & Boys Comparison
	Gains (Post-Pre)	SD	*t*	*p*	Gains (Post- Pre)	SD	*t*	*p*	Differences between Gains by Points (pts)
E-textiles	9.14	7.08	3.42*	.014	5.44	4.85	3.37*	.010	Girls 3.7pts > Boys
Breadboard	0.43	1.13	1.00	.356	1.33	4.56	0.88	.405	Boys 0.9pts > Girls
Paper circuitry	8.43	7.72	2.89*	.028	11.11	5.67	5.89**	.000	Boys 2.7pts > Girls

Highest scores = 18pts; *$p < .05$ **$p < .001$

Discussion and implications

The findings suggest that all students' competence of circuitry concepts improved from the paper circuits workshop, which indicates that paper circuits are a sufficient toolkit for meeting the relevant standards in basic circuitry/physics. The results showed significant differences by the types of toolkits. Students showed significant improvement on both e-textile and paper circuitry toolkits, indicating that learning circuitry in the context of paper circuits allows individuals to transfer this understanding to similar contexts, like e-textiles but not to breadboards or other more distal contexts. This may also be an artifact of the way that the workshop was taught to emphasize learnings that would easily transfer to e-textiles kits and conditions. Particularly, the findings supported our prior work that there are gendered patterns of practices and materials which may impact the performance of the circuit.

Moreover, the power of the more arts-based toolkits is echoed in studies where learners who used such kits outperformed their peers. Maker toolkits and the integration of new materials bring promising new ways to rethink how concepts are taught, and help educators and designers imagine new approaches for electrical engineering to advance societal needs unmet by our current uses of electrical energy. For future work, we will examine the qualitative aspect of the data to understand how these toolkits are perceived by gender and how these differences impact the ways they approach learning in specific domains. Building on the results of the study, we will investigate the inextricability of material property and gendered practice in an effort to understand how we can better design tools and materials to rupture stagnant norms around educational practices.

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Creating Synergistic Scaffolding Between the Tools of Discourse and Technology

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Abstract: Research has looked at how teachers use discourse to develop aspects of the learning environment such as argumentation or autonomy. However, few studies have focused on how teachers utilize discourse surrounding educational simulations in practice (Erduran, 2019; Tabak & Kyza, 2018). More specifically, attention has not been given to how teachers use discourse to create synergistic scaffolding as characterized by Tabak and Kyza (2018) between tools such as discussion and technology. This case study uses two analytical frameworks, Rasmussen's Inquiry Oriented Discursive Moves (IODM) and Lidar's Epistemic Moves Analysis (EMA), to reveal how a teacher uses discourse to create synergistic scaffolding between the discussion and simulations. This case also demonstrates that by creating synergy between discussion and simulation the teacher positions students with opportunities to support shifting practical epistemology around chemical concepts.

Introduction

Providing students with opportunities to evaluate knowledge surrounding scientific phenomena can lead to epistemic shifts (Jiménez-Aleixandre & Brocos, 2018). Interactive technologies, such as simulations, have been developed that support students as they engage in these types of explorations by guiding students to reason, defend, and critique claims and explanations about the natural world. Research on educational technologies mainly focus on how designs achieve learning outcomes (Perkins, 2014) or how students interact with the tool (Smetana, & Bell, 2012; Price, 2019). Similarly, research on teacher discourse is often used to understand how teachers develop student inquiry through argumentation alone, rather than how teachers create epistemic opportunities for students to engage in reasoning. Surprisingly, little attention has been given to teacher discourse around the use of educational simulations, even though teacher discourse plays a role in developing students' scientific practice (Tabak & Kyza, 2018). We know that teachers orchestrate the learning environment through their practice choices, yet we have not captured how teachers use tools, like discourse, to purposefully integrate technology into the existing learning environment. Here we use two analytical frameworks to observe this interaction with a focusing on question: How do teachers' discourse choices create synergistic scaffolding between tools in the learning environment?

Theoretical frameworks

Argumentation has often been looked at as a means of replicating scientific sense-making in the classroom (Ford, 2012; Kuhn, 2013; Osborne, 2019). When teachers place students into roles that require them to use evidence to reason toward a conclusion rather than accepting answers given by the teacher, students participate in science practices that develop reasoning (NRC, 2011; Erduran, 2019). This creates the ability for students to engage in evidence-based argumentation that can support revising practical epistemology (Berland & Resier, 2011; Linn, 2018).

Two theoretical frameworks were used to characterize how teachers' discourse and the role of technology impact students' learning and potential for epistemological change. The first is Inquiry Oriented Discursive Moves (IODM; Rasmussen, 2008) defined as moves that involved questioning, telling, managing, and revoicing. These moves provide specific attention to discourse related to teacher and student inquiry as they are situated in settings of argumentation. By looking at inquiry-oriented discourse, we can observe the social setting of the learning environment created by the teacher. The second framework is Epistemological Move Analysis (EMA) developed by Lidar, Lundqvist, and Östman (2006) defined as discourse moves that are instructional, reconstructing, reorienting, generative, and confirming that allows us to examine how teachers use discourse to guide and support students in noticing information is important to the construction of knowledge. While the ultimate responsibility for shifting practical epistemology lies with the students, the teacher can, through their discursive and epistemic moves, provide the opportunities for this to occur.

Tabak & Kyza's (2018) scaffolding functions were utilized to reveal how discourse created synergistic scaffolding to support student reasoning. The role of technology, and in this case educational simulations, is

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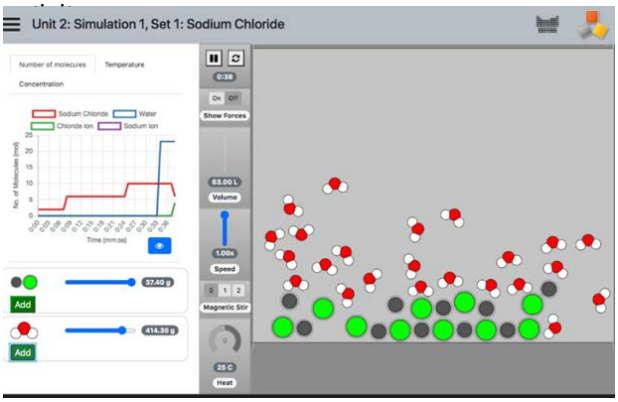
investigated to look at how teachers use discourse in classrooms utilizing educational simulations. Specifically, how teachers use discourse to create a synergistic relationship between discussion and simulation tools, in such a way that supports students' development in scientific reasoning.

Present study and context

The present study analyzed a subset of data collected during the Connected Chemistry Curriculum (CCC; Stieff, 2019) project that implemented chemistry curriculum accompanied by visualization software. As part of the project, video recordings of teachers were analyzed using the Reformed Teaching Observation Protocol (RTOP; Piburn et al, 2000, p. 34). Data of teachers who utilized the simulation while also demonstrating reformed teaching practices were identified and considered for further study. Here we present one case study out of a collection that demonstrates how teachers use inquiry-oriented and epistemic discourse moves to create synergistic scaffolding between the discussion and simulation tools of the classroom. This case takes place during the last 25 minutes of a 90-minute class period where CCC materials were in use. The topic of molarity, or concentration of a solution, is discussed and then observed using the simulation. A screenshot of the simulation screen for this activity is shown in Figure 1. Discussion takes place in a whole class setting whereas simulation use is done in smaller groups of 2-3 students. The teacher walks around to engage students in questions about their work during the simulation time.

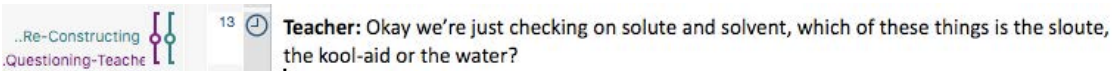
Figure 1.
Example of a simulation screen from the Solutions



Results

The teacher in this case, begins with a whole class discussion to initiate interest in the topic of concentration. The topic of concentration is first connected to an everyday scenario by the teacher asking students if they have ever had a drink that was too strong and had to water it down. Using a telling discourse move the teacher explains this phenomenon is called concentration. The teacher then uses instructional discourse move to create an epistemic reconstruction of the task of thinking about concentration in terms of the chemical words, *solute* and *solvent*. The teacher does this by drawing a representation of a mixture of Kool-Aid™ and water. The teacher then asks students to label the solute and solvent in the diagram (See Figure 2).

Figure 2.
Labeling the diagram with terms solute and solvent.



This demonstrates how the teacher creates synergistic scaffolding to connect discussion and the simulation by pointing out that this diagram will be a reference when using the simulation (See Figure 3). The teacher, using instructional and reorienting moves, make explicit the terminology is important to understand because it will "*come up in the simulation*" (Figure 3). Using Tabak & Kyza's (2018) scaffolding lens, we can see the function of the notes aim to reduce complexity of using the simulation.

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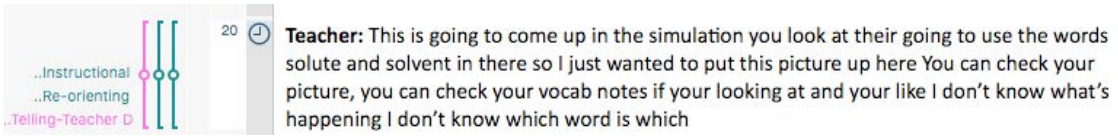
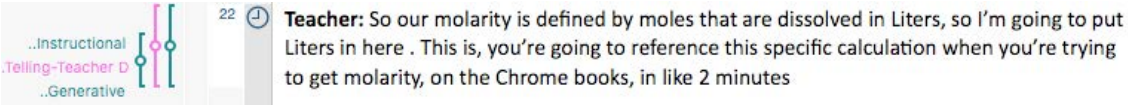
Figure 3.
Modeling language important to understanding molarity.



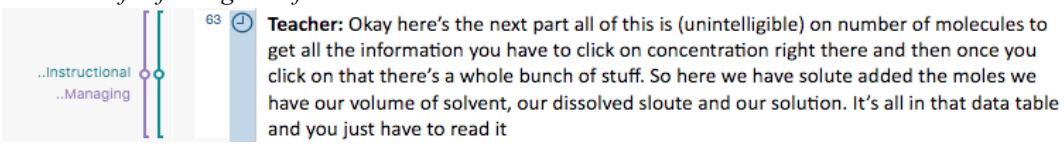
The teacher continues using instructional moves to provide students with a way to calculate the concentration called molarity. This equation specifically identifies the concentration as number of moles of solute per liters of solution. The teacher uses this generative epistemic move to reduce complexity and create synergistic scaffolding between tools stating, "*reference this formula*" when they switch from discussion to using the simulation (See Figure 4).

Figure 4.
Equation for molarity calculations.



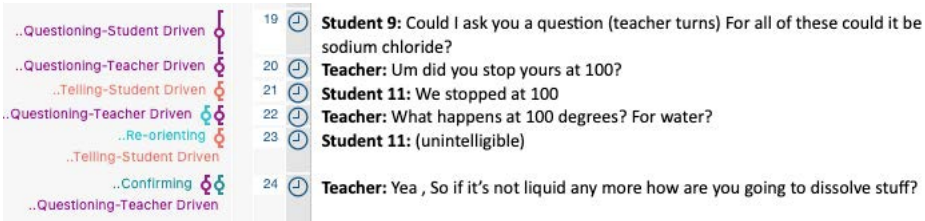
Students in groups of 2-3 collect a worksheet, and one Chrome book to begin work with the simulation. The teacher uses managing and instructional discourse moves to help students navigate the simulation while also providing instruction on what data to collect and how to manipulate the variables to create that data. The teacher also uses these moves to tell students what to notice and how to use this information to complete the task of calculating molarity (See Figure 5). These epistemic moves support students in finding the information they need to reason.

Figure 5.
Directions for finding data for calculations.



Variable manipulation is left up to the students giving them epistemic agency to explore the simulation while executing the task. A problematic scenario is created for one group seen in Figure 6. At line 19 a student observes that the simulation is displaying only one type of particle. The teacher uses a questioning discourse move creating an epistemic reorientation for students in the group to pay attention to the variable of temperature (line 22). The teacher uses a questioning move to reveal what prior knowledge students have about what happens to water at 100°C, the temperature the group has used in the simulation (line 22). The student's response is not audible due to data quality however based on the teacher's response, "*so if it's not liquid,*" we can deduce the student concludes that the water has vaporized. The teacher also uses this moment to ask the question "*how are you going to dissolve stuff*?" creating an epistemic reorientation that signals the student now has the knowledge to be able to reason about the initial observation that only sodium chloride was present in the simulation.
Multiple groups create the same problematic scenario, setting the temperature either too high or too low, inhibiting the mixing of the solute. This teacher repeats the use of inquiry-oriented and epistemic discourse moves creating a dialogue that helps students make sense of their observations from the simulation.

Figure 6.
Students ask what happened to the water?



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Discussion

While classroom technologies have been integral in giving students access to scientific phenomenon, we demonstrate here how the teacher makes this technology accessible such that epistemic shifts and student reasoning can occur. By using the IODM and EMA frameworks we see how the teacher creates this accessibility by using synergistic scaffolding between the tools of the classroom such that tools function to scaffold one another. This is created through the deliberate discursive moves that use the basis of argument to support inquiry and epistemic agency for the students. How students understand observations are revealed by the teacher through discourse moves that develop and draw attention to conceptually important details. Using these details, the teacher prepares students to make observations that provide opportunities to reason and create epistemic shifts.

Revealing how the teacher integrates discussion and simulation using discourse moves demonstrate how creating synergistic scaffolding can provide Between tools. Students could have made similar observations while using a simulation without the presence of the discourse, however, what would be missing are the scaffolds provided from the discussion that students can tap into when attempting to make epistemic shifts. The same can be said in the reverse; that discussion alone may have afforded some students enough to reason through concepts, but by providing the visualization of phenomenon with opportunities to create a problematic scenario, students were able to observe a phenomenon giving them a visual opportunity for solidifying their reasoning.

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Distributed Creativity Mediated by Social and Material Interactions in a Collaborative Pop-up Makerspace in India

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Abstract: Collaborative making involves the coming together of makers, sharing resources in the situated environment, influencing each other's ideas and design processes. The article aims to contribute to the understanding of social and material interaction in making, which can inform the design of socio-technical spaces that promotes creative outcomes. In this study, we investigate how makers engage with each other and with materials while working in ill structured problem-solving making context. We specifically look at data from a medical device innovation camp which is a pop-up makerspace setting, to assert the distributive nature of creative making. Our analysis suggests that social and material conversations are significant in shaping the making process, engendering distributed form of creativity.

Introduction

Places like hackerspaces, FabLabs, schools, museums, libraries, homes, online communities, and temporary 'Pop-Up' makerspaces have been explored as part of the growing Maker movement to promote maker engagement with technology, afford knowledge sharing, and collaborative creative production (Halverson & Sheridan, 2014). Making often involves events of problem solving, where makers work in groups and utilise the available resources to arrive at feasible solutions. In this context, group creativity has become increasingly important with emphasis on understanding how creativity emerges from sites of collaborations. At the group level, creativity is not an individualistic mental process but it is embedded and distributed in social groups and collaborative networks (Sawyer & Dezutter, 2009). As per this perspective, creative thinking is *distributed* via interaction between people, dialog between people and objects, or interactions over time (Glăveanu, 2014; Sawyer & Dezutter, 2009). The idea of design as a conversation with the situation (Schön, 1983) opens the path to understand the interplay of social and material aspects in making, where makers converse with fellow makers and materials, resulting in creative design possibilities. Often the maker-material interaction leads to *being*, *doing* and *becoming* material conversations in finding creative solutions to design problems (Gravel & Svihla, 2021). *Being* material conversations considers the materials as well-known and not improvable, whereas *doing* material conversations involve exploring known material affordances that can be utilised to make progress in solving a design problem. A *becoming* material conversation is characterised by transformed purpose, reconfigurations and modifications of materials (Gravel & Svihla, 2021).

Drawing from all these prior literatures, in this paper, we investigate how maker and material interactions involving being, doing, and becoming conversations contribute towards the distributed form of creativity in a pop-up makerspace. The temporary makerspace for this study consists of a five-day medical device innovation hackathon attended by medical, design, marketing, and engineering domain experts. Drawing on the perspective of design as an inherent practice within the making process (Halverson & Sheridan, 2014; Dougherty, 2012), we consider the domain experts as makers, the process they engage in as the making process, and the medical innovation camp setting as the pop-up makerspace. We position the creative aspects of the making process as distributed phenomena (Hutchins,1995; Glăveanu, 2014; Sawyer & Dezutter, 2009).

Analysis

Data for this study was collected as part of a larger five-day medical device innovation camp organized by the Biomedical Engineering & Technology Incubation Centre at a leading engineering institute in India. The organizers facilitated team formation by enabling participants to form clusters around a predefined set of twenty medical problems generated by multiple doctors. Teams were provided with prototyping kits consisting of: basic hand tools (knives, screwdrivers), power tools (hand drill, pillar drill), marking pens, pencils, rulers, drawing chart papers, plastic sheets, tapes, glue, sticky notes, basic electronic components (e.g., breadboard, LEDs, jump wires, battery). The audio and video data along with field notes and observation logs for day 1 and day 2, of two teams - Team A and Team B- formed the data set for our analysis, as the rest of the data was not available due to hard-disk storage failure. We follow the case study methodology (Merriam, 2007) to investigate the role of social and material elements on distributed creativity in making. We used the content logs to conduct interaction analysis (Jordan & Henderson, 1995) focusing on talk and use of artifacts and technologies, to unpack the moment-by-

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moment emergence of distributed creativity during group work. We identified 'significant moments' for analysis by looking for discussions on design decisions, participants talking with and through materials, ideational dialogic exchanges between participants, and shared agency (Gravel & Svihla, 2021) in our dataset. Further we used the approach of being, doing, and becoming material conversations to analyze these episodes (Gravel & Svihla, 2021).

Findings

We found that makers in the pop-up makerspace demonstrated episodes of collaborative idea transfer, negotiation, building shared knowledge, and taking part in *being, doing,* and *becoming* material conversations. We present these episodes in the form of two cases to show the kinds of social and material conversations and the interplay of human and non-human factors that shape the distributed creative making processes.

Figure 1

The prototypes made by Team A, PVC model (a), Mask-PVC model (b), Team B's SME drawing circle and making markings on the sheet (c), Mobile phone-plastic sheet prototype (d)

(a) (b) (c) (d)

Case 1: Blow through unit

The particular episode discussed in this case is from Team A's first design session (Day 2 of the medical innovation camp). Team A worked on medical needs arising out of obstructive lung diseases to extract the sputum that gets deposited in the patients' respiratory system. Team A consisted of a doctor - Subject Matter Expert (SME) (male), designer (male), mechanical engineer (male), and an electrical & electronics engineer (female). The team has at their disposal a nebuliser mask, an intermediate PVC prototype previously made by the SME, plastic balls, steel balls and marbles, in addition to the prototyping kit. The following excerpt illustrates how maker and material conversations together contribute to the creative making process of addressing the problem of air leakage.

Designer:	[looks around] what if I have this mask [takes the nebuliser mask from the work table and inspects the profile].. and attach it to the pipe... not with the holes [points to the holes in the mask].
SME	[connects the PVC prototype with the mask by pressing the pipe entry to the mask hole] You want to have it like this, right angles?
Designer:	We need to seal the holes to make it work.. we can tape it.
Designer:	It should be taped from inside, otherwise. [tapes the holes in the mask]
SME:	Let me try it now. [wears the mask and PVC assembly, then blows]
SME:	I can feel it now.. the air, but it is reduced.

Here, Team A members are sitting around the assigned work table, investigating the intermediate PVC prototype (see Figure 1(a)) and subjecting it to tests and manipulations. Even though the nebuliser mask was present at the table for a long time, the designer is the one having a *doing* material conversation with the material, by inspecting the profile and suggests using it along with the pipe. The SME acknowledges the idea, initiates material negotiation by connecting the PVC prototype and nebulizer mask in angular configurations (see Figure 1(b)). The makers move towards *becoming* material conversations through manipulating the joint affordances of PVC prototype and the nebulizer mask, integrating into a single unit and covering the holes with tapes, thus giving the unit a transformed purpose for ease-of-use and minimized air leakages.

Team A continued to work on designs which were based on the heuristic of air column vibrations. The following excerpt shows an episode where externally prompted questions from the mentor are embedded in interactions and facilitate the material conversations resulting in a shift in guiding principle from that of *air column vibration* to *pressure difference in layers of air*.

Mentor:	[points at the PVC prototype] Why is it vibrating?
SME:	I believe that it is vibrating because the air is just escaping from the top end and the marble drops, then air vibrates.
Mentor:	I will try with the plastic ball [places the ball in the prototype and blows]. Still, I can feel it but very less.
Mentor:	What if it's a heavier ball.? [takes a steel ball, places it in the prototype and then blows] vibrations, vibrations.
Mentor:	You must have seen the tractor with the chimney and its lip? What happens there? it also vibrates, right? Why does it vibrate?
Designer:	[thinks for a moment] It is a buildup of pressure, there comes a point where the pressure exceeds the weight of the chimney lip, it goes up, then again when there is not enough pressure, the lip falls back.
Mentor:	So.. that is why it vibrates.

In the above episode, the mentor joins the team at the work table and questions the team members about the principles used. The mentor tests the prototype with different kinds of loads (e.g., plastic ball, steel ball, marbles) to understand the solution approach and show the possible prototype responses to Team A, by utilizing the properties of the size and weight of different types of balls available. Thus he engages in *doing* material conversion with the balls, prototype, and enters into conversation with the team about the various outcomes. The prototype thus becomes an anchor point for further interaction thereby leveraging the social and material conversations for co-construction of knowledge required to improve their design.

Case 2: Angular measurement unit

The episode shown below is from Team B's ideation session (Day 1 of the medical innovation camp). Team B is focused on monitoring clubfoot deformity to help doctors monitor the changes in deformity during the course of treatment. Team B consisted of a doctor - Subject Matter Expert (SME) (male), designer (male), software engineer - S/w engineer (male), and market expert (male). The team has at their disposal a soft foot model and a skeleton foot model, in addition to the prototyping kit.

SME:	So.. what I am thinking is to use mobile phone, to take photo and process it.
S/w Engineer:	That means..we need a device, which has some scale sensor, added to a mobile phone and software.
SME:	[draws sketches on paper with pencil and explains] If we standardise foot position and mark the points on foot with stickers, it is possible to capture those in photos and then we can connect dots to get the angles..
S/w Engineer:	mm.. if we move the entire set up to a box, [gestures the imaginary walls with hand] and we keep the top open, bottom with a footrest.. then we use a selfie stick like attachment for camera.. and with clean backgrounds..we can use cardboards and white chart papers for making it and a dial.
SME:	That's why I want to have the mechanism prebuilt in the device, then we don't have to carry the dial.. like an app..our mobile phone.

Here, team members are sitting around the work table, discussing ways in which the concept of measuring deformity and continuous evaluation can be achieved. We find *doing* material conversations coming into play when SME considers using the mobile phone for image processing, satisfying portability, by exploring the affordances of the device. The software engineer identifies cardboard to build the frame and white chart papers for clean backgrounds, where both the materials get tangled in *being* material conversations. As the making progressed, the SME interacts with a thin plastic sheet by examining the transparency. Then, he cuts the sheet into a rectangle shape, draws a circle at the centre of the sheet, marks angular measurements and fixes the sheet over the mobile screen with transparent tapes (see Figure 1(c)). The Mobile phone was part of *being* material conversations initially, meant for only capturing images and later got extended to *becoming* material conversations through the various modes of interactive operations between SME, mobile phone and plastic sheet. (see Figure 1(d)).

As in the case of Team A, the mentor interaction has significant influence in Team B's making process. At multiple instances during the ideation and prototyping sessions, we observed the mentor problematizing the

use of *reference planes* and *reference lines for angular measurements*, which further refined the particular guiding principle for the solution approach.

Discussion and Conclusion

We have presented two cases of making in a pop-up makerspace having the theme of medical device innovation, where domain expert makers and materials involved in *being*, *doing,* and *becoming* material dialogues through which, they traverse through the problem and solution space. As the makers and materials get into such conversations, we find makers trying to explore the available materials and related affordances, to which the materials respond, effectively entailing creative formulations. The makers are found to approach materials with preconceived material properties, which are either embedded in the making as such, or transformed into other qualities so as to address the problem scenarios. In Case 1, we have seen the translation of *doing* to *becoming* material conversion in a sequence of interactions involving the designer, SME, PVC model, and nebuliser mask while negotiating the problem of air leakage. Similarly, in Case 2, we have shown instances where SME involved in *becoming* material interactions leading to the creation of a proof-of-concept with a combination of mobile phone and plastic sheets. These sociomaterial conversations show materials are more than just mediators, but taking up the roles as actors, similar to that of makers (Latour, 1996), which reiterates the material aspect of creative actions (Pickering, 1993). The findings point towards the distributed creative process, where team members and material resources were actively contributing to tackle uncommon problems (Glăveanu, 2014; Sawyer & Dezutter, 2009). In both cases, the mentors played a crucial role in problematizing and refining the guiding heuristics, which enabled the teams to make progress towards a useful solution.

The findings from the study suggest that makers, materials, and mentors collectively contribute to the making actions thereby upholding our argument that creative making processes are distributed across the social and material elements of the situated environment. Analyzing distributed creativity in makerspaces using the social and material conversations lens, may help us reframe our outlook towards the natural emergence of creativity in making and calls for more attention towards human and non-human factors in situated learning contexts. Further studies are required to expand our understanding related to the sociomaterial entanglement in creative making contexts.

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Co-Construction of Third Space of Joy and Playfulness Through Critical Transdisciplinarity: Land-Based STEM Learning With Refugee Children

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Abstract: People from non-dominant farming communities have rich engagement with STEM concepts, rooted in their families' everyday lives, intergenerational cultural practices, and environments. However, such culturally embedded knowledge and associated STEM literacy often remain separate from STEM learning at school. Particularly working with Yazidi and Syrian refugee families from rural regions, we co-designed land-based STEM learning opportunities that center embodied knowledge of traditional farming practices. In this paper, we present examples where facilitators and child participants co-created spaces to express their intergenerational and emerging understanding of land, farming, and STEM, with joy and pleasure. Particularly, we decenter damage-centered narratives associated with refugee children by centering their agency, creativity, and desire for joy in the learning spaces. Participants co-created a Third Space where they engaged in the learning activity on their own terms, while challenging and reimagining some underlying socio-political ideologies and power dynamics.

Disciplinary formation under the hegemonic institutionalized practice of knowledge production can be regulatory and constraining. In the disciplined spaces of learning, learners paradoxically become subjugated as docile bodies in hegemonic disciplinary practice, as they gain more "aptitude" or a "capacity" as a form of capital (Takeuchi et al., 2020). Critical transdisciplinary perspectives to STEM education acknowledge this hegemonic production of learners through the western capitalistic gazes and urge us to move toward reimagining disciplinary boundaries to center embodied and community-based knowing of historically marginalized communities (Strong et al., 2016; Takeuchi et al., 2020). In this reimagination, we need to understand disciplinary contexts that youth and children co-construct for their joy, pleasure and meanings *on their terms* (Alim, Paris & Wong, 2020). We draw on the concept of Third Space, where the formal and informal learning spaces intersect to create a space for emerging student-teacher interactions that are expansive, generative and historically profound (Gutiérrez et al., 1995). Third Space emerges when diversity, conflict or tensions within the learning space are directed towards rupturing, innovating, and reorganizing the official learning activity (Gutiérrez et al., 1995). Within Third Space where playfulness of children and youth are embraced, opportunities arise for challenging the traditional learning hierarchies, collectively redefining what counts as knowledge, and transforming pedagogical spaces into "a site where no cultural discourses are secondary" (Gutiérrez, 1995, p. 447). In this paper, we present examples where facilitators and child participants co-created spaces to express their intergenerational and emerging understanding of land, farming, and STEM, with joy and pleasure.

Methodology

We draw from participatory social design-based experiments research methodology (Gutiérrez & Jurow, 2016) that centers historicity, diversity, equity, and ecological resilience as design principles with aims to co-design just practices and futures in partnership with a range of communities. Our co-design was centered around a vision to design and study land-based learning through Soil Camp to amplify learning opportunities for refugee children and youth in STEM that are relevant and connected to intergenerational and community knowledge of soil, ecosystems, and farming on a regenerative farm (see Takeuchi et al., 2021). Our university team, composed of educational researchers, teacher candidates, and teachers who are mainly racialized multilinguals with diverse disciplinary expertise (e.g., mathematics, sciences, arts, and social sciences) designed and led activities to understand the soil and ecosystem better. In 2021, 65 youth and children (aged from 5 years old to 15 years old) and over 20 families joined our program. All attendees were refugees from Syria, Northern Iraq, Kurdistan, New Guinea, Pakistan, South Sudan, Ethiopia, and Eritrea who had resettled in Canada within the last five years. The activities during the two weeks of Soil Camp in July 2021 were documented using Go Pro and still cameras (total of 31.43 hours of video data) by both the participants and researchers, and

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Handycam video cameras held by the researchers. In addition, each member of the research team has taken field notes right after each activity.

The analytic focus of this paper is one of the activities that participants engaged in where participants accepted and designated roles involved in a farming season and acted them out. The setting of the activity involved participants sitting in a circle on the land at the urban farm. The activity began with the facilitator prompting the question, "What is a farm?" and inviting participants to enact the events that happen during the growing season. Participants interacted with props made by the facilitator which included seeds, plants, farmers, worms, bees, weeds, butterflies, and vegetables, but they also spontaneously added additional props. Our analysis focuses on instances where the participants shared their knowledge about the soil, ecosystem, and community farming practices. Instances of intersection between the formal and informal script of the learning activity, co-creating a Third Space became our analytical focus (Gutiérrez et al., 1995). Through collective watching of these instances, we observed that the interactions during the activity were immersed in a sense of joy, humor, and playfulness among the participants. The sense of joy was evident both during planned pedagogical activities and unplanned moments through smiles, humorous interactions, and creative engagement with the activities, as the pedagogical approach supported and encouraged the identities, strengths and autonomy of the participants. Any interruptions to the planned activity were viewed as agentic and creative attempts by the participants to engage on their own terms. Participants not only showcased their intricate informal knowledge of farming, but also exercised their agency in choosing when and how to participate in the activity. Particularly, two representative episodes of activity were chosen to demonstrate children's participation in the learning activity on their own terms.

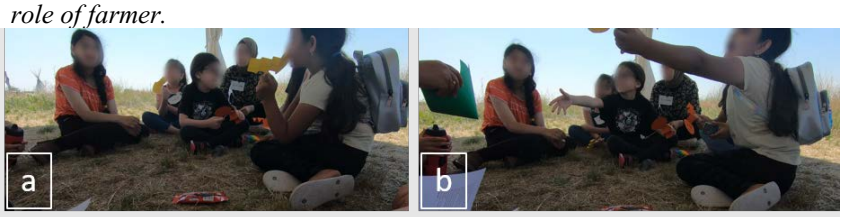
Findings

Who wants to be a farmer?

This group was composed of six students and four facilitators. After acting out the roles of soil and worms, the discusion was directed towards including the role of farmers. When the facilitator asked for volunteers to become farmers, participants in the circle refused to take on the role and become physically disengaged (Figure 1a). As many of the participants were from farming backgrounds and had experience of farming on the land with their families, enacting the role of a farmer was assumed to be familiar and relevant to their life experiences. However, the refusal to take on the role of farmers could be related to multiple contextual powers and social hierachy and social valorization (de Abreu & Cline, 2007). When all children refused the role of farmer, one of the facilitators accepted the role and was given a green paper hat. This hat caught the attention of some of the children who immidiately became interested in taking up the farmer role (Figure 1b). In the context of the activity, the participant and facilitators overcame the hesitation to take on the role of the farmer by building on elements of joy and playfulness. In this interaction, this hat became a "pivot" (Vygotsky, 1978) that invited children to enter into a playful world, shifting the frame of the ideological world where the role of farmer and farming was valorized to one of playful engagement with farming.

Figure 1

(a) Participants become disengaged when asked to play the role of farmer, (b) when the green aper hat is associated with the role of the farmer, participants are enthusiastic to assume the role of farmer.



Once the role of the farmer was accepted, the facilitator invited the farmers to sow their seeds on the make-believe farm at the center of the circle. Lamiya took the role of the lead storyteller. When asked "how are you going to do it?", Lamiya gave an embodied overview of the process with the help of Wassim and Farida as shown in Excerpt 1. For the next few minutes of the activiy, the participants enacted the sowing of seeds and dynamically recreated a scenario where the worms, sun and water played a role in helping the seeds grow. The intricate knowledge of farming expressed by the students (excerpt 1) indicate that their initial hesitation to take the role of farmer was not due to a lack of knowledge or understanding. Instead their participation in the activity

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was motivated and influenced by their desire for joy and playfulness (eg., wearing the hat). During the activity, the students used their unofficial understanding of farming and associated STEM literacy to negotiate and enact events in an official learning space, thus creating a collective Third Space (Gutiérrez et al., 1995).

Excerpt 1		
1	Lamiya:	We are going to dig over here ((removes some grass)) put a seed in it ((places the cardboard seed and covers it with grass)) then we plant some, we put some water in it ((enacting with fingers spread out)) then we wait for a long time ((Farida places her worm near the buried seed)) then the worms come in the soil and rub ((picks up the worm and moves around)) they go around everywhere
2	Farida:	[And they eat this ((taking out the buried seed))
3	Wassim:	[What about the sun?
4	Lamiya:	And they eat ((takes the seed from Farida, but is interrupted))
5	(F) Mahati:	What about the sun?
6	Lamiya:	The sun shines on the soil till (1.0) till it makes the plants grow
7	Farida:	This could be the sun ((brings a green ball and places it in the circle))

Dinosaurs and Rabbits

This group was composed of nine students and four facilitators. In this episode, it was harvest season, towards the end of the activity. The facilitator introduced rabbits as animals that would visit the farm. There were only two props available to play the roles of rabbits. Instead of being passive observers of the events on the farm, the participants exercised their creativity and agency to take up active roles. Bringing in dinosaur toys from their ongoing games outside the context of the soil camp activities, the participants grouped dinosaur toys as 'animals' who were trying to eat the vegetables along with the rabbits. Participants initially navigated tensions around incorporating carnivorous dinosaurs into a farm where the only available food was vegetables. This created a temporary impasse, where the dinosaurs were unable to participate on the farm (utterances 1 to 4 in excerpt 2). However, when the facilitators prompted the participants to save the produce, they creatively distorted the behavior of carnivorous dinosaurs, who immediately proceeded to consume the vegetables. The act of resisting the collection of the produce from the farm was a source of humor and joy for the participants (utterances 6 and 7 in Excerpt 2).

Excerpt 2		
1	Usub:	I (.) eat(.) meat(.) ((holding a dinosaur toy with both his hands))
2	Emine:	((inhales deeply to show shock, then picks up a tomato and extends his hand towards Usub's dinosaur toy)) Okay, here you go. [You need to eat healthy now. Eat(.) eat a tomato ((waves the tomato near the dinosaur)) eat a tomato
3	(F) Mahati:	[let's pick our vegetables so that we can eat it ourselves (,) oka:y?
4	Usub:	<I hate tomato> ((Emine takes back the tomato))
5	Raneem:	Let's protect all our toma:toes, all our ca:rrots, all our zucchinis
6	Usub:	((places a tomato in the dinosaur's mouth and turns towards Raneem)) they're going to be protected in my stomach
7	(F) Mahati:	((Hazim puts down a robot toy, picks up a dinosaur and slowly moves his dinosaur towards a zucchini in front of him to eat it)) No:: <I'm going to take it> ((Hazim looks at Mahati as she grabs the zucchini from him and smiles slightly))

Participants introduced dinosaur toys from their informal games in the formal learning space to recreate a unique farming scenario. Altering the course of the activity by bringing in dinosaurs to the farm reenactment, students supported the emergence of a Third Space with renewed opportunities to participate and rewrite the script (Gutiérrez et al., 1995). With the conclusion of dinosaur rampage, one of the children who assumed the role of farmer turns his storyline back to the rabbits. Earlier in the activity, he described potential interactions with rabbits, "there is a rabbit that wants carrots or anything, if it can't pull it out, the rabbit will be scared. When he goes away, you can pull some carrots out and leave it. They will come and eat it". Building on the

same narrative, he created a physical separation from the rest of the farm where he placed a few carrots, a tomato, and a rabbit. Ignoring the facilitator's plea to pick up all the remaining produce from the farm, he offers to put on a show. Through the enactment of a compassionate farmer who allows a rabbit to eat his carrots and tomatoes, the participant challenges the facilitators' goal of saving all the produce for human consumption. Instead, he draws on his understanding of the values of farming and depicts care for more than humans. Throughout this episode, participants constructed a layered and complex learning space not only based on their intergenerational knowledge and values of farming but also based on their everyday games and toys. Through their unique interactions with dinosaurs and rabbits on the farm, participants demonstrated that their ways of knowing and being "both remains rooted and continues to shift in the ways culture always has" (Alim, Paris, & Wong, 2020, p.267).

Discussion

In the context of STEM education where the formal curriculum is deeply rooted in Eurocentric knowledge systems, we presented co-constructed interactions where non-dominant ways of STEM knowing and doing can be made visible. Specifically, we draw attention to the emergence of a Third Space (Gutiérrez et al., 1995) driven by participants' desire for joy and playfulness. In this space, interruptions to the planned learning activity through play and humor were not acts of disruption, but agentic and creative attempts by the children to bridge formal and informal knowledge of farming and embedded STEM literacy. Our paper highlights how participants and facilitators co-constructed ways of challenging prominent socio-political ideologies around the discipline of STEM through moment-to-moment interactions that center joy and pleasure. This research builds on critical transdisciplinary approaches to STEM teaching and learning that aims to decenter the western capitalistic discourse and center knowledge and experiences of historically marginalized communities (Strong et al., 2016; Takeuchi et al., 2020). Through this study, we learned that making STEM discipline relevant to *fixed* cultural knowledge around farming, building on refugee families' farming background, is not sustaining or transforming (Alim et al., 2020). The findings highlighted how children exercised their agency to participate and bring in relevant knowledge around farming *on their terms* and co-determine the trajectory of the learning activity. While being cognizant of relevant STEM knowledge, participants created unique narratives to humorously and playfully engage with their peers and facilitators. These observations advance critical transdisciplinary approaches to STEM education towards accounting for complexity of non-dominant learners, dynamically shifting relationships with their communities and evolving cultural practices (Alim et al., 2020). Particularly, to effectively advocate for the interests of non-dominant communities, our work advocates for adoption of desire-based pedagogical approaches (Tuck, 2009) that build on learner creativity, agency, and joy.

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Tensions in extending visions for social change through educational research in Indian contexts

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Abstract: Newly evolving methodological approaches in Learning Sciences that use critical and ecological lenses to design provide ways to identify and address emergent tensions regarding social change through educational research. Such tensions get uniquely manifested in different socioecological contexts. We analyse them in the three studies that we conducted in India. Based on intersubjective insights into the data, we identify '*how do'* different tensions manifest in four categories (educators/researchers, practices, learners, and learning environments) and '*how to'* engage in various ways to address these. Our work attempts to contribute to the discussion around educational approaches to social change making with the help of cases from contexts other than where the approaches were developed.

Introduction

We, the authors of this paper, along with many other Learning Sciences researchers, care about translating our evolving personal visions into the domains outside the academic field of Learning Sciences. As different methodological approaches in the Learning Sciences evolve with the intention of 'social change making'; from the iterative approaches of design research to design-based research (DBR) to community-based design experiments to participatory design research (PDR) to Social Design-Based Experiments (SDBE) (e.g., Gutiérrez, Jurow, & Vakil, 2020), it is also important to think about how the goal of 'social change making' and the methodological approaches to getting there extend in educational contexts outside the United States where almost all these approaches have been developed and studied.

The evolving methodological approaches in Learning Sciences such as Social Design-Based Experiments (SDBE) try to address a gap between theory and praxis by engaging with members of communities outside academia (Gutiérrez, Jurow, & Vakil, 2020). SDBE approach seeks to co-design learning ecologies in which learning is made equitable and consequential for youth from nondominant communities. SDBEs are different from DBR because they focus on joining equity and learning goals that centre people's lived experiences as the driver of possibilities for learning such that participants become intentional designers of their own futures. Extending these approaches beyond the contexts in which these are developed requires deep consideration of some of the foundational ideas such as nondominant participants, experts, communities. For instance, such extension in Indian contexts would require treating these contexts as sites of knowledge production by recognizing ground realities, diversity of ideas, and lived experiences (Sarukkai and Guru, 2012).

As learning sciences researchers, we attempt to extend our personal visions for social change through education by learning about these methodologies and partnering with members of our communities. In this paper, we analyse our work to answer the research question: *Which tensions surfaced when we used critical and ecological approaches to social design to analyse our visions for social change through educational research?*

Methodological approach

Our methodological approach is inspired by an approach of Jackson and colleagues that builds on academic friendships and shared histories to generate analytical and theoretical insights into developing a Learning Sciences research agenda (Jackson et al., 2020). The academic friendships of the three authors of this paper led the authors to discuss the possibility of reflecting together on their Learning Sciences research visions and tensions. We used auto-ethnographic (Ngunjiri, Hernandez, & Chang, 2010) methodologies to identify and analyse tensions. Using the grounded theory approach (Charmaz, 2006) we developed emergent themes based on our intersubjective insights into the empirical data from prior case studies. We identified four common constituent categories in educational ecosystems. For each category, we developed questions that see the common emergent tensions in a broader light to enable further conversations and develop actionable directions. Our positionalities, positions, and shared histories influenced our collaborative auto-ethnographic work.

Cases: Contexts and Tensions

In this section, we present three studies, each conducted and written by an author of this paper. In each study, we highlight tensions that surfaced as we attempted to extend our visions through our works. We then present tensions cutting across the studies, which allow us to extend the discussion to broader contexts.

Case 1 - Epistemically Agentic Science Learning: My (Sugat's) evolving vision for my contributions to the field of Learning Sciences and education is about designing learning environments to support the development of epistemic consciousness. The idea of epistemic consciousness is inspired by Morales-Doyle's (2017) operationalization of Freire's Conscientização, or critical consciousness (Freire & Macedo, 2005), in his justice-centered science pedagogy (Morales-Doyle, 2017). Epistemic consciousness is about an in-depth understanding of one's relationship with knowledge and knowledge-producing practices. My goal is to study if and how such epistemic consciousness develops and translates into changed participation in different contexts.

Research context: I conducted two related studies in the US and India to design for participation in knowledge-producing practices in science classrooms. The first study investigated a learning environment designed for students to engage in investigating molecular mechanisms of gene regulation using computational microworlds (Dabholkar & Wilensky, 2020) in extra-school settings with middle school students (n=41). I was a teacher in these iterations and studied how the design features of the learning environment, both technological and pedagogical, supported students' epistemic agency. The second study was a shift towards participatory design. It was about a program called CTSI (Computational Thinking and Scientific Inquiry) to co-design science and mathematics curricular units with high school teachers.

Tensions: My vision is aligned with the SDBE impetus of designing for potential opportunities for meaningful and consequential participation for the social futures of students and teachers. Such participation is meant to transform their relationship with 'knowledge', from seeing knowledge as something to be acquired to something to be evaluated and generated by them. This matters more in the Indian educational context, in which textbooks are considered a prime source of knowledge, and students are often put in the position of accepting even problematic content at the face value (Darak, 2018). However, the first tension arose when I positioned the values of the community of practice of 'scientists' as desirable values, which are mainly influenced by Western ways of doing science to design (Bang & Medin, 2010). The second tension was about co-designing learning experiences that use contexts that youth from nondominant communities find meaningful to engage with contemporary ideas and practices in science. Meaningful integration of contemporary disciplinary ideas and practices into contexts that are relevant to students of nondominant gender, caste, religion requires identifying ways that would support equitable participation. Since the discourse around supporting such participation is severely limited in India, I found it hard to press for these design goals while working with Indian teachers.

Case 2 - Urban farming as a transformative space: As an activist-researcher, my (Deborah's) vision includes creating learning environments that can enable sustainable transitions through developing critical skills and agency amongst youth; To empowering them with tools and perspectives required for reimagining just socio-ecological systems. This effort, however, entails a radical rethinking of the role of environmental education as a crucial scaffold for creating the political, techno-scientific, and cultural mobilisation to bring about desired systemic changes. There is an urgent need to pay attention to the particular histories, contexts, and perspectives underrepresented in the environmental education discourse to create alternate imaginaries that are not dominated by superficial technocratic visions of 'fixing' a problem.

Research context: My efforts to expose students to alternate forms of learning and critical inquiry took the shape of an urban terrace farm that was co-created with them. I chose food-garden as a topic of physical engagement because farming naturally provides a space to raise questions, and develop an integrated understanding of weather, food, nutrition, the economics of food production, water, and local geography. I worked with 40 students from grade 8 who were studying in a private school in the suburbs of Mumbai. The school I worked with is situated in the backyard of a landfill. The project was ungraded, and the school managed to allocate an hour every week in the morning for the activity. I worked with the students as a co-facilitator for an entire academic year along with two school teachers. The broad goal of the project was to understand and facilitate students' evolving engagement with the space, in terms of knowledge, practice, and motivations.

Tensions: The question of authenticity and legitimacy remained constant tensions that I had to negotiate with, while facilitating the project. On one hand, students' prolonged exposure and experience of creating a terrace farm from scratch led to a range of interesting responses and helped them connect ideas of waste, resource, pest-predator relationships, the role of biodiversity, respect for labour, and so on (Dutta & Chandrasekharan, 2019). However, the terrace farm failed to be seen as a legitimate space for inquiry within the curriculum. While it was positively received in the school by teachers, its definition as an 'extra-curricular activity' rendered it ineffective in expanding or subverting the conventional science/ social science topics in the school, even as students raised critical questions such as the relation between farm labour, livelihood and food price, consumption patterns in cities, rural-urban migration and so on. The possibilities were thus curtailed because teachers found it difficult to

transgress their own disciplinary boundaries and embrace the 'possibilities of radical openness' offered at the farm site. In fact, the space to a certain extent got appropriated as a tool to teach 'better science'. The question I wrestled with throughout was, 'What voices can radical, transformative experiences assume if they don't find a legitimate space in mainstream educational practices?' Additionally, though the experience of growing food was transformational for the students in many ways, it was still an isolated activity that did not engage with other aspects of their life or aspirations, unlike a rural population who are engaged in farming as means of livelihood, and thus would have a lot more at stake in terms of practice.

Case 3 - Contours of just and sustainable technology design: Designing solutions, including technologies, to address the unmet needs of the marginalised while mitigating the threats of climate change, is an imminent messy challenge that educational systems want to build agency and competency for. Towards this vision, as a Learning Sciences researcher, one of my (Geetanjali) efforts has been to characterise the examples of alternate practice, such as that of grassroots technology design, and draw takeaways to supplement, augment, or redesign learning systems or environments.

Research Context: In the Indian context, grassroots technology designers have developed micro hydropower systems as sustainable and renewable energy solutions for communities that the mainstream systems have failed to serve. I characterised the design practice of two such innovators: 1) a grassroots innovator[1] and 2) an engineering professional[2] (Date, 2019). An insight, from analysis of these and other documented cases, supplemented by a simulation-based probing of the design thinking of these innovators, suggests that the society-technology connection can be just and equitable when the design process starts with need identification and problem formulation, and not context-sanitised technical specifications (Date, 2019).

Tensions: Since one of the designers had studied only up to grade ten, a major underlying tension that surfaced from this study was the legitimacy of other forms of knowledge (procedural, experiential, place-based, traditional) and thinking (situated, distributed, embodied) vis-a-vis the formal, declarative, disciplinary bodies of engineering sciences and mathematics knowledge. This reflects in the mainstream industry's success criteria for a technology - efficiency, replicability, mass-manufacturability through standardisation leading to profit - and the values of the innovators that prioritise addressing the problems of the underserved, creating livelihoods for the local community, and supporting entrepreneurs, while causing minimal disruption to the natural ecosystems. The tension translates into the question of whether the alternate practice gets a legitimate space in the education, practice, and identity of future engineers, alongside the dominant formal knowledge. Another tangible aspect of the tension was how the other designer - a B. Tech from a top Indian Institute of Technology - negotiated the hierarchy between him and the uneducated villagers, to arrive at *their* desired solution. Expertise, when understood as formal training, and knowledge of formal structures, concentrates the power to define the 'desirable' into the hands of the trained engineers, even if they aspire to design *for* the nondominant. This generates the question of how students can be trained to recognize other forms of 'expertise' so as to develop the sensibilities to design *with* the nondominant, including the non-human species whose voice it is hard to capture?

Findings and Discussion

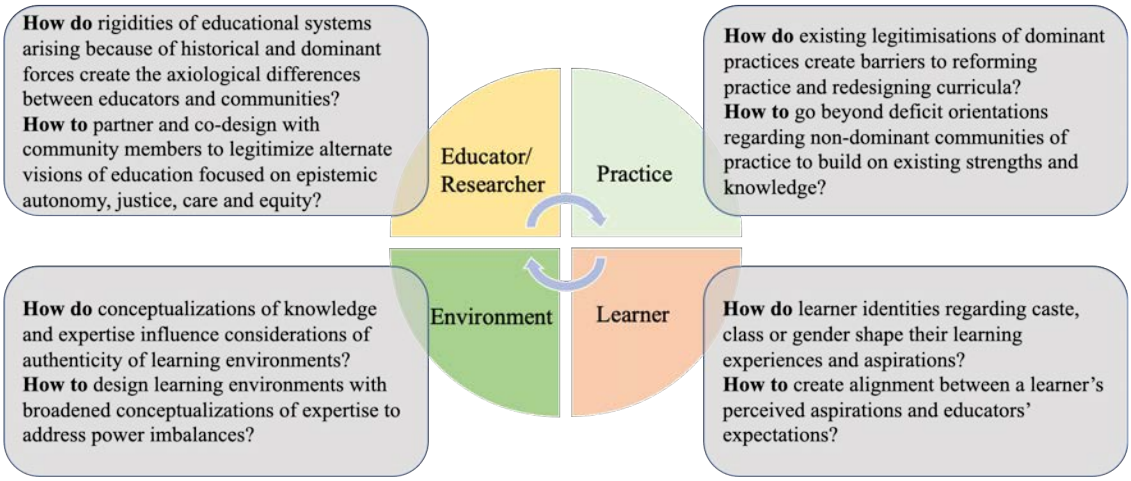

Figure 1: 'How do' and 'how to' questions to consider for translating our visions into realities

[1] Innovators recognised by National Innovation Foundation (see http://nif.org.in/) for their novel solutions to societal problems.

[2] A trained engineer who took up the design of micro hydro power systems for underserved grassroots communities.

Our analysis revealed that the tensions were spread across the range of stakeholders in the education ecosystem. The present and historical considerations of dominant and nondominant communities manifested in various ways for researchers, practices, learners, and designs of learning environments. In the further analysis of the tensions, we focused on these four categories (Figure 1). Based on the crosscutting tensions across our studies, we developed ‘how to’ and ‘how do’ questions. The first - 'how do' – question in a category captures tensions that we see as generative outcomes of our work. Building on these, we further developed 'how to' questions, which are intended to generate ongoing conversations and enable evolving ideas for future work.

The main commonality across these studies in different Indian contexts is that they aim towards reimagining learner participation in different communities of practice - scientific knowledge production, organic farming, and technology design. Such reimaginations requires questioning rigidities in educational systems - the ontological (who are considered experts in a particular field?), the epistemological (what practices of knowledge construction and evaluation are privileged?), and the axiological (what value considerations govern decision making in these systems?), which manifest in designs of the learning environments and educational practices. Given the existing legitimization of dominant educational practices, such as, focusing on student performance in standardised exams, our visions entailed a certain normative imagination regarding the desired direction of envisioned social futures and educational design. As we hold our axiological positions as researchers, regarding designing educational experiences (epistemic autonomy, justice, care, equity), and had other curriculum-specific goals such as computational thinking or organic farming, we need to be open for continuous re-evaluation as we seek to align those with our design partners who work in the existing rigid education systems with severely limited epistemic autonomy.

Our research engagements with the nondominant individuals and communities in diverse Indian contexts highlight some tensions that need to be explored, understood, and clarified as we engage with SDBE and similar methods. Rather than seeing these tensions as limitations, we treat them as generative outcomes that could be used to identify existing lacuna and build newer imaginaries. These may help the research community better understand what elements of the design and processes of social experiments need to be foregrounded in such work.

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International Society of the Learning Sciences

A Framework for *Assessing* Teachers' Readiness for Pedagogical Transformation

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Abstract: Creating conditions that empower science teachers to innovate in their classrooms is important yet challenging. The Next Generation Science Standards (NGSS) invite teachers to educate in ways that differ markedly from traditional pedagogy. We posit that this transition requires more than asking teachers to implement novel instructional approaches after participating in a few professional development sessions. We present a preliminary framework for assessing whether teachers and learning communities have the beliefs, abilities, and motivations necessary for sustainable transformations.

Introduction: The need for readiness evaluations

Science teachers feel pressure to align with the Next Generation Science Standards (NGSS) and embrace innovative methods and technology. Yet, their daily classroom practices rarely incorporate these innovations (van Driel, Beijaard, & Verloop; 2001). Research into this phenomenon includes studies of professional development (PD) effectiveness and teacher learning, beliefs, and resistance to change. Findings have yet to uncover how to reverse the trend (Wang, Olivier, & Chen; 2020).

Tensions surface when teachers and students are expected to replace traditional activities, including lectures, worksheets, teacher-led step-by-step labs, and tests, with innovative activities, including student-led inquiry, developing and using models, arguing from evidence, and constructing explanations. The aim of the present study is to identify the specific elements creating tensions and barriers that undermine teachers' readiness for change.

Video recordings of a summer PD and follow-up interviews provide insights into these tensions and barriers. Themes that emerged during a grounded analysis of the data were found to relate to Bandura's human agency work and the influencer framework by Grenny et al., (2013). Drawing on our grounded analysis and these two literatures, we present a new framework, which we call the *agency influence* framework. The framework points to areas within an education system that need evaluation and intervention before change can begin. This education-specific change-readiness framework provides direction for in-depth investigation of any educational entity's fitness to fully embrace innovation. We hypothesize that following a framework like the one presented can facilitate pointed inquiry and discussion that increase the chance for successful uptake of educational innovation in the classroom. Our discussion of the framework below documents its chronological unfoldment.

Empirical context

Data were drawn from a 4-week professional development institute, during which three middle school science teachers created NGSS-aligned instructional materials. These materials introduced students to computational modeling microworlds and scaffolded their use of the microworlds to construct their own theories of different phenomena. During our time together, the teachers spontaneously expressed the tensions and barriers they experience when asked to implement new pedagogies and technologies in their classroom. Recordings of the PD sessions were transcribed and then coded to capture and categorize teacher utterances like the ones below.

> "We have to move on [to] keep the pace, because we have to cover all the standards that the tests are going to assess students on."

> "What you can do with one kid in 4 hours is probably equivalent to what you do with 35 kids in 8-12 hours. With more kids, it takes a lot longer."

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> "It's because we have this evaluation system in place, that we have to give the tests, that we have to focus on the grades, because we're held accountable to the grades. "

> "I'm going to be like the typical 8th grader because I don't like coding. I'm not engaged in it. I don't like to do it [and] don't want to do it. I'll do [it] as a means to an end."

These utterances conveyed that our teacher partners were not empowered to take a new approach to scientific inquiry in their classrooms, despite their desire to do so. We have created the agency influence framework for making sense of the tensions and barriers experienced by our own and other teachers. The framework integrates components from both Bandura's and Grenny's work on agency.

Making sense of the influences on teachers' readiness for change

Bandura's (2001) work suggests that underlying influences deterring teacher action can be found within their beliefs, sense of self-efficacy, abilities, and motivation. Teacher utterances during the summer PD contain evidence of reduced ability and self-efficacy, as well as lack of motivation and negative beliefs. Bandura (1997) found that these kinds of affective traits can limit individuals' experience of agency. While Bandura's findings describe individual agency, they lack insights into educational resistance toward pedagogical transformation. Grenny et al. (2013) investigated influences that constrain agency and prevent people from changing behaviors in schools and societal situations where change is difficult. Grenny's key findings build upon Bandura's ability and motivation work by creating three subcategories: personal, social, and structural. A matrix showing the cross-product of *ability* and *motivation*, with dimensions of *personal*, *social*, and *structural* influences, is shown below in Table 1. These subcategories form the backbone of our agency influence framework, shown on the next page in Figure 1.

Table 1: Personal, social, and structural sources of influence on ability and motivation

	Ability	Motivation
Personal	The individuals have skills, understanding, strengths or tools to do the right thing.	They want to engage in the new behavior.
Social	Resources, training, encouragement & support are provided by the community.	Leaders and community members encourage and reward the new behavior.
Structural	System constraints or expectations and environmental characteristics such as space, time, tools, or other elements are provided.	Systems are rewarding the right behaviors that are effective in the new behaviors.

Grenny et al.'s (2013) findings show that people are more likely to change behavior when all six sources of influence support that change. We evaluated the six sources of influence against the utterances of the teachers (Table 2). Evaluating the teachers' talk in this way brought to light structural systems, social relations, and personal states of being that influence behavior decisions. Other phrases like, "I'm not good at coding," correlate with Bandura's (2001) belief influences. These are also included in the table below.

Table 2: Evaluating teacher utterances to determine sources of influence

Teacher utterance	Source of influence	Explanation
We have to move on, [to] keep the pace, because we have to cover all the standards…	Ability structural	A structure is causing and rewarding things the teacher doesn't feel capable of changing.
	Motivation personal	The teacher doesn't enjoy or want to engage in the behavior.
… I don't like coding. I'm not engaged in it. I don't like to do it, [and] don't want to do it. I'll do [it] as a means to an end.	Ability personal	Skills, resources, or training are needed.
	Ability social	The community doesn't provide support.
	Motivation structural	Ineffective actions are rewarded.
	Motivation personal	The teacher doesn't enjoy or want to engage in the activity.
It's because we have this evaluation system in place, that we have to give the tests, that we have to focus on the	Ability structural	Systems don't enable choice .
	Motivation structural	Systems don't reward actions outside tests and grades.

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grades, because we're held accountable to the grades."	Motivation personal	The teacher doesn't enjoy the activity.
	Motivation social	People are measuring test and grade performance not NGSS skill development.
I'm a little overwhelmed right now, because I've had no experience with the aggregate-pattern theory building.	Belief personal	The teacher is questioning their ability with something new.
	Belief social	The teacher is questioning getting the support they need.

Recognizing the importance of belief, we crafted personal, social and structural influence questions following the pattern of Grenny et al., (2013). We present these questions in Figure 1. When Bandura discussed agentic action he included self-reflectiveness, self-reactiveness, self-influencers and intention. We saw that self-reflectiveness plays a role in evaluation of beliefs, self-reactiveness helps define ability, and self-influencers get to the root of motivation. Intention is included as a final step to help leaders and staff clarify their courses of action and commitments.

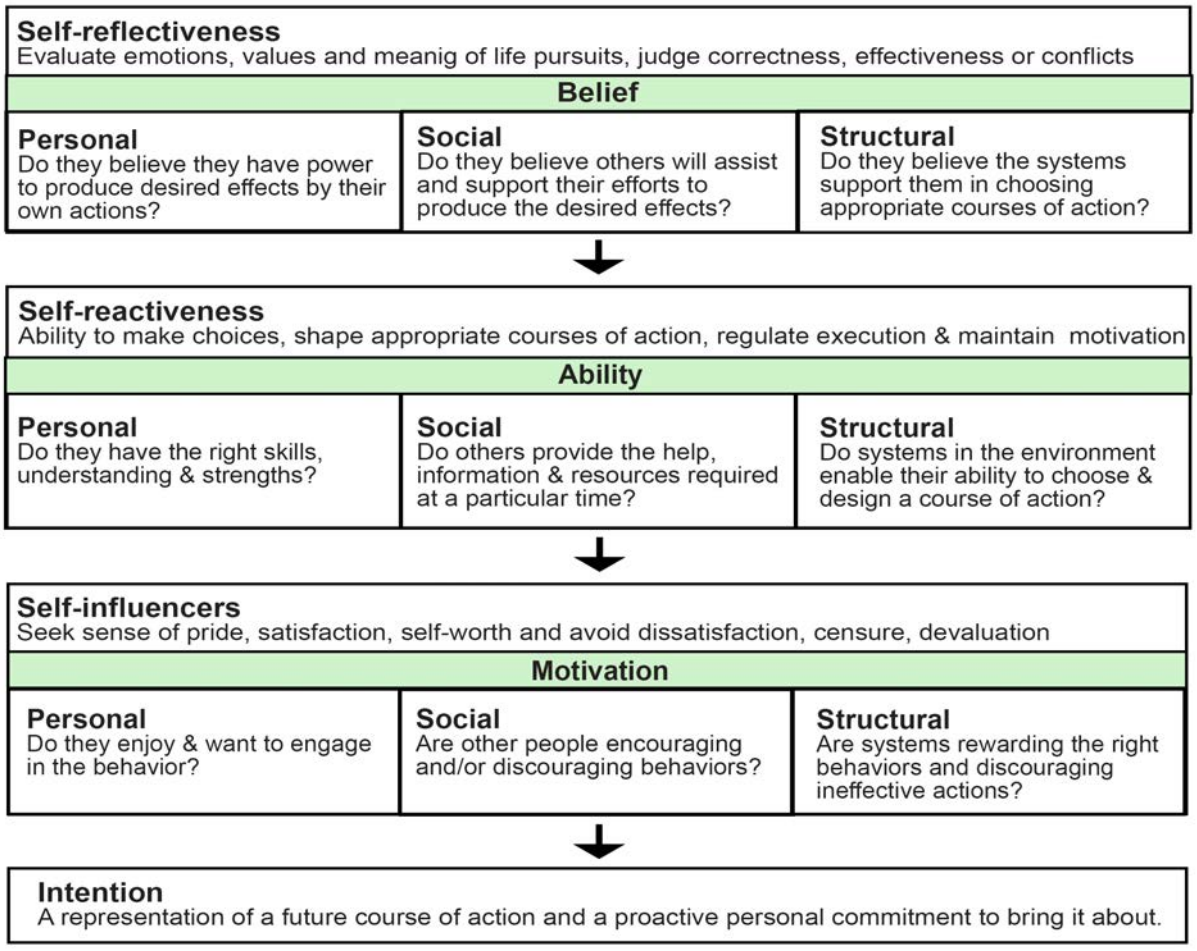

Figure 1: Agency influence framework

This framework can be used to guide education leaders through self-reflection, where they consider and discuss the state of their communities' beliefs, abilities, and motivations with respect to the proposed pedagogical changes. The discussion outcomes can be used to set a course of action supported with personal commitment to the new goal. If it is determined that the community is not ready, areas that need preparation are illuminated. Table 3 takes each part of the framework and provides possible questions education leaders can ask as they follow the guide to investigate their learning community's readiness for pedagogical transformation.

Table 3: Example of questions a leader might ask to implement the framework and evaluate their community's readiness for change

Framework component	Questions a leader might ask as they go through the readiness assessment.
Self-reflectiveness	What school culture elements cause teachers or students to feel unsafe evaluating emotions, values, judging effectiveness, or addressing conflicts? What changes do we need to make?
Belief: Personal, Social, Structural	When do teachers or students believe they do not have power to do what they feel is best for their classroom or learning? Do they believe others will assist them? When do they feel that culture/systems restrict their ability to make choices incorporating new ideas? What in our culture/systems need to change?
Self-reactiveness	Armed with beliefs, teachers need time to contemplate courses of action, regulate execution and maintain their motivation. What adjustments are needed to give this time?
Ability: Personal, Social, Structural	What skills, understandings or strengths are the teachers lacking to accomplish this goal? What do they need? When do they need it? What systems/culture are restricting their ability to take this course of action? What changes need to be made? How will we do it?
Self-influencers	When someone has taken risks to try something new, what are the responses? What are unhealthy ways we censure, devalue, or communicate dissatisfaction? What changes need to be made so that a sense of pride, satisfaction, recognition is given for the risk they have taken and value the have provided to the community?
Motivation: Personal, Social, Structural	Are cultures/systems requiring actions that are ineffective, lack time, space or engagement? Do rewards/milestones encourage or discourage people taking actions they value as most important? What culture/system changes are necessary?
Intention	Do our teachers and students have the stewardship to plan a learning course of action and a personal commitment to bring it to fruition? What prohibits this? How do we change it?

Conclusion

The agency influence framework provides a systematic approach for evaluating a learning community's readiness for change. It asks us to consider the multidimensional, complex, and complicated conditions associated with enacting change in pedagogy, tools, and practices. This new framework is intended to encourage readiness evaluation before attempting to implement new technologies, practices, or pedagogies in learning communities. Future directions include studying the capacity of this framework to help learning communities identify and create supports before attempting a pedagogical transformation.

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International Society of the Learning Sciences

INDIGENOUS LEARNING LAB: INCLUSIVE KNOWLEDGE-PRODUCTION AND ENACTED UTOPIAS TOWARDS DECOLONIZING SCHOOL SYSTEMS

Abstract: The United State was built on settler colonialism, slavery, and capitalism. Settler colonialism strives for the dissolution of Indigenous societies by establishing a new colonial society on seized land with the elimination of Indigenous societies as an organizing principle. Through the education system, Native Americans experienced downward assimilation and cultural genocide. Today, Native American youth disproportionately receive exclusionary disciplinary actions more frequently and severely in schools. Disproportionality in school discipline is a result of historically accumulated contradictions such as widening disparities in health, justice, housing, and wealth. As an enduring systemic contradiction, disproportionality demands sustained collaborative systemic transformations led and owned by local stakeholders. This paper presents a new formative intervention model, *Indigenous Learning Lab.* In a partnership with an Anishinaabe nation, Indigenous students, educators, and family and community members and non-Indigenous school staff, our research team worked at a rural public high school to collectively design and implement a new, culturally responsive, decolonizing school-wide behavioral support system.

Objectives

Settler colonialism strives for the dissolution of Indigenous societies by establishing a new colonial society on seized land with the elimination of Indigenous societies as an organizing principle (Wolfe, 2006). Through the education system in U.S., Native Americans experienced downward assimilation and cultural genocide. Today, in the U.S. education system, Native American youth receive exclusionary disciplinary actions more frequently and severely for more subjective reasons such as disrespect (Whitford et al., 2019). Disproportionality in school discipline is a result of historically accumulated contradictions arising from a racist, settler colonial society (Bal, 2017). Addressing inequity requires a situated conceptualization to help develop systemic solutions led and owned by community members in response to school communities' diverse and often opposing histories, interests, and goals.

In this study, we examined how Indigenous Learning Lab, a community-based, inclusive systemic design intervention that aimed to facilitate the inclusive design of a culturally responsive school-wide behavioral support system in partnership with a tribal nation of the Anishinaabe people and school staff at Northwoods High School, a rural high school in U.S. We addressed the following question:

> How did Indigenous Learning Lab facilitate the collaborative problem-solving and systemic design process with Indigenous and non-Indigenous members of the school community for the systemic transformation?

Theoretical Framework

Indigenous Learning Lab is a formative intervention model (Sannino et al., 2016). It is grounded in Cultural-Historical Activity Theory (CHAT) and Decolonizing Epistemologies (Engeström, 2016; Smith, 2012). Indigenous Learning Lab builds upon "refusal" of metanarrative in social science research and leverages "resistance, reclaiming, recovery, reciprocity, repatriation, [and] regeneration" (Tuck & Yang, 2014, p. 244).

Methods

Indigenous Learning Lab included 14 participants (See Table 1). Members participated in 11 video recorded sessions. They followed a cycle of expansive learning actions consisting of forming Learning Lab, questioning, analyzing, modeling, testing, and stabilizing new solutions to resolve the systemwide problems of practice (Bal, 2017).

Results

Forming Inclusive Problem-Solving Group

The research team worked with the community and school liaisons to hold initial meetings on the reservation to disrupt asymmetrical power relations embedded in the bureaucratic school system. Each session started with a pipe smudging ceremony by lighting up traditional tobacco and sage. The American Indian education mentor led the pipe ceremony. As suggested by the Anishinaabe community members, the research team introduced the

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Seven Grandfather Teachings of the Anishinaabe as inclusive group norms to run a mutually respectful problem-solving process. The Seven Grandfather Teachings are orally passed-down moral and ethical principles elders have used to educate future generations on living a good life: Nibwaakaawin (Wisdom); Zaagi'idiwin (Love); Minaadendamowin (Respect); Aakode'ewin (Bravery); Gwayakwaadiziwin (Honesty); Dabaadendiziwin (Humility); and Debwewin (Truth).

The collaborative examination of systemic contradictions (e.g., racial disparities) and the creation of new instrumentality aimed to resolve daily disturbances and conflicts resulting from the inner contradictions. Learning Lab facilitated the expansion of the school discipline system's object from the punishment and exclusion of students with challenging behaviors to prevention and inclusive, positive support for *all* students and adults in a school community. A new, culturally responsive system was designed around the expanded object. The following academic year, the Learning Lab members worked on the implementation of the new system.

Analysis of Systemic Contradictions in Settler-Colonial School System

Learning Lab utilized multiple mediating tools to stimulate a critical analysis. Members mapped out the school's exiting discipline system and identified multiple systemic breakdowns in the existing system that contribute to (re) production of the racialization of school discipline.

Designing Systemic Solutions for an Enacted Utopia

Members designed a new, culturally responsive school-wide behavioral support system. Members used the system map to generate solutions for the inner contradictions in their system. In the 2020-2021 academic year, the school implemented the new system.

Significance

To offset the cumulative effects of colonial harms through education systems, critical indigenous scholarship has emphasized the necessity of building culturally decolonizing systems (McCarty & Lee, 2014). Learning Lab can be utilized to address historically accumulated contradictions through strategic community-school-university coalitions for building a socially just school systems. In the learning sciences, design-based research moved toward more situated, collaborative forms of research (Bang et al., 2016).

Forming inclusive, productive, and sustained design teams requires time, commitment, interest convergence, negotiations and more importantly robust methodologies and theories of organizational learning and transformation (Adler, 2015). The present study shows how CHAT and formative interventions can be instrumental in this paradigm expansion and may contribute to recently emerging inclusive, community-based research methodologies such as DBIR and social design experiments. Indigenous Learning Lab may add more to the field's toolbox for facilitating the decolonizing knowledge-production activities and systemic transformation of the oppressive social systems towards *buen vivir* – collective well-being.

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Table 1

Demographic Information of Participants

Participant Name	Roles		Race	Gender
Kevin	School administrators	Principal	White	Male
Bart		Dean of students	White	Male
Gwenwyn		Director of special education	White	Female
Jeremiah		Native American education mentor	Native American	Male
Carson		Social worker, student support strategist	White	Male
Jane	Educators & staffs	Classroom teacher (English)	White	Female
Katie		Classroom teacher (physical education, health)	White	Female
Hannah		Classroom teacher at K-8 public school on the reservation	Native American	Female
Lola	Parents & community members	Vocational/higher education transition coordinator of the Tribal Education Department	Native American	Female
Diana		Parent, community member	Native American	Female
Mr. Black		Parent, community member	Native American	Male
Nick	Students	Current student	Native American	Male
Darren		Current student	Native American	Male
Andrea		Current student	Native American	Female

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Figure 1
The expansive learning cycle fir the systemic change (Bal, 2017)

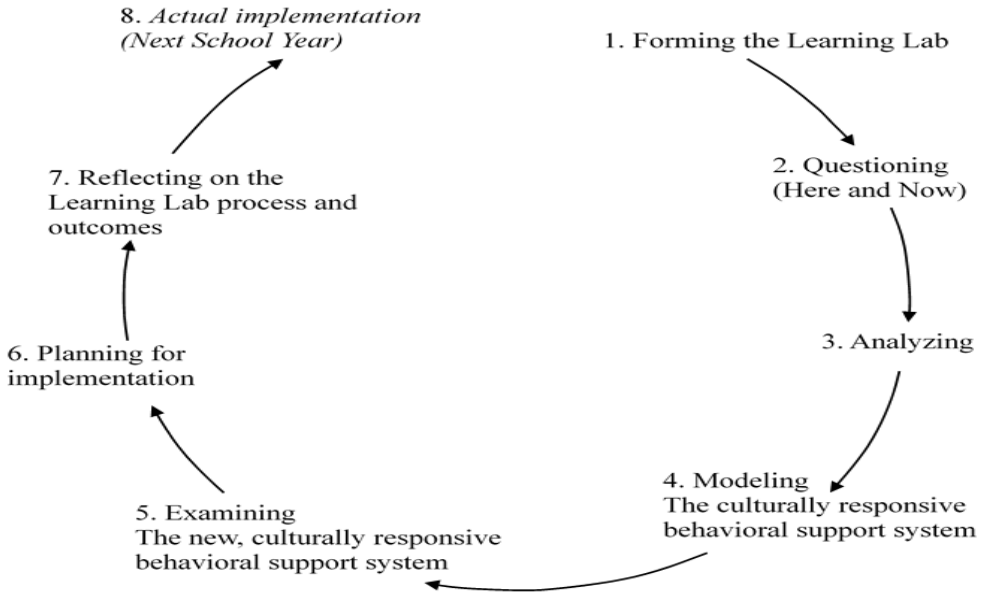

Figure 2
Indigenous Learning Lab members are engaging in cultural-historical analysis of the system (Bal et al., 2021)

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Comprehensive Student Records as a Tool for Networked and Connected Learning: Using Social Media Research to Frame Inquiry

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Abstract: Comprehensive Student Records (CSRs) are an emerging model for life-long and life-wide learning transcripts. As they are currently conceived, CSRs would allow students to track and curate learner profiles aligned with industry recognized skill frameworks, making them potentially powerful tools for promoting pipelines to future learning and employment. How CSRs could support connecting and networking within these pipelines is, however, undertheorized. In this paper, social media research is used as a frame to inform future work of designing CSRs as tools for connecting and networking students to learning and employment opportunities. Special attention is paid to the need to focus on the design of CSRs to promote equitable access to employment.

Introduction

In 2015, the American Association of Collegiate Registrars and Admissions Officers (AACRAO) partnered with the National Association of Student Personnel Administration (NASPA) to implement the *Comprehensive Student Record Project* to imagine the future of student records for lifelong and life-wide learning (Green & Parnell, 2017). Comprehensive Student Records (CSRs) differ from typical student records in that they allow for richer accounts of skill and ability by shifting the measure of learning away from seat-time metrics to competencies demonstrated through experiential learning. CSRs also take advantage of the affordances of digital technology to include micro-credentials and other digital evidence of learning. It has been argued that CSRs can be a powerful tool for students to construct learning profiles that can be aligned to industry-recognized skill frameworks (Shendy et al., 2019) making them useful tools for scaffolding future learning and connecting students to learning employment opportunities.

Research on CSRs has so far focused on demonstrating their viability as a medium for communicating more explicitly about experiential learning. This has been demonstrated through the *CSR Project* that saw CSR models expand from twelve models in the pilot study to over 150 models in Phase II of the project. Another line of research has sought to understand student (Parish, Parks, & Fryer, 2017) and employer (Cederquist, Fishman, & Teasley, 2022) perspectives of CSRs as tools for communicating learning. Findings from both studies suggest CSRs are perceived as more informative than traditional transcripts in that they more holistically communicate the broad range of skills and competencies students are developing within and outside classrooms. While this line of research has done well to demonstrate the viability of CSRs as an alternative transcript model, additional work must be done to understand their viability as a tool for connected and networked learning. In this paper, I use social media research to frame challenges and opportunities researchers should consider when designing and scrutinizing CSR systems for their ability to equitably and capably connect and network students to future opportunities. What emerges is the importance of understanding producer (student) and consumer (e.g., employer) behavior as it relates to CSR curation and consumption. Before moving into this discussion, I first describe CSRs as a tool for "connected learning" (Ito et al., 2013) by highlighting the unique features of CSRs.

CSRs as a tool for connected learning

As they are currently conceived, CSRs largely reflect existing static academic transcripts with the addition of experiential learning outcomes documented on the transcript. To understand the potential of CSRs as a tool for connecting and networking to opportunity, it is important to highlight two key features: 1) the emphasis on their interoperability with different employment and learning platforms, and 2) ownership of the record is vested in the student rather than the credentialing institution (Torres, 2020). Torres (2020) argues this is particularly useful for those students who ultimately leave postsecondary education with some credits but no degree; with a CSR system, any learning achieved or competencies demonstrated could be stacked and credentialed. This would allow students to "translate their full education, training, and work experience to a record of transferable skills" (Torres, 2020, p. 46). As a personally-managed digital record of one's achievements and interests across time and space, CSRs would support models of connected learning: socio-cultural models of learning that are interest-driven, peer-supported, and production-centered and powered by networked technology (Ito et al, 2013). This interpretation of CSRs as a tool for connected learning is further supported by ethnographic work on social media as a tool for job-

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seeking—notably the work of Gershon (2017). Gershon documented how the changing technological infrastructure of networking and hiring (e.g., LinkedIn) presents a scenario in which the individual is encouraged to view themselves "as a business" in which their bundle of curated skills are viewed as business solutions publicly displayed for the purpose of networking and gaining employment (p. 11).

The possibility of curating one's bundle of skills is supported by a feature of CSRs often highlighted by their proponents—the possibility for collecting rich and granular data on student activity through digital learning tools (Black, 2016). Black argues that an increased level of detail in data collection and representation "can lead to a fuller analysis of strengths, weaknesses, and opportunities" in a world in which continuous assessment of skills is becoming increasingly important (Black, 2016, 4th para.). In theory, data collected on student behavior could be analyzed by admissions officers, hirers and applicant tracking systems to support decision-making in applicant screening and evaluation. While intriguing, Teasley and Kelly (2020), in their report on the potential of linking learning and employment data, have noted there are short and long term issues that must be addressed before this idea can be fully realized in practice: for example, defining higher education outcomes as competencies and developing methods for communicating these competencies. Ultimately, as issues of data measurement and communication are addressed, it will become increasingly important for researchers to understand how questions related to CSR platform features may impact consumer and producer behavior. In the following sections, I point to research from social media studies that can help scholars examine these issues.

Framing CSRs through social media research

As discussed above, CSRs have the potential to be a tool for managing one's self-presentation as employable, or ready for future learning, through data derived from a wide variety of learning experiences. From this perspective, we can assume there are implications for how students (producers) would utilize the affordances of CSR systems to document their learning and connect prior experiences to new opportunities. There are also clear implications for how both humans and machines will interpret the data contained within CSRs to support recruitment and hiring decisions. In the following sections I use social media research to further explicate the two perspectives of producer and consumer, showing how both are vital to understanding the potential opportunities and pitfalls of CSR systems as tools for connecting and networking to opportunity.

Self-presentation: Audience and affordances

Social media research into self-presentation has a long history and finds its roots in Goffman's *Presentation of Self in Everyday Life* (Donath, 2020; Goffman, 1959). An issue often addressed by self-presentation research is whether the unique environmental cues of social media result in distinct affordances for self-presentation (Donath, 2020). This question is crucial because it points to two social media theories—audience and platform affordances—that may help researchers better understand how CSR-users might manage self-presentation in networked environments. For example, Duffy and Chan (2019) documented emerging adults' response to "imagined surveillance." Duffy and Chan's participants described using privacy settings on social networking sites to manage an imagined audience's access to certain content, thus controlling their identity presentation. (Duffy and Chan, 2019, p. 125). Viewed through the lens of *affordances*—the "multifaceted relational structure between an object/technology and the user that enables or constrains potential behavioral outcomes in a particular context" (Evans, Pearce, Vitak, & Treem, 2016, p. 36)—Duffy and Chan's participants were able to control their visibility on platforms because of these privacy features. This allowed the participants to manage who saw what information, and as a result the impressions they believed potential employers would form about them. The framing of affordances will be particularly useful for understanding the unique advantages a digitally networked record of student learning has over traditional transcripts. Additionally, as CSR designs evolve over the course of students' lives, taking an affordances perspective will allow for a contextually stable object of inquiry. This points to the moving target problem in social media research, i.e., "the challenge of researching media artifacts and effects that are constantly in flux" (Bayer, Trieu, & Ellison, 2020, p. 472). Employing an affordances perspective with CSRs will help researchers and designers understand how changing features of the technological system either support or hinder the presentation of one's self as competent in order to align with evolving standards and expectations of professional communities.

Impression formation: Signaling and warranting theory

Proponents of CSRs typically frame the process by which evidence of competence contained in CSRs could help people find jobs as follows: 1) CSR data connects a student to an opportunity, 2) a student presents evidence of competence, 3) the evidence is interpreted by human or machine, and 4) the student is accepted as competent. CSR research would benefit from a consideration of how information cues, or the hidden signals given off by characteristics of the information and channel, specifically affect impression formation. Additionally, while hirers

do review work portfolios, less is known about how they would interpret the granular data on learning that differentiates CSRs from portfolios. Interpreting these issues through signaling and warranting theory can help explain how a focus on CSR design can help us understand how impressions are formed through digital media.

Signaling theory argues the perceived reliability of information relates to the perceived cost of producing the information; two types of signals are noted in the literature. Assessment signals are those that are more costly to produce and are thus deemed more reliable because "their production mandates the possession of the quality." Conventional signals, because they are believed to be more easily produced, are viewed as arbitrary signals of a quality (DeAndrea, 2014, p. 197). Warranting similarly describes how people interpret information cues, but unlike signals which convey reliability through production cost, warranting conveys reliability based on cues presented by the source of the information. The more control a user has over the source of the information cue describing them, the lower the warranting value. As a result, third party warrants are generally believed to be more reliable.

Taken at face value, we might assume evidence within CSRs would be interpreted as assessment signals with high warranting value: student competency data and examples of work can be reviewed to determine if a job applicant is qualified for the job, and the validation of the credential issuer would imbue the evidence with high trust. However, findings from CSR research suggest additional research into the signaling and warranting powers of CSR features is needed. For example, to understand the advantages and challenges of implementing CSRs into entry-level hiring, Cederquist et al. (2022) presented hirers with a publicly available exemplar of a CSR designed around mastery- and competency-based learning known as the Mastery Transcript™. While perspectives were generally positive, two potential challenges emerged from the study. First, how complex non-cognitive skills could be presented through the CSR's data visualizations was unclear to the hirers—they were unsure how such a contextually situated competency like teamwork could be represented through data on a digital transcript. The second challenge relates to the similarities hirers drew between the Mastery Transcript™ and LinkedIn. Due to the school's verification of learning, hirers viewed the personally curated competency profile in the Mastery Transcript™ as a more reliable presentation of competence than what students curate on LinkedIn. While we can interpret this as a potential advantage CSRs could contribute to social media professional networking sites such as LinkedIn, it is unclear if this opinion would be held by other hirers. Cederquist and colleague's population size was too small (n=12) and the background of informants too similar (participants came from one professional pathway) to draw generalizable findings. Future research should include larger and more diverse professional pathways to determine if CSRs maintain their high warranting value.

The importance of designing CSRs for equity and inclusion

Before concluding, it is important to note why it is of vital importance to consider the social networks through which job seekers access labor markets when studying CSRs. Referring back to Gershon (2017) we see that professional networking sites such as LinkedIn are designed with a specific type of worker in mind—white collar professionals. Similarly, research on low-resource workers' use of social media for job-seeking shows that when using Internet-based tools to look for work, low-resource workers tend to rely on social network sites like Facebook and Instagram and job posting sites like Craigslist to find information about work (Lu & Dillahunt, 2021). Lu and Dillahunt (2021) show that this has implications for equity as the design of communication channels on sites like Facebook reinforces power asymmetries between employers and low-resource job seekers; employers interviewed in the study framed Facebook recruitment as a process of "accessing a *pool* of low wage workers" (sec. 5.3, emphasis original). Lu and Dillahunt argue that this framing potentially makes low-wage workers both "more accessible" but also "more expendable and replaceable" (sec. 5.3). A focus on equity and inclusion also highlights the necessity to vest control of CSR data with the student. Failure to do so opens low-wage workers to potential exclusion through surveillance of the digital traces of their education and employment records.

This asymmetry between hirers and job-seekers echoes McDonald and colleagues (2019) study of two online labor markets—Monster.com and LinkedIn. The former site was described by hirers as "black holes" in which the ease of uploading resumes to the site resulted in information overload as thousands of applications came in for only one position. LinkedIn, however, was described as a site for looking for and recruiting "specialized superstars" away from their current jobs. Sites liked LinkedIn are not designed with the great diversity of job seekers in mind. Thus, designing CSRs with only LinkedIn in mind would likely obscure the needs of a wide swath of the labor market. These findings suggest it would be prudent to focus the work of designing CSRs with those typically left out or disadvantaged by the existing technical infrastructure of job-seeking. Dillahunt and colleagues' body of participatory design work with underserved job seekers provides a useful starting point for the design of such an agenda (see Dillahunt, Lam, Lu, & Wheeler, 2018; Wheeler & Dillahunt, 2018).

Conclusion

As CSRs develop as tools for connected learning, it will be important to develop a more rigorous theoretical understanding of their design and use within networks. Findings from social media research can help in framing studies with these objectives. Studies of CSRs should pay particular attention to the affordances offered by features unique to CSRs, particularly the affordances offered by interoperability and student ownership (as opposed to institutional ownership). Additionally, research on the imagined audience can help scholars understand how CSRs help students curate self-presentations of competence and network within communities of practice. Research into consumers of CSRs should examine how both humans and machines interpret evidence, including granular data on learning, to form impressions of the individuals represented through CSRs. This should include the unique environmental cues communicated by diverse information sources and channels. This also strongly suggests a focus on developing CSR systems that support the job-seeking behavior of those typically left out of the labor market. Such a focus will forefront the needs of low-resource job seekers and help promote the development of equitable pathways to employment.

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Exploring Elementary Teachers' Perceptions of Teaching a Science, Engineering, Mathematics, and Computer Science Project

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Abstract: While national frameworks call for the integration of science, technology, engineering, mathematics, and computer science (STEM+CS) in K-12 contexts, few studies consider elementary teachers' perceptions of implementing STEM+CS projects in science classrooms. This single case study explores elementary science teachers' perceptions of enacting STEM+CS curricular materials. Survey and interview data were collected over the four-week project and qualitatively coded. Findings demonstrate teachers' reported struggles to implement unfamiliar disciplines and leverage students' prior knowledge in familiar disciplines as well as unanticipated consequences of instructional decisions based on perceived student engagement and pacing. Results underscore the value of teacher voice for curricular and professional development and highlight the need for further investigation of how teachers' perceptions may influence enactment of STEM+CS curricular materials.

Introduction and background

Interdisciplinary science, technology, engineering, mathematics, and computer science (STEM+CS) curricular activities involve deeply integrated practices for developing knowledge. National frameworks in the United States describe a STEM+CS vision involving students developing science knowledge and engineering design solutions by using mathematics and developing computational models to solve authentic problems and create scientific arguments and explanations (i.e., ASEE 2020; K-12 Computer Science Framework, 2016; National Research Council, 2012). In the elementary grades, implementing interdisciplinary STEM+CS projects includes integrating mathematics, computational thinking, and engineering concepts and practices into science classrooms where students define problems, analyze and interpret data, model solutions and science phenomena, and develop, test, and communicate solutions while considering constraints (NGSS Lead States, 2013).

Teaching this type of interdisciplinary curricula is challenging (Fulmer et al., 2018), especially for elementary teachers who may have differing amounts of knowledge of each individual discipline. For example, elementary teachers report feeling well prepared to teach mathematics and science but not engineering and computer science (Plumley, 2019). Although elementary teachers typically teach multiple disciplines to their students, interdisciplinary curricula require making connections across disciplines. As teacher education programs largely focus on siloed domain approaches to disciplines, teachers may need support to implement interdisciplinary approaches effectively in their classrooms. For instance, teachers may perceive content from integrated disciplines as skills instead of content, which may then affect how these disciplines are integrated and taught (Estapa et al., 2017). For example, mathematics can be implicitly integrated in STEM+CS activities (Lilly et al., 2021) and often takes the form of calculations or data representations (Baker & Galanti, 2017). However, making mathematics more explicit could change the student perspective from only focusing on a contextualized problem to a more explicit use of mathematics and disciplinary epistemologies (Fitzallen, 2015). In engineering, it may be challenging for elementary teachers to center engineering practices when they feel like they must prioritize the logistics of implementing engineering activities (i.e., Diefes-Dux, 2004). Additionally, elementary teachers may also be challenged in supporting students when content and practices are unfamiliar (Lilly et al., 2022). For example, elementary teachers may not be familiar with engineering analysis and so struggle to respond and guide students' varied design ideas to meet project constraints (Brophy et al., 2008).

This study then investigates how elementary science teachers perceive enactment of a STEM+CS project and aims to privilege the teachers' own voices to provide insights into their perceptions of challenges and necessary supports for the consideration of curriculum designers and professional development facilitators.

Methods

This study uses an embedded, single case study methodology (Yin, 2018) to examine teachers' perceptions of implementing a STEM+CS project in a public elementary school in the southeastern United States. The project challenged fifth-grade students to engineer a design solution to solve the authentic problem of water runoff at their school grounds by developing scientific models of runoff and absorption and using mathematics and computational thinking to develop computational models to test different engineering solutions. We define the

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case as two fifth-grade teachers, pseudonyms Mr. Skelton and Ms. Banet, who implemented the project in their two co-taught classrooms. We focus on this specific case as these teachers both hold an undergraduate science degree and thus have atypical content knowledge for elementary teachers. Further, both teachers have more than five years of teaching experience. Both teachers also have knowledge of project goals and educative supports as co-developers of the project who implemented a pilot version of the project the previous year.

Over the four-week project, both teachers answered open-ended questions on daily written surveys and weekly face-to-face interviews. Two researchers worked together to inductively code (Miles et al., 2020) the data through first and second level coding. First, the researchers identified if a teacher's answer demonstrated (1) perspectives about STEM+CS disciplines or (2) implementation of the STEM+CS project and then coded these statements for challenges, changes made to support student engagement, and additional supports that teachers perceive as necessary for equitable facilitation of STEM+CS activities. The researchers then looked across coded statements for patterns and wrote analytic memos (Miles et al., 2020).

Results

Teachers reported challenges with supporting computational modeling and mathematics and customizing and adapting the activities. First, both teachers discussed challenges with supporting students in computational modeling, including technical aspects of how to access and save students' computational models. For example, Ms. Banet discussed the difficulties that students faced saving and accessing their code within the computational modeling environment, "Explaining to the students how to save your computer, just in case something happens. That's pretty key. Because that kept happening, it kept disappearing." Ms. Banet also reflected how they could have addressed these difficulties by having more whole-class demonstrations of these problematic areas, "We should have done it at the beginning, showing how to shrink and enlarge the stage … That was a struggle."

The teachers also reported struggling with using pedagogical strategies for computing, such as debugging students' programs and supporting students to understand computing concepts such as variables. For example, Ms. Banet stated, "Students' programs were malfunctioning, I didn't know how to help other than having them close out their program and bring up a whole new copy … they ended up having to start over because I didn't know what to do." Here Ms. Banet reported on one debugging strategy that she used, starting over from scratch, but also recognized that she did not use any other strategies like stepping through each block together or asking the students to explain their code. Similarly, Mr. Skelton stated, "I also struggled to predict the sorts of observations kids make about their models and thus transition from those observations to useful questions that students could answer." In this comment, Mr. Skelton discussed his challenges for appropriate questioning strategies with the computational model. Teachers also found it challenging to support students using terminology or concepts from mathematics in science contexts. For example, Ms. Banet said, "A lot of students struggled with the word *relate*. They don't understand 'How does hourly rainfall relate to total amount of water'. And I don't know how to simplify that myself." Furthermore, even though Ms. Banet also taught mathematics classes, she reported struggling to support all students to use the mathematics concept of *ratio* with the science phenomena of absorption and run-off.

The teachers reported modifying the project to attend to these challenges. First, teachers reported adapting activities to maintain student engagement. For example, teachers reported adding an activity that was not in the curriculum in which students went outside to take pictures of their water runoff problem. The teachers considered the lesson to positively impact student engagement, as students "were able to connect pieces of the curriculum", the activity "reminded them of why we are doing all this in the first place", and it "sparked so much creativity." Adding this lesson enabled the teachers to see students that they perceived would struggle more with these lessons as capable of making connections within the curriculum. Additionally, the teachers reported altering activities as a result of time constraints. For example, Ms. Banet reflected that, "Due to time, we cut out all the math … so the kids didn't do pages, the last page we did was 18 and then we had them skip to page 26." When faced with pacing concerns, the teachers often chose to remove mathematics. However, teachers also acknowledged difficulties that may have emerged from their choices to skip parts of the project. Ms. Banet said, "I struggled to rush through the lesson without having students really understand why we were developing this model. Many students have lost interest … there's a disconnect between the hands-on experiments and how this relates to the computational model." As the mathematical tasks were designed to serve as connections from the hands-on activities to the computational modeling activities, Ms. Banet noticed the consequences of skipping activities.

Discussion and conclusions

This study focused on teachers' perceptions of challenges when implementing a STEM+CS project (i.e., Johnson et al., 2020; Pleasants et al., 2019). Even in this unique case, where both teachers have science degrees and

extensive curricular knowledge of the STEM+CS project, teachers discussed a range of challenges during classroom enactment. Teachers reported struggling with integrating disciplines with which they had more experience (i.e., mathematics into science) as well as disciplines with which they had less experience (i.e., computer science through computational modeling). For example, teachers noted the difficulty with mathematics terminology and concepts in science contexts. Results highlight how teachers may need support not only to integrate more unfamiliar disciplines like engineering and computer science into familiar disciplines of mathematics and science, but also to integrate mathematics and science content and practices.

Enacting STEM+CS curricular materials requires teachers to have pedagogical knowledge about each individual discipline (i.e., Johnson et al., 2017), and how pedagogical strategies in one domain (e.g., debugging in computing) may relate to pedagogical strategies in other domains (e.g., problem solving in mathematics) or how to use pedagogical strategies across domains (e.g., questioning). Teachers reflected on struggling with the broader, interdisciplinary nature of the curriculum in terms of recognizing how to enact such strategies across disciplines. Specifically, they did not feel as if they had the pedagogical content knowledge to make in-the-moment instructional decisions. Future research should explore how the kinds of pedagogical knowledge and strategies that teachers utilize for enacting STEM+CS curricula may affect student outcomes.

The teachers also reflected on their concerns about pacing and how to adapt the project to stay on pace (e.g., what to cut or what to focus on if students struggle). Although teachers reported challenges that stem from students' lacking foundational skills from integrated disciplines, they did not make connections about how their customization of the project may have compounded these challenges. For example, teachers reported students struggled with implementing their coding but did not make a connection as to how altering their project by cutting mathematics from early activities might have impacted later activities in which students were expected to code conceptual models. Specifically, without recognizing how knowledge would build and the importance of specific activities for students to understand concepts and engage in activities later in the project, the teachers may have cut important activities due to their beliefs about their students' abilities to engage in those activities in face of pacing concerns. This demonstrates unintended consequences in teachers' adapting an STEM+CS curricula without support to understand how practices and concepts may build across disciplines and supports prior research of teachers' challenges in STEM+CS contexts (Baker & Galanti, 2017). An implication is that curriculum developers need to support teachers' knowledge about how concepts and practices will progress throughout a STEM+CS project so that students are able to successfully engage in activities across disciplines.

Further, teachers used the challenge of implementing ratios to recognize that they must safe-guard against allowing students' abilities and individualized needs, as well as teachers' beliefs about students' abilities in mathematics, to dictate students' opportunities to engage in science activities. For example, the teachers reflected on the challenge of leveraging students' prior mathematics knowledge and attempted to differentiate for students with different prior mathematics knowledge to equitably support all students to engage with this challenging interdisciplinary curriculum. However, although they also recognized that students' prior experience with coding affected their ability to engage in computational modeling, the teachers reported being unsure of how to support struggling students. Throughout the data, the teachers did not consider how or if their beliefs about students' abilities or individualized needs may have filtered students' opportunity to engage in engineering or computer science. Teachers may then need additional support to consider how to differentiate activities across disciplines to attend to differing levels of prior knowledge and equitably support all students.

By giving a voice to teachers and sharing their perspectives, we hope to help curricular makers to support teachers in their ability to adapt STEM+CS curricula to meet students' needs. This is particularly important as our results show that the teachers reported struggling more to adapt activities to resolve a challenge when implementing less familiar disciplines and suggested that they may need additional support in predicting, responding, and evaluating students' ideas (Brophy et al., 2008) and attending to technical difficulties that students may have (Diefes-Dux, 2004) across different disciplines. However, our results also highlight ways in which teachers adapted interdisciplinary activities, such as teaching students mathematically about ratios and then drawing connections to absorption ratios in science. This enabled the teachers to integrate mathematics into science and support the epistemic understanding that mathematics is part of real-world, science experiences in line with prior literature (e.g., Fitzallen, 2015). Such examples demonstrate that the teachers were capable of modifying the project to support students' needs. Thus, it is important to ensure that teachers have the support that they report is necessary to equitably implement STEM+CS projects across disciplines.

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International Society of the Learning Sciences

Does it Work for Everyone? The Effect of ELCII on Kindergarteners' Inference Skill Development

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Abstract: We sought to identify the extent to which an innovative educational technology called ELCII (Early Language Comprehension Individualized Instruction) improved inference making for various populations of kindergarten students. Analyses examined student performance based on individual-level demographic characteristics (i.e., gender, race/ethnicity, home language, English Language Learner status, and Free or Reduced Lunch eligibility) to shed light on whether ELCII addresses the needs of learners from marginalized communities. Results showed that all students, on average, improved in their inference making performance over time and that growth in inference making performance did not differ across subgroups. However, the results also highlighted persistent gaps that were present at the onset of the program, and unfortunately continued to persist. To bridge such gaps, the standard of 'working for all' is a necessary first step, but not sufficient. Future research should identify ways to accelerate growth of core skill development among students who need additional support.

Introduction

Our history in the field of education is dominated by the persistent efforts of researchers, policymakers, and educators to improve reading performance of all children across grade levels (e.g., Patton-Terry, 2021). Despite these efforts, yearly reports from the National Assessment of Educational Progress (NAEP) consistently show one in three U.S. students, on average, performing below basic proficiency levels in reading, and persistent achievement gaps across demographic characteristics, such as race/ethnicity, gender, home language, English Language Learner (ELL) status, and Free or Reduced Lunch (FRL) eligibility (NAEP, 2019).

These persistent achievement gaps are due to equally persistent and well-documented opportunity gaps. Poverty, one of the main predictors of reading comprehension (Ransdell, 2011), contributes significantly to racial and ethnic differences in achievement. Census data indicate that Black and Hispanic students, for example, are significantly over-represented in the population in poverty relative to their representation in the overall population (Shrider et al., 2021). Recent data indicate that only 53% of students who qualify for FRL achieved at or above basic reading levels compared with 83% of students who were not eligible (NAEP, 2019). Related opportunity gaps exist for ELLs who are more likely to be enrolled in under-resourced, low-performing schools and are at a greater risk for reading difficulties than non-ELLs (Roberts et al., 2021).

Early instruction in language comprehension skills such as inference making has the potential to prevent long-term negative reading outcomes across diverse groups of students (Silverman et al., 2020). Based on developmental research showing that young children can generate inferences well before the beginning formal reading instruction (Kendeou, 2015), an innovative educational technology called ELCII (Early Language Comprehension Individualized Instruction) has been designed to provide inference making instruction as early as kindergarten. ELCII is implemented via a web-based, interactive application called Inference Galaxy and includes twenty 20-minute learning modules that engage students to: (a) learn academic vocabulary words that are key to ideas in a video they are about to watch; (b) view age-appropriate videos (fiction and nonfiction); (c) respond to inferential questions during viewing of the video at points where inferences are needed for comprehension; and (d) receive scaffolding and specific feedback after each response. For example, after watching a video about how polar bears walk on ice, students will answer a multiple-choice question like, "Why don't polar bears fall into the water while walking?" If answered incorrectly, students receive scaffolding and feedback that guides them to the correct response.

ELCII has a strong theoretical and empirical basis (Kendeou et al., 2019), building on cognitive and developmental work highlighting that (a) early language comprehension skills that are developed in non-reading contexts (e.g., video comprehension) contribute significantly to later reading achievement (Kendeou et al., 2009), (b) language comprehension skills—and specifically inference skills—transfer across different media (Magliano et al., 2013), (c) children's inference skills can be improved using questioning that includes scaffolding and specific feedback (McMaster et al., 2012), and (d) technology provides cost-effective, standardized, individualized delivery of instructional tools in classroom settings (McCarthy et al., 2020). The efficacy of ELCII

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in improving inference making in kindergarten has been evaluated in quasi-experimental research showing good promise for improving inference making performance and the positive effects of scaffolding (e.g., Butterfuss et al., 2021).

The primary aim in this paper is to identify whether ELCII works for everyone, and specifically whether it addresses the needs of learners from marginalized communities. Thus, in these analyses we examine the efficacy of ELCII based on students' individual-level demographic characteristics (i.e., gender, race/ethnicity, home language, ELL status, and FRL eligibility). Knowledge of how different subgroups of students respond to ELCII is an essential first step in bridging any gaps that may exist. Only after understanding the program's effectiveness at this level of granularity can steps be taken to develop the program through an equitable lens with each student's unique needs in mind.

Methods

The final analytic sample used in this analysis consisted of 191 students (*M*age = 5.66, *SD* = 0.32) recruited from a mid-sized suburban school district in the United States Midwest. There were no exclusion criteria. Demographic characteristics of the sample were analyzed by gender (47.6% female, 52.4% male), race/ethnicity (34.0% white, 64.4% non-white, 1.6% missing), home language (62.8% English, 35.6% non-English, 1.6% missing), FRL eligibility (52.4% eligible, 46.0% not eligible, 1.6% missing), and ELL status (29.3% ELLs, 69.1% non-ELLs, 1.6% missing).

The efficacy of ELCII was examined using a quasi-experimental pretest-posttest design. Fidelity of implementation was confirmed based on students' high engagement during the intervention across the observation measures developed by the research team. ELCII was implemented in classrooms with diverse groups of students with no significant clustering as a function of demographic characteristics.

Mixed-effects models were used to assess students' inference making performance over time and whether trajectories varied across subgroups. The unit of analysis was one time-period, equivalent to two weeks. In each time-period, students completed four ELCII modules (two fiction and two non-fiction). Scores assessing inference making were aggregated for a total score out of 20. Plotting mean trajectories of students' inference making ability over time suggested that a linear function could be used to explain student trajectories. Thus, a linear model was fit to the data using the lme4 package in R. The model included a fixed intercept and a time predictor. Students' demographic variable characteristics were included as additional covariates. Demographic variables serving as covariates were race/ethnicity (White vs non-White), gender (male vs female), home language (English vs non-English), ELL status (ELL vs non-ELL), and FRL eligibility (eligible for FRL vs not eligible for FRL). One demographic variable was included at a time in separate models to facilitate interpretation and to reduce multicollinearity issues for interaction terms.

Results

Figure 1 shows the estimated ELCII mean score trajectories for all students and by race/ethnicity, gender, home language, ELL status, and FRL eligibility. Parameter estimates for each model are shown in Table 1. Highlighted in bold are the main effects of each covariate.

The base model without covariates showed a main effect of time for all students, with all students, on average, showing improved inference making performance across 4 timepoints (Figure 1a).

The model with race/ethnicity as a covariate showed a significant main effect of race/ethnicity but no significant interaction with time (Figure 1b). White students performed significantly better than non-White students across all ELCII modules. However, the learning trajectories for the groups did not differ over time.

The model with gender as a covariate showed no significant main effect of gender and no significant interaction with time (Figure 1c). However, the learning trajectories for the groups did not differ over time.

The model with home language as a covariate showed a significant main effect of home language but no significant interaction with time (Figure 1d). Students who spoke English at home performed significantly better than students who did not speak English at home across all ELCII modules. However, the learning trajectories for the groups did not differ over time.

The model with ELL status as a covariate showed a significant main effect of ELL status but no significant interaction with time (Figure 1e). Students who were not ELLs performed significantly better than students who were ELLs across all ELCII modules. However, the learning trajectories for the groups did not differ over time.

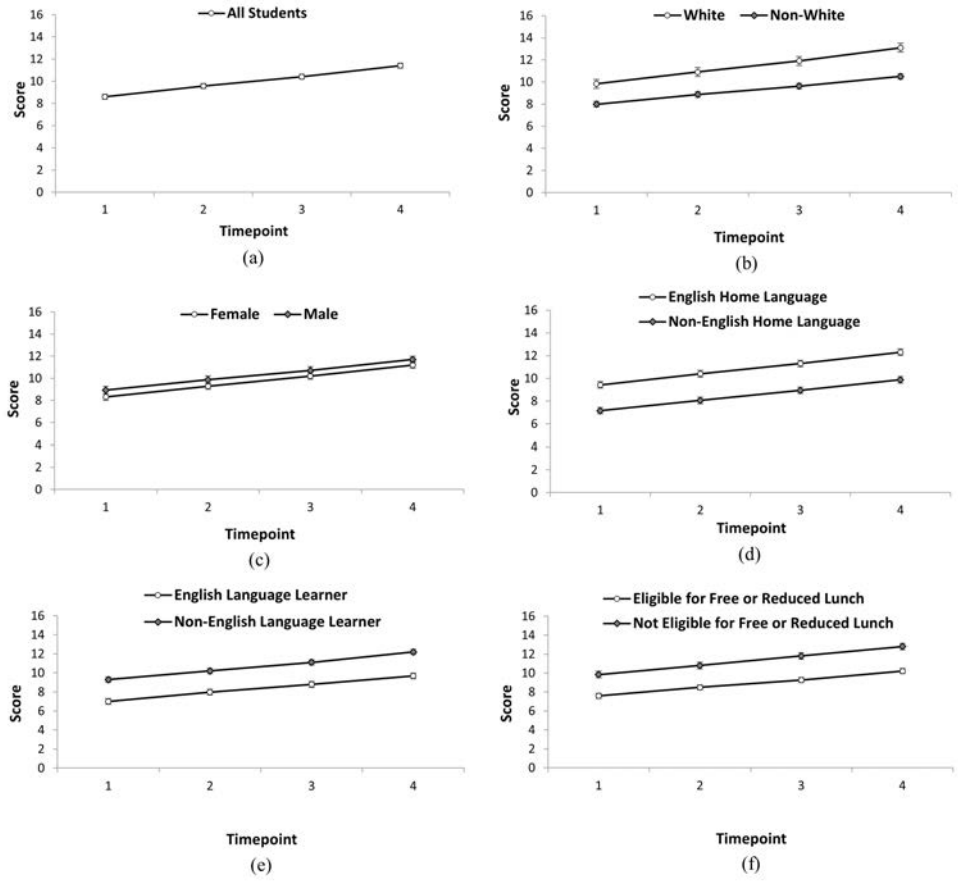
Finally, the model with FRL eligibility as a covariate showed a significant main effect of FRL eligibility but no significant interaction with time (Figure 1f). Students not eligible for FRL performed significantly better than students who were eligible for FRL across all ELCII modules. However, the learning trajectories for the groups did not differ over time.

Table 1
Parameter estimates for ELCII trajectory model by covariate

	All Students	Race/ Ethnicity: White	Gender: Female	Home Language: Non-English	ELL Status: ELL	FRL Eligibility: Eligible
Fixed effects						
Intercept	7.69 (0.31) ***	7.16 (0.38) ***	8.01 (0.45) ***	8.49 (0.38) ***	8.36 (0.36) ***	8.87 (0.45) ***
Time	0.91 (0.07) ***	0.83 (0.09) ***	0.92 (0.10) ***	0.93 (0.09) ***	0.93 (0.09) ***	0.97 (0.10) ***
Covariate	-	**1.62 (0.65) ***	**-0.61 (0.62)**	**-2.22 (0.64) ***	**-2.23 (0.67) ***	**-2.13 (0.61) ***
Covariate*Time	-	0.23 (0.15)	-0.01 (0.14)	-0.05 (0.15)	-0.07 (0.16)	-0.12 (0.14)

Note. Covariate and reference group in each column. Standard errors in brackets. *p<.05, **p<.01, ***p<.001.

Figure 1
Estimated ELCII mean score trajectories for all students (a), and by subgroup (b-f)



Discussion

Computer-based learning environments aimed at improving literacy skills help adapt instruction to an increasingly diverse student population (McCarthy et al., 2020) and have the potential to bridge persistent opportunity gaps that manifest as achievement gaps (Patton-Terry, 2021). We investigated whether the effect of such a program, called ELCII, differed based on students' demographic characteristics to identify how well the program works for all students in kindergarten. Results indicated that all students, on average, showed improved inference making performance over time and that growth in inference making performance did not differ across gender, race/ethnicity, home language, ELL status, or FRL eligibility. However, the results also highlighted persistent gaps that were present at the onset of the program, and unfortunately continued to persist. Specific factors relevant to initial gaps in inference making performance were race/ethnicity, home language, ELL status and FRL eligibility.

Promisingly, ELCII works equally well for all students, which is a necessary first step in the eventual bridging of opportunity gaps. However, for gaps to be bridged, future research must identify ways to accelerate growth of core skill development among students who need additional support. In the context of ELCII, such acceleration may be possible by, for example, increasing dosage. This would allow students who struggle initially to receive additional opportunities for developing inference skills (e.g., four modules per week instead of two). The use of language supports should also be examined (Roberts et al., 2021), which may serve to tailor the program more adequately to students learning English or to students who do not speak English at home. Since pre-existing background knowledge has been found to influence socioeconomic differences in children's learning and comprehension (Kaefer et al., 2014), future research should also determine how to minimize prior knowledge demands in educational interventions. Considering the complex relationship between socioeconomic differences and race/ethnicity (Shrider et al., 2021), future analyses must first improve on the rudimentary race/ethnicity categorization used in the present study before more precise interventions can be developed. Without question, each learner's identity is represented across each of the groups defined in the present study.

With the ideal in mind of an intervention that is responsive to every component of a learner's identity, we hope for this study to serve as an initial step. Importantly, the findings from this study not only identify the benefits of ELCII for developing inference making skills generally, but also identify groups of students who may need additional support. We believe that this identification is critical in the evolution of such interventions from equal to equitable.

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"Do we have to do this every time new germs come out?" and other questions from children about Covid-19

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Abstract: Uncertainty and concern marked the spring of 2020 as the Covid-19 pandemic rapidly disrupted daily life and brought up highly consequential questions about living in a public health emergency. In this paper, I present an analysis of questions that 109 caregivers of elementary schoolers reported receiving from their children about the early pandemic. Understanding what questions children were asking of their caregivers and how the caregivers respond to their questions helps reveal both children's informational needs and caregiver approaches to handling those questions. Findings indicate the salience of questions about daily life and highlight the importance of the affective valence of the questions and responses.

Introduction

The start of the Covid-19 pandemic was a massive disruption that introduced new, highly consequential questions for people around the world. Parents and other caregivers of young children found themselves in the tricky position of answering questions about daily life that did not necessarily have clear-cut answers. "What is the coronavirus?," "Will we have school next year?," "Do we have covid?," "Will you die?," and "Did China make the virus?" are all examples of questions from children that reflect the uncertainty of pandemic while varying in the level of factual and emotional difficulty. For some caregivers in the U.S., the pandemic may have been the first time they were confronted with questions from their children that they were not sure how to respond to. Others may have had more practice fielding difficult questions, but not in times as uncertain as the beginning of the Covid-19 pandemic.

Asking questions is a purposeful information-seeking mechanism that children use to respond to and understand the events in their lives (Chouinard et al., 2007). Research in child development suggests that questions are sparked by "first-person cues (such as novelty or surprise), third-person cues (such as a knowledgeable adults' surprise or question), and future-oriented cues (such as expectations about information gain or future value)" (Linquin & Lombrozo, 2020, p. 14). As children encounter concepts and ideas for which they do not have direct evidence or experience, such as gravity or the existence of a God, they depend on more knowledgeable others (Vygotsky, 1978) for testimony. Through these processes, children learn ways of knowing and questioning that are culturally salient to their communities in interactions with their caregivers (Callanan et al., 2012; Menendez, 2020; Crowley et al., 2001; Sak & Shain-Sak, 2020). The dynamics around question asking and responses are complicated, yet they provide insight into the norms of communities and how they mediate information.

Specifically with regards to the Covid-19 pandemic, understanding what questions children were asking and the responses from the caregivers to those questions help us understand the children's information needs and how caregivers supported the mental, physical, and emotional well-being of their children in adjusting to the pandemic. An early study in June 2020 by Nelson and colleagues (2020) surveyed a sample of caregivers of 5-10 year-old listeners to the science education podcast BrainsOn! found that 97% of the caregivers reported their children asking a question about the coronavirus, and 62% indicated that they were "very uncomfortable" answering questions their children had about the coronavirus. Nelson and colleagues (2020) also found that 68% of caregivers said their children expressed worry or fear about the pandemic, primarily about loved ones catching the virus and the uncertainty of how long the pandemic would disrupt their lives. This paper presents a complimentary analysis of elementary school-aged children's questions close in time to Nelson and colleagues' study (May 2020). Examining children's questions from early in the pandemic reminds us that our youngest participants in communities are paying attention to the forces that structure their routines and are concerned for the well-being of their communities.

Methods

This paper presents preliminary findings from an analysis of questions caregivers reported hearing from their children. I ask, what can we learn about children's information needs in times of crisis from the questions they asked of their caregivers about Covid-19? To explore this question, I describe the topics of questions that caregivers reported their

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children asking about the pandemic and offer examples of conversations caregivers had with their children about the major categories of questions that emerged from the analysis. The data used in this analysis is part of a larger five-part diary study conducted with 109 families of elementary school children from across the U.S. in May 2020 (c.f. Barron et al, 2021; Pozos et al, 2022). The caregivers were recruited through the *dscout* platform which was also used for multimodal data collection via smartphone. They lived in 28 states and were mostly women (67%) with children in public elementary schools (84%). Racially, 55% self-identified as white, 16% as Black, and 15% as Latinx, 9% as Asian, and 4% as Middle Eastern or North African. Slightly over half (55%) of the caregivers reported an annual household income of at or above the national median income of $75k.

In one part of the study focused on learning about Covid-19, the caregivers responded to a series of prompts eliciting reflections on the questions their children were asking, conversations they were having, what resources they were using to learn about Covid-19, and any challenges they faced in communicating with their children about the pandemic. We collected two sets of child-initiated questions: general questions about the pandemic and questions about the pandemic that the caregivers found difficult to answer. Both sets of questions were coded using the same codebook consisting of deductive drawn from Chouinard et al. (2007) and Nelson et al. (2020) and inductive codes generated from open-coding (Saldaña, 2013). Inter-rater agreement was calculated to be 0.88 using Cohen's Kappa, indicating strong agreement (McHugh, 2012).

Findings

Most frequently asked questions point to daily concerns

In total, 353 examples of general questions were coded ($M = 3.0$, $S = 2.0$) Seven caregivers did not offer an example question in their response or stated only that their children were not asking questions (five also stated the latter, but also offered examples of questions.) Overall, 75.2% of the caregivers gave an example of at least one question that was coded as one of the four most common topics (school, impact on self, length of the pandemic, changes in routine, see Table 1.)

A few significant differences were found between families with higher/lower incomes. Children from higher income families were more likely to ask questions about impacts on themselves (impact on self, $X^2 = 5.825$, $p = 0.015$). Children of lower income families were more likely to ask about the nature of the virus ($X^2 = 7.568$, $p = 0.006$). Girls were more likely to ask about virus transmission ($X^2 = 11.293$, $p = 0.004$). Any further interpretation as to why these differences may have been significant would be speculative. However, it is interesting to note that there were few significant effects within the categories that make sense to run those tests on (i.e., there are enough questions included in those participant groups to make a Chi-Square meaningful). Importantly, the data do not indicate differences in how caregivers were responding to girls compared to boys, a pattern that has been documented in multiple studies about sensitive topics (e.g., sex; Sak & Sahin-Sak, 2020) and science talk (e.g., Crowley et al., 2001).

Table 1

Frequency of Question Topics, Clustered, with Sample Questions

Count*	Topic	Sample Questions
Personal Impacts (n=187)		
55	School	Will I go back to school in the fall? Why are schools closed?
50	Impact on self	When can I play with my friends?
39	Changes in routine	When is it safe for me to go with you to the store? Can I go outside and play with the neighbors if I wear a mask?
18	Impact on family	When will we see our family again? Will Daddy be ok at work?
13	Kids and corona	If kids don't get it, why can't we play with our friends?
12	Personal protection	How do we stay safe when we do have to go out? What is the point of wearing a mask?
Virus & Treatment (n = 75)		
19	Infection	Are you infected mom? Do we have coronavirus? How do people get

		sick? If our cat can get sick?
15	Nature of virus	What is it? Why is it so dangerous? How does the virus work?
14	Virus transmission	How is it spreading? How many cases are in our area? Why can't we just wipe away the germs?
13	Virus origin	Where is it from? What caused it? Did China make the virus?
9	Virus treatment	What medicine will help? Is there going to be a cure for it? How can we beat it?
5	Vaccines	When will they have a shot for it? Will there be a vaccine and is it safe? If I [mother] would get the vaccine if they had one
Future (n=61)		
49	Length of pandemic	When will the virus be over? How long until things are normal again?
12	Death	Can the whole world die from it? Why have people died? If [our] grandparents were going to die?
Misc (n=30)		
16	Not asking questions	
14	Other	What are some things we can do to help? Why are things closing down?

*Number of questions reported

Difficult questions

In total, 91 difficult questions were identified from 51 caregiver responses (M = 1.6, SD = 0.99). Again, the most frequently asked questions were about how long the pandemic would last (n=29), how the pandemic restrictions were impacting them personally (n=13), and when schools would reopen/ how they would operate (n=9). Caregivers found questions that did not have specific answers at that point in the pandemic, questions that they were unsure about themselves, and questions to which they had an emotional reaction the most difficult to answer. As one mother of an 8 year-old daughter commented, "It's hard telling children their [*sic*] is no cure for something that has killed so many and has affected thousands of people." A father of a 6 year-old son confesses that he responds to his son's question about if they will all be safe, "I say yes but its [*sic*] not something I can garuntee [*sic*] and I feel a little poorly when I say it." Another father of a kindergartener wondered if his son would still trust him as an information source after not having answers: "to be honest I would not trust us either, just because we just don't have a lot of answers to critical questions in his mind." The caregivers' reflections on their responses to their children's questions, especially their young children, show concern for their mental wellbeing and also conflict as their desire to protect their children meet the reality of the all-consuming nature of the pandemic in the early months.

Discussion & directions for future research

In May 2020, children were most concerned about how the virus was going to impact them personally as they experienced significant disruptions in their routines, especially concerning school. However, they also showed interest in knowing about the virus itself and how the pandemic would shape the future. Some of the questions were sparked by disruptions in routines, while others came from what children were hearing through the media or from friends and family. The reflections caregivers shared on questions they found difficult show discomfort with the questions that did not have concrete answers. The lack of concrete answers sometimes meant that children kept asking, as they are known to do when they want to check in case an answer has changed (Linquin & Lombrozo, 2020). Though this study did not ask caregivers to record the frequency with which their children asked each question, many caregivers volunteered that they regularly responded to the same questions from their children. For some this may have been their first experience of not being able to be the expert or authority on a topic that was consequential for the health and well-bring of their children. This raises an interesting issue for learning and media designers about what children's information needs actually are and how to meet them. Emotion regulation and the knowledge frameworks that the caregivers draw on to offer reassurance shape the home learning environment and implicitly teach children ways of knowing and questioning during emotionally difficult times. What do children need to know about sensitive topics, like severe illness and death, if people in their sphere of influence are not being directly impacted? How should we

think about the potential differences between what the caregivers are comfortable answering and what questions children have that caregivers might not have answers to or feel that they cannot be completely honest about?

As the Covid-19 pandemic continues to unfold, new questions emerge, and old ones are revisited as new scientific studies are released and political battles shape discourse about health and social responsibility. As new developments occurred, the children likely began to ask different questions based on the national news (e.g., mask-wearing controversies, vaccine approvals and hesitation), as Nelson and colleagues (2021) found in their follow-up study. Further research might continue to explore the role of children's questions about health topics and caregivers' affective responses in the development of health literacy and decision making.

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International Society of the Learning Sciences

Children's Place-based Gesture: An Understudied Resource in Socio-Ecological Sensemaking

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Abstract: In the learning sciences, there has been a growing focus on the body and place, elevating the multi-modal and situated dimensions of learning. I bring attention to children's place-based depictive gestures, revealing how such gestures are a generative but often overlooked resource in science sensemaking. Analysis focused on 11 and 12 year-old children's gestures as they discussed what organisms needed to thrive in their schoolyard, within a late elementary school curriculum that centered on place-based approaches to teaching science and data science. Findings reveal children's depictive gestures made visible their rich and varied knowledge of the schoolyard in collective discussions. Such gestures were also integral in children's conjecturing, contesting and clarifying relationships within a socio-ecological system, layering together multiple ways of knowing. Implications for teaching and learning about socio-ecological systems are discussed.

Introduction

Children have rich and varied knowledge about the social, natural and built world around them, steeped in the routines and rhythms of their daily lives (Nespor, 2010; Seyer-Ochi, 2006). Across childhood studies, geography, environmental education and science education fields, there has been detailed documentation of such understandings, enmeshed in smells, sights and sounds of local places shaped by broader cultural, political and historical forces (Lim & Barton, 2010; Mitchell & Elwood, 2012). Yet rarely do children have the opportunity to meaningfully interweave this multi-modal, multi-temporal knowledge into their disciplinary learning.

Such place-based knowledge appears particularly generative for youths' understandings of complex socio-ecological systems. Conceptualizing socio-ecological systems entails considering multiple interacting parts of a system, and their relationships with one another, across varying spatial and temporal scales (Pugh et al., 2019). This includes considering the abundance, scarcity and distribution of organisms and the relationships within and between these organisms and their environment (Korfiatis & Tunnicliffe, 2012) but also, how such systems are shaped by broader socio-political institutions and historical legacies (Davis & Schaeffer, 2019). Yet to date, there is limited research in this area because common approaches to teaching about socio-ecological systems often removes learning from actual places that children know by focusing on far away, virtual, or simulated settings.

In this study, I examine how children's place-based depictive gestures emerged in discussion, supporting weaving together understandings of socio-ecological systems in relation with children's knowledge of the built, natural and social worlds central to their daily lives, particularly children's memories and histories. Existing accounts of gesture in science education have pointed to the importance of this semiotic form (Crowder, 1996; Mathayas et al., 2019) but nascent research, especially in science education, learning sciences and environmental education research, has documented how place-based knowledge is depicted through gesture. In this study, I aim to understand how children's place specific knowledge emerges and becomes visible in science discussions through gesture, examining how such depictive gesture supports children's sensemaking about complex socio-ecological systems as children interweave multiple ways of knowing (Warren et al, 2021).

In this analysis, I ask, What place-specific gestures emerge in collective discussions? and How did this gestured local knowledge support sensemaking about complex socio-ecological systems? In the sections that follow, I describe the context of this study and methods of analysis, followed by sharing key findings and discussing implications for research and practice.

Methods

Study Context

Data presented are drawn from a larger multi-year design-based research project that aimed to support children understanding socio-ecological systems through engaging in science and data science practices, with a participatory GIS mapping technology, *Local Ground* (Van Wart et al., 2020) and local places central to the design (Lanouette, 2022; Lanouette, 2019). Key to this work was a commitment to expand what ways of knowing could be brought to bear as children learned about how socio-ecological systems functioned and thrived. The author and colleagues collaborated with a K-5 public elementary school in the Western United States, working closely with

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two late elementary classes, the school's science teacher, and the 4th and 5th grade homeroom teachers (Lanouette et al., 2016). In this analysis, the focus is on year 3 of the project, where I worked with one 5th grade science class with 27 students (Lanouette, 2022).

Across 9 weeks (18 class sessions, lasting 60-90 minutes each), I designed and taught the multi-week curriculum during the students' science class time, in collaboration with the science teacher. The curriculum engaged students in two cycles of sampling, data visualization, and discussion. During these earlier lessons (Lessons 1-4), children conjectured potential important "parts" of the schoolyard soil ecology, with the teacher posing the question "Who lives underfoot and what do they need to thrive?" Children then visited different schoolyard locations of their choosing and selected an initial site for sampling to study in greater detail. At their sites, children collected a range of data about earthworms, other invertebrates, and plants' root structures, as well as soil characteristics such as moisture, compaction, and composition. They also recorded notes about schoolyard activities that they thought might be important to understanding who might thrive and where, such foot traffic, sound levels, and other children's play activities. After several class sessions devoted to exploring relationships in the aggregated data using *Local Ground* participatory GIS maps and canonical data forms (L7-L12), students had the opportunity to select a second sampling site in Lesson 13 to further support studying relationships emerging in the class data, as well as to explore puzzling patterns, outliers, or anomalies in the data.

Data sources relevant to this analysis included five class sessions where children discussed emergent relationships or patterns in their aggregated data (Lessons 11, 12, 16, 17, 18). These five lessons were selected because they involved children discussing what organisms needed to thrive in their schoolyard, using their aggregated data to conjecture, contest or clarify their claims drawing on multiple sources of evidence.

Analysis

Drawing on multi-modal interaction analysis techniques (Stivers & Sidnell, 2005), a research assistant and I analyzed video recordings of several whole class discussions. We focused on children's *depictive gestures* (Streeck, 2008) where the "hands depict by enacting their familiar, "real-world" capacities as users, transporters, experiencers, assemblers, molders, and shapers of things" (Streeck, 2008, p. 285). In the first phase of video analysis, we reviewed conversations in the five class sessions where children conjectured, contested, and clarified potential relationships or patterns in their data, related to who could thrive underfoot and where. Using video coding software (MAXQDA), we documented all instances of children's gesture depicting place-based knowledge of the schoolyard. In the second phase of analysis, we returned to these highlighted instances, examining how depictive gesture supported children's collective sensemaking about relationships within the data and the schoolyard socio-ecological system. We also noted what place-based knowledge was being depicted (e.g., natural, built, social), what socio-ecological relationships were being discussed, and the work of depictive gesture in this collective sensemaking (e.g., elaborating on data points, clarifying relationships among vertebrates, invertebrates and the soil, showing transient elements like sunlight and rainfall), to better understand the work these gestures were doing.

Findings

In this section, I first provide a brief overview of the place-based depictive gestures emergent in children's sensemaking as they conjectured, contested and clarified understandings of socio-ecological relationships and processes. Next, I show one sequence of place-based depictive gestures in more detail, briefly describing the context in which the gesture appears, what place-specific knowledge was elevated, and how the gesture supported children in refining understandings about how multiple parts of a local socio-ecological system come to function together and thrive.

Overview: Children's place-based depictive gestures

Children's place-based gestures communicated varied knowledge about their schoolyard, evoking natural, built, material and social dimensions of the schoolyard occurring across days, seasons and years. For example, such gestures included knowledge about *environmental phenomena,* such as the pathways of sunlight and shade throughout the day as well as seasonal patterns of rainfall and related puddle formation. Such knowledge was often shared with sweeping hand gestures over the *Local Ground* map or creating imagined landscapes in front of themselves where varied environmental phenomena were overlaid. Children's gestures also depicted knowledge of the *social rhythms of the day,* such as where people in the school community gather and activities they engage in. This included mimicking running bodies along a walkway with marching fingers or showing how 3rd graders dispersed during recess using undulating hands. Lastly, children's place-based gesture included detailed knowledge of *built and material configurations* about their particular sampling sites or specific schoolyard locations. Gestures showed knowledge about the perimeter, composition and height of buildings, fences, and

playground structures, depicted through fingers tracing building footprints in the air or bringing hands together to show angles and areas created by structures.

Example: Preeti and Isaac's tucked away sampling site

In this instance, Preeti and Isaac are contesting classmates' earlier claims that earthworms need roots, shade and moist soil to thrive. Using their own experiences at their selected site and their site data, the pair argues that even though they had moist soil, shade and roots, they only found one earthworm at their hidden garden site. As the discussion ensues, a student asks about additional aspects of their garden sampling site to understand their discrepant data and counter claims, asking "Do a lot of people walk around there?" Isaac replies, "In our area? *(pointing towards the map).* Not at all! It actually is in a tight little corner."

As shown in Figure 1, Isaac then steps away from the interactive data map and orients his body towards his classmates on the rug below. Using gesture to provide an on-the ground perspective, Isaac says, "Because ours [our site] is like … See, the classroom is here, actually here (*moving his hands together to classroom wall*, see Figure 1a) and this wall is here and our site is fa::::r from where kids walk a lot (*shifting hands to show his groups' site to peers seated below and wiggling his right thumb to show walkers at a distance,* see Figure 1b).

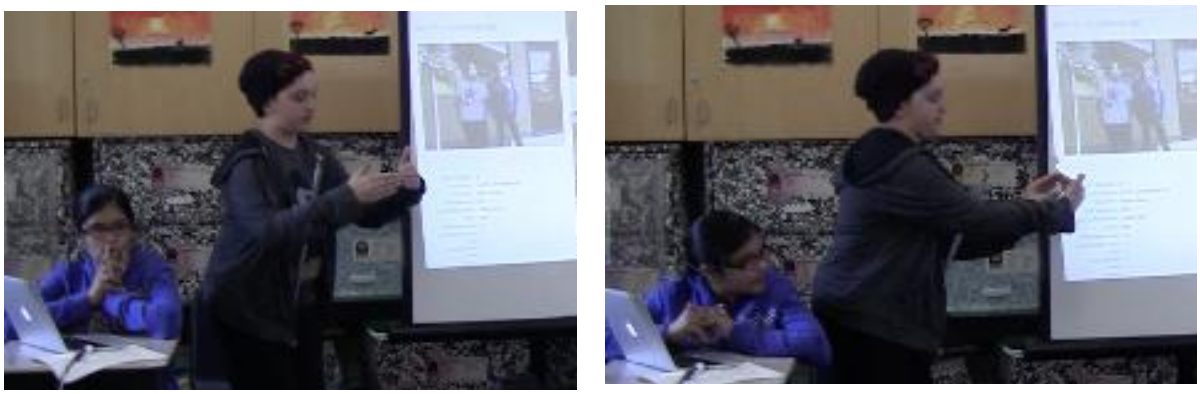

Figure 1 (a, b): *(a) Isaac's initial gesture depicting their garden site in relation to the classroom buildings, facing towards himself, (b) Isaac at the end of a series of gestures, depicting his actual site location in relation to children's daily foot traffic and the school building wall, from his classmates' perspectives.*

Through this series of gestures, Isaac recreates his and Preeti's tucked away garden site, depicting built structures (e.g. "the classroom is here") and children's movement through the space (e.g., "where kids walk a lot", wiggling his thumb). In the process, he interweaves his first-person experiences collecting data with his daily understandings of being in that garden as he reasons about what earthworms need to thrive and considering the classes' aggregated data. In doing so, multiple intersecting elements of the schoolyard ecosystem are considered and made visible to one another, interweaving the natural, built and social layers of the schoolyard into the collective discussions about how socio-ecological system function and thrive. Here, children making sense of multi-variate relationships in their aggregated data (earthworm counts, soil moisture measurements) are interpreted in relation to more dynamic (e.g., shade, footsteps) and less dynamic (e.g., build structures) elements of the socio-ecological system across varying time spans.

Discussion

Children's descriptive gestures about the schoolyard were shown to be a powerful resource in making visible emplaced knowledge in collective sensemaking about what organisms need to thrive. Additionally, children's gestures made possible coordinating together multiple parts of complex socio-ecological systems, blending together natural, built and social dimensions of the schoolyard across days, weeks and years to reason. Such coordination supported further considerations of underlying mechanisms and explanations for relationships emergent in the classes' aggregated data. Together, this coupling of depictive gesture and place-based knowledge supported children bringing together expansive knowledge about a socio-ecological system as they conjectured, contested and clarified emergent relationships in their data and the system at large.

Significance of this study are two-fold. First, analysis suggests the depth and breadth of children's local knowledge as a generative resource in learning about complex socio-ecological systems. To date, existing research on learning and teaching about complex systems has tended to overlook children's emplaced, historical and social

knowledge about place, particularly embodied forms. Second, this work contributes to existing research related to gesture in science learning, elevating how depictive gestures showing emplaced local knowledge can be a powerful resource in learning about complex socio-ecological systems. Combined, this analysis extends existing work on gesture in science education to become further situated within and about place while also making visible the ingenuity and expertise children bring to science sensemaking drawing on multi-modal resources like gesture. As the learning sciences and science education fields further focus on place-based approaches to teaching and learning, particularly approaches that elevate heterogenous and expansive modalities for expression and sensemaking (Warren et al., 2021), young peoples' place-based depictive gesture appears a generative resource warranting further study.

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International Society of the Learning Sciences

Becoming Visible in a New Learning Environment

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Abstract: This paper explores an episode of a Black student seeking attention from a classroom adult at a majority white, middle-class coding camp. I explore how the theory of perceptual affordances and attunement intersect with racialized experiences at school to understand how attention moved in a classroom and was ultimately distributed in a way that the Black student's needs were missed.

Introduction

The racialized practices of policing and disciplining Black children while at school is well-established in the field of education (Monroe, 2005; Lewis et al., 2010; Skiba et al. 2011, etc.). In particular, research has consistently shown that Black boys are more likely to be suspended, referred to the office, and expelled than their White peers (Welsh & Little, 2018). This creates a culture where doing the exact right thing at all times becomes pertinent for Black students' survival of school. Understandably, one survival tactic for Black students is to be less visible. This is necessitated particularly in contexts such as charter networks using behavior management strategies based in the theory of broken-windows policing (Lemov, 2010, p. 195), which encourage teachers to monitor even the smallest behaviors, and settle for no less than 100% compliance.

But what happens when students who were socialized to behave in this way once they enter new environments? Research has raised concern about such behavior management practices due to their mis alignment with cultures found in the colleges and workplaces students will encounter after they leave school (Golann, 2015). To highlight this lack of alignment more concretely at the micro level, I explore a case study of a Black boy from a low income, high discipline urban middle school attempting to gain attention in a coding summer camp with a majority White, middle-class student population. Even though the summer camp had a student/teacher ratio of 2:1, the boy remained mostly invisible for 7 minutes as he tried to seek help on his coding project. In my analysis I seek to show not only that a student was missed in a highly supervised environment, but I also try to make sense of why, and how he attempts to understand the adults' system of attention, that does not at first seem to operate in familiar ways.

Conceptual framework: How attention works in classrooms

Attention and its distribution is a joint accomplishment between group members, environmental affordances, and attunement. However, there are certain patterns in identity that have been demonstrated to be predictive of who will gain the most attention, which is often highly inequitable. For example, students who receive the most attention in a classroom are most likely to be high achieving white males (Martin, Milne, & Scantlebury, 2006). There can often also be a socioeconomic divide, with wealthier students being more likely to actively seek help than their economically disadvantaged peers (Calarco, 2011). The expectation of "seeking help if you need it" is also commonly upheld by teachers, in alignment with the culture of middle-class students (Calarco, 2011). The picture of a white, middle-class, high-achieving male student as the most likely collector of attentional resources is central to this analysis of a focal student: a Black boy named Prince.

Methods

I used interaction analysis (Jordan & Henderson, 1995) as well as Gibson's theory of affordances (1979) to explore an episode where Prince, is attempting to gain an adult's attention for help on his coding challenge. Prince was stuck on his code for 20 minutes, and the focal 7-minute clip encapsulates the moments where he sought attention from an adult. This is an anomaly during this activity, as all other students during this time can be seen receiving substantial support during the same focal minutes.

Data

The focus episode occurred on the first day of a week-long camp called *Code Your Art,* an introductory coding class in which students learn how to create various art projects using NetLogo (Tisue & Wilensky, 1999). During the clip, students were engaged in an independent "coding scavenger hunt" where they were challenged to use code to create different images, such as stripes or a border.

The focus student for this analysis is Prince, a rising 9th grader. Prince attended East Middle School, a majority Black and Latinx urban school with a suspension rate of 15%, compared to the district average of 9%. At camp, he was the oldest student in the class of 10, one of two Black students, and the only Black boy.

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Before the focal episode begins, Prince is trying to complete the first scavenger hunt challenge: changing one half of the interface to one color and the other half to a different color. However, as commonly seen, he was writing code using plain English, and continuously received error messages. The clip begins when Prince started attempting to ask for help. The adults relevant to the analysis are "Researcher," Ms. Turner, the lead teacher of the class, and Victor, the classroom TA and coding expert. While the activity lasted about 30 minutes, Prince struggled for the first 20 minutes to accomplish any of the challenges. The focal clip details the final 7 minutes of his struggle with the code as he is trying to troubleshoot this new system of adult attention.

For this piece, I analyzed both screencapture and webcam data from Prince's laptop. The screencapture software depicts both what Prince was currently seeing and doing on his laptop while the webcam and laptop microphone recorded Prince and his immediate surroundings.

Analytic Framework

Gibson's (1979) theory of perceptual affordances states that what can happen in any particular moment is made up of possibilities that are co-constructed by the affordances of the environment, effectivities of the people in the environment, and the dynamic intentions of those in the environment based off of the current situation (Gresalfi, Barnes & Cross, 2011). *Affordances*, are the actions that particular objects or stimuli invite in an environment (Greeno, 1994). For example, in a classroom a raised hand often invites a teacher to call on that student. The ability for student bids for attention to become affordances in a classroom setting can strongly depend on the attunement of the adults in the room. *Attunement* is shaped by a person's culture, identity, and previous experiences, and therefore poses a situated set of limitations in what can become possible for a given individual. For example, in a culture that values students who are quietly following directions, it will be common for the teacher to be more attuned to the activity of the active student, sometimes at the expense of missing quieter bids from others.

Findings

Figure 1 shows an overview of Prince's four attempts at interacting with adults in the space. A common strategy he employed throughout the episode was using eye contact and other quiet bids for attention. However, as will be shown below, the organization of adult attunement during this activity left his requests for help unanswered for 7 minutes.

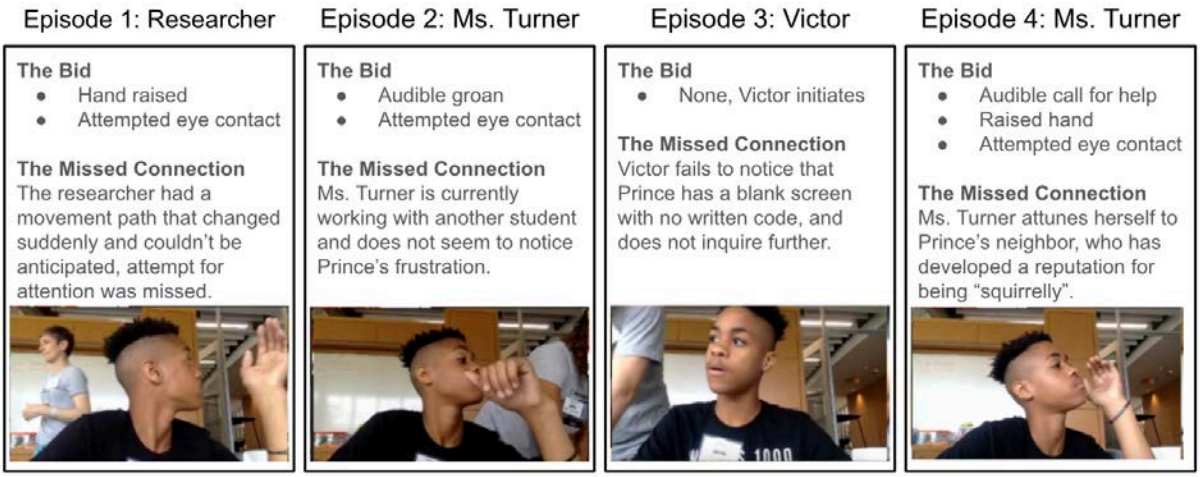

Figure 1. An overview of the interactional bid that outlines the attempt and the reasons adults did not respond.

Episodes 1 & 2

In the beginning, Prince offers interactionally quiet bids for attention as he is trying to understand how to interact with the adults. To begin, "Researcher" was working with the student sitting directly to the right of Prince. After she finished, she looked quickly at Prince, turned back to her original position, and then exited the room. From the first image in Figure 1, we can see that Prince was anticipating Researcher's appearance on his left side. Because we can see that Researcher was not looking when the hand is offered, we know that Prince's raised hand did not become an affordance for help, and he was missed.

The second moment of Prince's bidding to lead teacher Ms. Turner seems to, in part, be a response Researcher's failure to recognize Prince's silent hand. As Ms. Turner was working with the student directly to

the left, Prince let out a long, audible groan, and looked toward Ms. Turner. However, it is unclear from the record if Ms. Turner heard the groaning or not, and Prince was missed a second time.

Episode 3

Later in the activity, Prince was approached by Victor, the class TA. In the approximately 9 second exchange, Victor asked how it's going, to which Prince replied, "It's good." Prince also nodded when Victor asked if he was "getting this figured out." However, by this time, Prince had still not been able to complete a challenge of the scavenger hunt, and his screen remained blank. The challenge here, then, was in Victor's position in the camp was that of "coding expert," as he spent the class period solving various errors and debugging code. Although Prince's screen remained blank due to not yet solving any of the coding problems, it is entirely possible that since Prince didn't have buggy code, Victor was not attuned in a way to help him get started.

It is unclear from the record why Prince says that things are good after a string of error messages. It could be that in this moment Prince was developing an idea that he wanted to try before asking for help. Seconds before this interaction, Prince let out a verbal "mmmm!" as if he had an idea. Nonetheless, "How's it going" did not become an affordance for Prince to ask for help, and Victor moved on.

Episode 4

The moment on the record where it is most obvious that Prince was needing of attention was when he verbalized it directly to Ms. Turner. Approximately one minute after Prince expressed to Victor that things were "good", he employed his new idea, which again received an error message. With signs of exasperation, Prince offered a strong bid with three potential affordances: eye contact, a raised hand, and verbal confirmations that he needed help. However, Ms. Turner's attention was not on Prince. She was instead attuned to his more vocal and active neighbor, and at the same moment Prince asked for help, Ms. Turner was already asking what the neighboring student was working on. After his bid, there was never a moment where Ms. Turner cycled back to Prince, or acknowledged that she would get to him soon, so these bids for attention, though interactionally strong, did not ultimately become affordances for Ms. Turner to help.

Much could be said about this interaction when it comes to the movement of Ms. Turner as well as her attunement. It could, for example, speak to Ms. Turner's attunement toward certain children and behaviors. Prince's neighbor was, as Ms. Turner described, a "squirrely" kid, while Prince was extremely compliant. Prince, for example, had thus far not done anything on his laptop that he was not explicitly told to do. On the other hand, his neighbor had consistent redirects to maintain his attention to the task at hand. This shows up as well in adult attentional patterns. In the same 7 minutes, Prince's squirrely neighbor is attended to by adults four separate times. It is possible that Ms. Turner's attunement was seemingly toward the kid with more "squirrely" tendencies, with less of an urgent need to attend to the activities of student who was extremely compliant.

Finally crossing the threshold

The moment where Prince was finally able to be noticed and receive help from Ms. Turner was still fairly quiet, in line with Prince's other gestures and potential bids. In a moment where she was standing behind him, Prince simply turns to make eye contact and says, "I don't know how to separate it," which alludes to the first challenge of having a split screen that is half one color, half another. This sets off an extended interaction between Prince and Ms. Turner that puts him on the path to understanding how to use NetLogo syntax to accomplish his goal. Ultimately, Prince did not have to change his strategy to finally receive attention. However, by the time Prince had received meaningful help, every other student had had significantly more interaction and help from adults in the room. What seems to have made the difference for Prince in his actions becoming affordances in the end was his ability to correctly understand and anticipate Ms. Turner's movements in a way that he could employ eye contact and gain attention.

Discussion

When Prince did seek attention, he generally relied on quiet bids such as eye contact to signal his need for help. Due to his identity as a Black boy in a new environment, and the consequences for expressing defiance for Black boys has historically been severe, expressing silent bids for attention can be seen as reasonable on his part. However, these quiet bids seemingly took adults longer to notice in this environment. It is clear that temperaments such as his neighbor's "squirreliness" was worthy of a great deal of attention, but historically, a squirrelly disposition is not one that is available to Black boys. Prince's quiet demeanor paired with his ultra-compliance and status as the oldest student seemingly created a "perfect storm" of adults perceiving Prince as a kid that that didn't have to focus on as much. This was not the story of Prince throughout the whole camp: eventually, he

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would go on to become incorporated into the classroom and even receive special recognition for some of his work. However, this case has implications for educators serving marginalized students, as it presents a concrete example of the unequal weight that many may carry into new environments. Creating educational spaces in urban contexts that necessitate quiet compliance may create order in the short term, but disadvantage marginalized students in the long term as they need to negotiate how to participate in new spaces. And in learning environments that bring together students from different contexts, the tacit assumption that students are asking for help if they need it can lead to less visibility for marginalized students, who may be more used to environments where being silent is imperative for survival.

Conclusion

This paper explores a 7-minute episode of Prince, the focus student, attempting understand the workings of adult attention in a new, less formal coding environment. In the beginning, teachers were seemingly attuned elsewhere (e.g. to the more "squirrely" kid), but there was seemingly, at first, a learning curve for Prince to understand how to seek help in such an environment. Learning how teachers moved was consequential for Prince, who relied heavily on quiet but reasonable methods to get noticed that were unsuccessful in the new learning environment. Further analysis around how other students gained attention is needed.

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"What a Lovely Discussion!" Reconciling Disparate Assessments of Small-Group Interactions from Teacher and Student Perspectives

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Abstract: This study examined student participation during one small-group calculus task, comparing students' firsthand accounts of their learning experiences to observations made by their teacher, student teacher, and peers. Taken together, these varying perspectives paint a more comprehensive (though sometimes contradictory) picture of what happened during the task. Working toward participatory equity – cultivating classrooms with fair (not necessarily equal) opportunities to participate – requires a deep understanding of students' learning experiences. Findings revealed students' accounts of the task differed in consequential ways. Despite the teacher's positive assessment, considering student perspectives suggested this experience was equitable for the three male students, but not for Guadalupe, a young Mexican woman. She earned A's in the course, yet still encountered barriers to participation resulting in her disengagement from the task. Exploring further how students' learning experiences are shaped by gender, race, and other contextual factors are important directions for future research.

Introduction

Working toward participatory equity – cultivating classrooms with fair (not necessarily equal) opportunities to participate (Esmonde, 2009; Secada, 1989) – requires a deep understanding of students' learning experiences. As researchers, we can observe how students participate during lessons, we can compare participation patterns across groups of students by gender and/or race, and we can judge what seems equitable based on expected distributions of talk (e.g., Shah & Crespo, 2018). However, if our analysis stops there, we are missing critical pieces to the equity puzzle. Fairness is connected to power, privilege, and participatory expectations (Rasooli et al., 2019) and is not always visible to outside observers. To assess the extent to which every student has *fair* opportunities to participate in support of rich content knowledge and positive mathematical identity (Esmonde, 2009; Schoenfeld, 2014), we must examine learning experiences from classroom participants' perspectives (Sengupta-Irving & Vossoughi, 2019). Specifically, we need to privilege the perspectives of females and racially minoritized students, who often face additional barriers to participation in mathematics classes (Leyva et al., 2021).

This study examines the experiences of four students working on a small-group calculus task from multiple perspectives. I pay particular attention to what each perspective adds to the story of what happened for these students. Questions are: *1) How did the teacher and student teacher make sense of student participation during this task? 2) How did students make sense of their own and their peers' participation during this task?*

Theoretical framework

Teaching and learning are considered sociopolitical endeavors through which power is distributed, either perpetuating persistent inequities or challenging existing hierarchies and injustices (Gutiérrez, 2013; Philip et al., 2017; Valero, 2018). Learning is defined as changes in students' participation in collective classroom practices (Lave & Wenger, 1991) and is a function of students' opportunities to participate (Gresalfi et al., 2009). Opportunities to participate are shaped by the roles and responsibilities students are assigned through acts of positioning (van Langenhove & Harré, 1999) and influenced by racialized and gendered narratives about who can and should do math (Esmonde & Langer-Osuna, 2013). As students interact, expectations are negotiated for how each student should participate, distributing power among students (Herbel-Eisenmann et al., 2015). Students positioned with competence and authority have more opportunities to participate in consequential ways, offering better access to rich math learning and identity development (Langer-Osuna, 2011).

Methods

Data collection

This study took place during the 2020-2021 school year; all classes used Zoom. The focal group consisted of four 12th-grade students in a Calculus AB course at a US public high school: Yonas ("Black"), Guadalupe ("Mexican"), Hosein ("Mixed"), and Elijah ("White"). Guadalupe was the only female student. Ms. B was the calculus teacher ("White" female). Mr. K was the student teacher ("Mexican" male). Quotation marks indicate words used by

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participants to describe themselves. Names are pseudonyms. Students were given a "related rates" group task without formal instruction on the topic. The teacher wanted them to think about the underlying ideas before formalizing strategies. The problem read: *1. A ladder leans against a wall. It begins to slide down the wall. Does the top of the ladder move at the same rate as the bottom of the ladder? 2. Suppose the bottom slides away from the wall at a rate of 1 ft/sec. How fast is the top of the ladder sliding down the wall when the bottom of the ladder is 6 ft from the wall? Assume the ladder is 10 ft.* The group was video recorded through Zoom. Students spent 10 minutes on the task. During one-on-one stimulated-recall interviews (Erickson, 2006) with the teacher, student teacher, and the four students, participants were shown the video and asked to share their observations of the task. Questions included: What stands out to you as noteworthy? What do you wish had gone differently? In what ways were these interactions typical and/or atypical? Students were also asked: How comfortable were you working on this task? How easy was it for you to participate? Would you say that you enjoyed this experience? Follow-up questions probing for more details included: Can you say more about ___? And what does that mean to you?

Data analysis

Interviews were transcribed then divided into *observation units*, operationalized as talk in which a person attended to or interpreted a particular part of the task video. When the subject, topic, or timeframe of the observation changed, a new *observation unit* was assigned. I developed codes through an open-coding process to identify similarities and differences in data and to facilitate comparison across the participants' observations (Corbin & Strauss, 2014). I used an iterative process of redefining codes to eliminate redundancy and group similar codes together. For each observation unit, codes were assigned to capture the subject ([student name], teacher, student teacher, group, task); topic (e.g., actions, feelings, thinking, ways of being); timeframe (this day, different day, this year, previous year(s)); observation type (person, interaction, other); and tone (positive, neutral, negative).

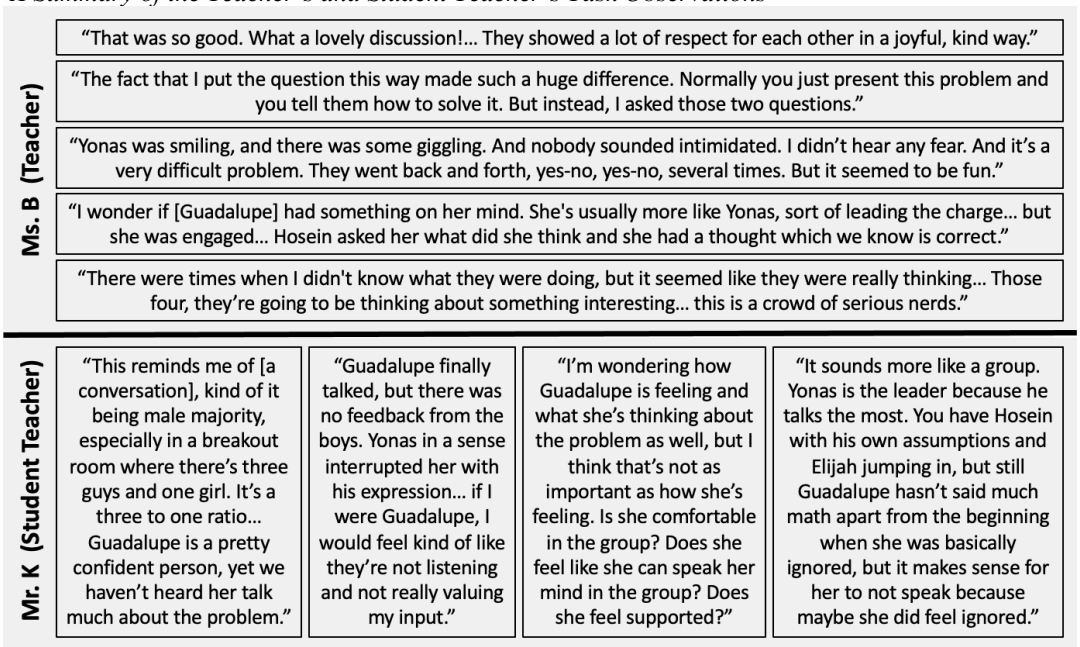
Findings

Teacher and student teacher perspectives

The teacher and student teacher shared their thoughts during interviews after watching the video (Figure 1).

Figure 1

A Summary of the Teacher's and Student Teacher's Task Observations



After watching the video, Ms. B exclaimed, "What a lovely discussion!" She went on to talk about the importance of task design and how the questions supported engagement. She described the interactions as joyful, kind, and fun. She spoke positively about the students' abilities ("this is a crowd of serious nerds"), their collaboration ("they went back and forth"), and their confidence ("I didn't hear any fear"). Ms. B noted Guadalupe spoke less than expected, suggesting she might have had something on her mind, but thought she was engaged.

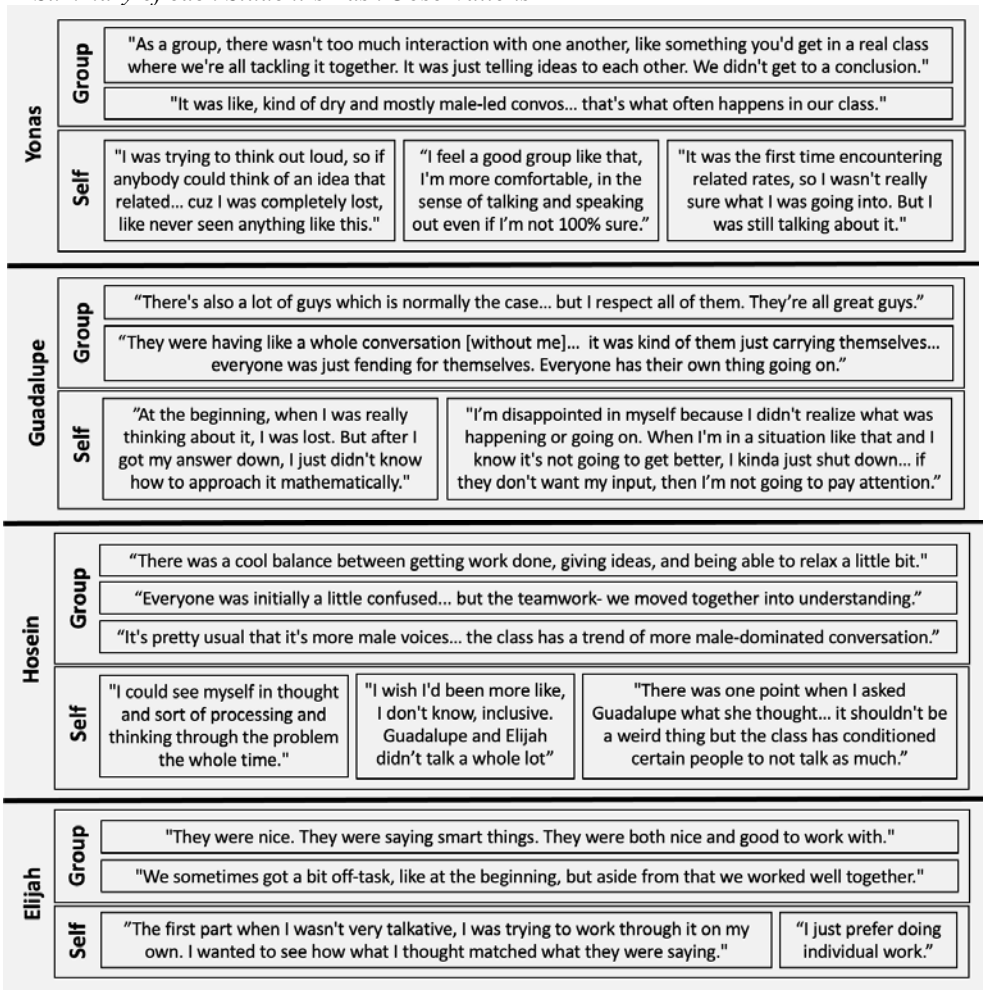
Because Mr. K shared his reflections throughout the video, his observations were sequential as opposed to holistic like the teacher's. He began by pointing out gender imbalance ("male majority"), noting that Guadalupe had yet to say much. Later, Mr. K noticed Yonas's interruption while Guadalupe was sharing and "no feedback from the boys." Mr. K imagined himself as Guadalupe ("I would feel… they're not listening and not really valuing my input"). He reflected further, wondering what Guadalupe was feeling and thinking, noting her feelings were most important. At the end, Mr. K described the group interactions positively, and yet, Guadalupe still had not "said much math stuff." Mr. K speculated that she might have felt ignored.

Student perspectives

The four students reflected on their own and their group's participation after watching the video (Figure 2).

Figure 2

A Summary of each Student's Task Observations



Yonas was confused but still comfortable sharing because it was "a good group," but expressed disappointment that they did not work together and did not reach a final solution. He also noted the conversation was male-led. Guadalupe was thinking hard about the problem but felt her ideas were not valued by her peers. She felt excluded from the conversation and felt it was not going to get any better, so she disengaged. Hosein enjoyed this experience because he felt they "moved together into understanding." He also acknowledged the conversation was male-dominated and talked about wanting to be more inclusive. Elijah thought hard about the problem and seemed to enjoy it but would have preferred to work alone. He thought everyone was nice and worked well together.

Discussion

In this case of four students working on a small-group task, findings revealed students' learning experiences differed in consequential ways. From the teacher's perspective, the group's "lovely discussion" was respectful,

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joyful, and fearless, and the students thought deeply about the intended math. But, to assess participatory equity, the question is… to what extent did *every* student have opportunities to participate and be seen as an important mathematical contributor? From the students' perspectives we learned that Yonas, Hosein, and Elijah felt comfortable thinking and talking about the math, but Guadalupe did not. She was confused, felt unsupported by her peers, and eventually disengaged. Everyone except Elijah noticed Guadalupe spoke less than her peers. Yonas and Hosein reasoned it was related to the pattern of male-led class conversations. Ms. B thought Guadalupe had something on her mind. Mr. K got closest to Guadalupe's reality with his speculation that she felt ignored. Despite the teacher's overall positive assessment of the group's work, a closer look at students' accounts suggested this small-group task experience was equitable for the three male students, but not for Guadalupe, a young Mexican woman who was "a pretty confident person" and was usually "leading the charge." Guadalupe got As in this course and earned a full scholarship to a top US university, but she was not immune to the barriers to participation faced by many females and students of color in advanced math courses. Exploring further how students' learning experiences are connected to gender, race, and other contextual factors are important directions for future research.

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Supporting remote programming instruction with real-time collaboration and awareness tools

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Abstract: Learning to program remotely can be difficult for novices due to a lack of adequate online communication and coding tools. The current paper empirically assessed the impact of real-time collaboration and awareness tools on improving remote programming learning and instruction. Novice programmers were randomly assigned to use either screenshare, a shared online programming notebook (with real-time collaboration), or a shared notebook with awareness tools (shared gaze, mouse and scroll position) with an instructor. Findings revealed that students learned better in the condition where they had access to both real-time collaboration and awareness tools. A discussion of the results reveals the differential benefits of shared gaze and shared cursor for instructors and students and explores the efficacy of sharing web-based eye-tracking data to assist programming instruction. A notable contribution of this work is an open-source chrome extension that enables real-time sharing of awareness tools for online collaborative programming notebooks.

Introduction

A rapid increase in online programming instruction has forced many CS educators to seek out novel tools for remote pedagogy. However, existing technologies for programming instruction, such as screen sharing, github and google docs are not adequately meeting student needs, particularly for novice programmers (Ying & Boyer, 2020). While a number of tools, such as real-time collaboration online notebooks and shared awareness visualizations, offer promise in improving learning, they have not been researched in instructional contexts for novice programmers. In the current study, novice programmers and instructors were either assigned to work through a remote lesson using screen share, a shared notebook (with real-time collaboration tools), or a shared notebook with a chrome extension that enabled awareness tools (shared gaze, shared mouse and shared scroll position). The primary goal of this research is to assess the impact of real-time collaboration tools and awareness tools in improving remote programming instruction, and the differential benefits of shared gaze and shared cursor for instructors and students.

Related Work

Instructors often utilize screen share to help students with their code in a remote setting (Kawash et al., 2021). Screen sharing affords many advantages for programming instruction. For example, when students are sharing their code, instructors can see what they are seeing, which provides a shared reference for discussion and can provide insights into what the student is thinking. However, instructors do not have proper tools to direct student attention or provide real-time code-input (Kawash et al., 2021). During learning, these communication barriers can overburden a students' cognitive load, which is already high for novice programmers.

Real-time collaboration tools for programming, which allow multiple users to edit the same code synchronously, can alleviate some of these issues. Instructors can enter a shared coding environment with a student, and both parties can contribute real-time code input. Several studies have shown the benefits of real-time collaboration tools during pair programming to facilitate peer debugging (Goldman et al., 2011). However, given the novelty of mainstream synchronous programming tools, to our knowledge, they have not been studied in the context of coding instruction and in relation to student learning gains.

While synchronous programming tools allow both instructor and student to work collaboratively on a piece of code remotely, they still lack many advantages afforded during in-person learning. For example, when an instructor and student are working side-by-side, the instructor can point with their finger to direct attention and read the student's nonverbal cues, such as their eye gaze and facial expressions. These can help the instructor infer the students' thought process and tailor their teaching accordingly (D'Angelo & Schneider,

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2021). The ability to point at a location on the screen or to see the other person's eye gaze or scroll position is not afforded in traditional real-time collaboration tools for programming. However, recent advances in low-latency interfaces and eye tracking software can enable transmission of nonverbal cues in a remote setting. These are known as awareness tools. Sung et al., (2021) found that when instructors could remotely see a student's eye gaze, students learned more, and instructors were better able to predict their understanding. In a review of shared gaze technology, D'Angelo & Schneider (2021) explain that shared gaze enables joint-visual attention, which provides a common ground for collaborators to ensure they are on the same page. However, it is yet unclear whether other awareness tools, such as a shared cursor, can better convey these cues. Additionally, these previously mentioned studies have only assessed the effect of instructors visualizing student eye gaze. Given that student-directed awareness tools can be beneficial for learning (Sharma et al., 2016), the current study seeks to differentiate the benefits of awareness tools for students and instructors during a two-way sharing session. Lastly, to our knowledge, prior studies leveraging shared gaze have all used high-cost, external eye trackers, such as a Tobii Pro. These trackers are often expensive and not widely accessible to instructors and students in a real-world context. In the current study, shared gaze was enabled through webcam-based eye tracking, which is more low-cost and accessible. Understanding the benefits of sharing gaze data from a webcam is a first step in democratizing this technology for education.

Methods

Students in the study were 39 English speaking adults between the ages of 19 and 43, who self-reported no prior programming experience. A total of 13 instructors taught the sessions and were recruited through a mailing list sent to teaching fellows for an introductory computer science course and through word of mouth. Each instructor participated in three one-on-one sessions with a student and experienced each condition once. Each one-on-one session was 90 minutes long and took place remotely on Zoom. Together, students and instructors worked through learning content in a Deepnote notebook (deepnote.com). Deepnote enables users to run iPython notebooks in a browser and supports real-time collaboration. The content of the notebook contained exercises and examples for the instructors to teach the learning content. Students were randomly assigned to one of three experimental conditions: Screenshare, Shared notebook and Shared notebook with Awareness Tools.

Based on the interviews with instructors and evidence from other studies (Ying & Boyer, 2020) screenshare is a widely prevalent tool for conducting remote programming instruction. Thus, this was chosen to be the control condition, and a comparison against more advanced instructional tools. In the **Screenshare condition**, instructors and students were given different instances of a notebook containing the same content. The session began with the student sharing their screen and the instructor looking on. The instructor and student were free to switch off screen sharing at any time as they felt convenient. The impact of real-time collaboration tools was assessed in a **Shared Notebook condition** where instructors and students worked on a shared notebook that updated edits and run results in real-time. Both instructors and students were only allowed to reference the shared notebook on their screen. In the **Shared notebook with Awareness Tools** condition, students and instructors worked on a shared notebook, like the previous condition. In addition, they were able to see each other's gaze, mouse and scroll position on the page (Figure 1). The other person's eye gaze was represented by a circle (50px radius), the other person's mouse position was indicated by an orange cursor, and the scroll position was represented by an orange rectangle on a mini-map representation of the notebook on the side of the page. These awareness tools were enabled by a chrome extension (github.com/jiangts/GazeCoder) that users enabled at the beginning of the session. The real-time gaze, cursor, and scroll position was broadcasted to the other user through our websockets server. We used the GazeCloudAPI (gazerecorder.com) for eye tracking, which uses computer vision to determine the position of a user's gaze on the screen.

At the beginning of each session, students watched a 10-minute video sourced from Udacity (udacity.com) which introduced them to the basic building blocks of python. After, they took a pre-test consisting of 6 questions to control for prior knowledge. Students were then introduced to their instructor, who was also in the Zoom room, and both were sent a link to the Deepnote notebook. In the conditions with awareness tools, instructors and students set up the chrome extension and calibrated their eye gaze. After, the students and instructors were given 45 minutes to complete as much of the notebook as possible. Instructors

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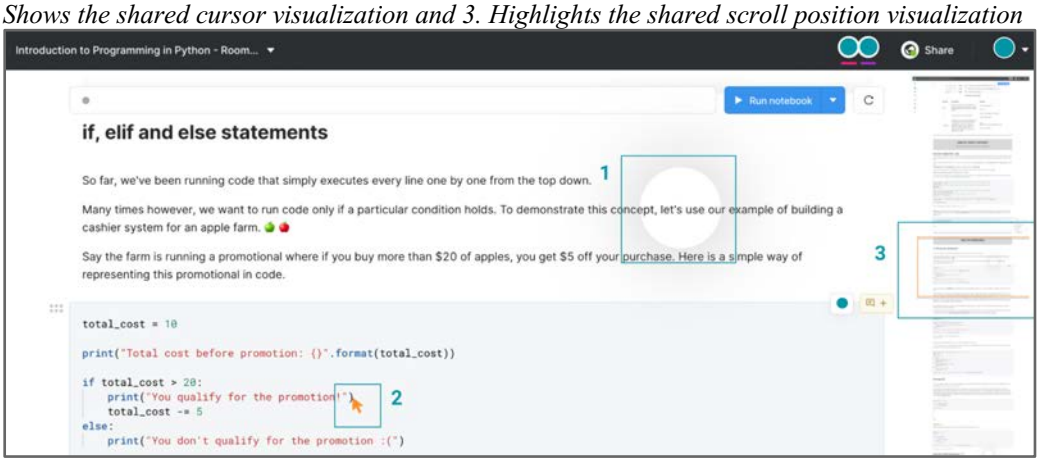
were encouraged to cover all the new content, even if they couldn't complete all the exercises in the notebook. At the end of the 45 minutes, students and instructors completed a survey about their experience, and students then took a 12-question learning post-test that closely mirrored the content of the pre-test, with an additional question for each original pre-test concept. This completed the students' participation. After instructors completed their three student sessions, they were interviewed about their experience teaching in each condition.

Student learning gains were measured using the pre- post-test taken before and after the learning session. The assessments contained multiple choice, short answer and coding questions, and assessed understanding of types, variables, if statements and for loops. Learning gains were calculated by subtracting the pre-test score from the post-test score. Additionally, the usefulness of the shared gaze and cursor tools were assessed based on responses from instructors' and students' post-experiment survey.

Figure 1

Screenshot of Shared Notebook with Awareness tools in Deepnote. 1. The shared gaze visualization, 2. Shows the shared cursor visualization and 3. Highlights the shared scroll position visualization



Results

A one-way ANCOVA was performed to compare the effect of the three different conditions on learning gains. The results revealed that there was a statistically significant difference in learning gains between at least two conditions ($F(2, 36) = 9.91$, $p < .001$). A post-hoc test found that learning gains were significantly different between the Shared Notebook with Awareness tools condition and Screenshare condition ($p = .002$, 95% C.I. = (1.87, 7.42)) and the Shared Notebook with Awareness tools and Shared Notebook condition ($p = .02$, 95% C.I. = (.61, 6.22)). There was no statistically significant difference in learning gains between the Shared Notebook and Screenshare condition ($p = .376$). In these analyses, we controlled for the age of participants based on prior evidence of a relationship between technological learning and age (Charness & Boot, 2009). Additionally, in our data, age was negatively and significantly correlated with learning gains ($r(39) = -.54$, $p < .001$).

In the post-experiment survey, students and instructors were asked to rate the shared gaze and shared cursor tools on a 5-point Likert scale in terms of the tool's usefulness for their learning/teaching. On average, students rated the shared gaze as "Not at all useful" (M=1.2, SD=0.4), and the shared cursor as "Moderately useful" to "Very useful" (M=3.4, SD=1.4) for their learning. Instructors rated seeing the students' gaze as "Moderately useful" (M=2.9, SD=1.4) on average, and the shared cursor tool as "Moderately useful" to "Very useful" (M=3.5, SD=1.2). In general, the instructors found the shared gaze to be more useful than the students, and both instructors and students thought the shared cursor was useful for their learning/teaching.

Discussion

In a one-on-one tutoring setting, students working in a shared notebook with an instructor, who could also see their eye gaze, mouse cursor and scroll position learned more than students who could only see the instructor's shared screen. No difference in learning gains was found between a student working with an instructor in a shared notebook and a student and instructor screensharing. These results suggest that real-time collaboration

tools are not sufficient in supporting learning, and that the addition of awareness tools are necessary for significant learning gains. Preliminary analysis of instructor interviews uncovered potential reasons for these findings. When instructors only had access to real-time collaboration tools (Shared Notebook condition), they recalled that they could easily write out code for students and took advantage of this when making small syntax changes or writing example code to further explain a concept. However, instructors also lost affordances offered in the screenshare condition. For example, they could not see where the student was scrolled to or where their cursor position was. Instructor's recalled feeling "lost" or "blind" in this condition when the student was silent since they could not tell if they were thinking, zoning out, or stuck. In comparison, when instructor's had access to both awareness and real-time collaboration tools, the awareness tools compensated for cues afforded during screensharing, providing both grounding and feedback.

Generally, instructors rated the awareness tools as more useful than the students did. Notably, the instructors found the shared gaze tool to be "Moderately useful" whereas students thought it was "Not at all useful". One instructor reflected that the shared gaze conveyed "thinking", whereas the shared cursor conveyed "intent". Indeed, during a learning situation, it is more useful for an instructor to receive cues about what the student is thinking or confused about so they can tailor their instruction. On the other hand, it is less useful for a student to know what the instructor is thinking, but more useful to know their intent, and what they want the student to pay attention to. This could explain why instructors found the shared gaze to be more useful than students, and why students thought the shared cursor was more useful than the shared gaze.

A few limitations caveat the findings of this research. First, the small sample size may hinder the reliability of these findings. Additionally, since a less accurate web-based eye-tracker was utilized in the study, the results may not be generalizable to other instructor-student gaze-sharing scenarios.

Conclusion

In this paper, we assessed the impact of real-time collaboration and awareness tools on improving remote programming instruction. The results show that synchronous code editing tools can benefit remote programming instruction, but only when supplemented with awareness tools that aid the communication and grounding between students and instructors. Given the rising number of commercial synchronous code editors, such as Deepnote and Replit (replit.com), and the open-source nature of the chrome extension developed in the study, these findings have real-world applications to many CS learning settings, such as office hours or tutoring.

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Using Simulations to Foster Pre-Service Teachers' Diagnostic Competences: What Aspect of Authenticity Matters?

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Abstract: Prior research is somehow divided about the importance of authenticity in simulation-based learning, but in simulations designed for fostering diagnostic competences, there seems to be no general relationship between authenticity and diagnostic competences. In the present study, we investigated perceived authenticity and its role for learners' diagnostic accuracy in a simulation that was designed to foster pre-service teachers' diagnostic competences. Pre-service teachers completed the video-based simulation and composed a written diagnosis of a student's scientific reasoning skills before rating the authenticity of the simulation on three dimensions (realness, involvement and spatial presence). The results showed that the simulation was perceived as authentic – except for spatial presence – and that only the relation of involvement to diagnostic accuracy was statistically significant. This is partly in conflict with previous findings and suggests that the design of simulations for fostering pre-service teachers' diagnostic competences should focus more on involvement rather than on realness.

Introduction

During a regular school day, there are many occasions on which teachers employ diagnostic competences. These diagnostic competences play an essential role in successful teaching (Helmke & Schrader, 1987) and especially as a prerequisite for the specific support of individual students (Schrader, 2009). Diagnostic competences can be defined as the ability to collect and interpret information for the purpose of making high-quality decisions or assessments (see Heitzmann et al., 2019), for example regarding students' knowledge, skills and so forth. Even though previous research pointed out that teachers' diagnostic competences are on average rather high, there is still room and a need for improvement (Südkamp et al., 2012). This is especially true for pre-service teacher education, as diagnostic competences often do not play a central role in university-based teacher training programs. Consequently, (pre-service) teachers need a sufficient amount of opportunities to improve their diagnostic competences. Since practicing with actual students may often not be an option due to organizational obstacles and ethical requirements, practicing with simulations can offer a convenient alternative.

Using authentic simulations to foster diagnostic competences

Simulations represent certain segments of reality and offer learners the opportunity to interact with these segments and thereby develop specific skills and competences (Heitzmann et al., 2019). Therefore, simulations are considered highly useful for fostering a variety of different competences, including diagnostic competences. This appears to be true in the field of medical education, where simulation-based learning already plays a significant role (see Peeraer et al., 2007). Meanwhile, it has also been gaining more and more popularity in teacher education (see Chernikova et al., 2020). This increasing interest in using simulations for learning in teacher education is also associated with an increasing interest in design guidelines for creating simulations and the question: What is an effective simulation?

The relationship between realness, involvement and spatial presence of simulations and diagnostic competences

Because of fast technical progress and increasing opportunities (like e.g. "virtual reality"), there often is a specific focus on the authenticity of simulations and on whether or not an effective simulation needs to be as authentic as possible. Prior research regarding the importance of authenticity of simulations is somehow divided. Henninger and Mandl (2000) emphasized that more authenticity is not always better, because it is sometimes advisable to simplify certain facets of a learning environment and therefore reduce the authenticity in order to avoid excessive cognitive load resulting from too many different sources of information (see e.g. Ayres & Sweller, 2014). However, a recent meta-analysis found higher learning effects with more authentic simulations than with less

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authentic simulations (Chernikova et al., 2020). Nonetheless, empirical research investigating the effects of authenticity in learning environments covers a variety of aspects of authenticity that range from evaluations of more objective criteria, such as whether a simulation contains all critical elements of the corresponding real life situation (see e.g. Norman et al., 2012), to learners' individual perceptions (see e.g. Frank, 2014; Schubert et al., 2001). Thus, in answering the question of effectiveness, a more differentiated analysis is needed, comparing different aspects of authenticity in order to understand which aspect of authenticity matters most in simulations. In line with a factor analysis conducted by Schubert et al. (2001), the most important facets of learners' individual perceptions of authentic learning environments might be perceived realness, involvement and spatial presence. Perceived realness is the realistic feel of a simulation. Perceived involvement is the feeling of being fully involved in an experience. Spatial presence is the feeling of really "being in the situation" (see Schubert et al., 2001; Vorderer et al., 2004). Research in the field of medical education suggests rather low correlations between perceived realness, involvement as well as spatial presence and diagnostic competences (Fink et al., 2021), but there are no findings yet on whether similar correlations can be found in the field of teacher education.

Aims and research questions

The purpose of the present study was to measure the perceived authenticity of a simulation that was designed and developed for the purpose of fostering pre-service teachers' diagnostic competences. We assume high perceived authenticity to be indicated by high ratings for perceived *realness*, *involvement* and *special presence*. Further, we aim to examine the relationship between the perceived authenticity of the simulation and pre-service teachers' *diagnostic accuracy* within the simulation.

RQ1: How do pre-service teachers rate the video-based simulation regarding the perceived *realness, involvement* and *spatial presence* of the simulation?

RQ2: Is there a meaningful relationship between the perceived *realness, involvement* or *spatial presence* and pre-service teachers' *diagnostic accuracy*?

Method

Participants

Participants were recruited at three different German universities. All 160 participants were enrolled in university-based teacher programs (53.8 % female, 43.8 % male; age: $M = 22.91$, $SD = 2.90$; semester: $M = 4.99$, $SD = 1.77$).

Simulation environment

To mimic a specific classroom situation that involves the process of diagnosing students, we created a video-based simulation focused on diagnosing students' scientific reasoning skills. This simulation contained staged videos showing pairs of students conducting inquiry tasks in class. Based on the respective school subject (physics or biology) the students' task was to find out whether or not certain independent variables influence the focused depiction of an object through optical lenses (physics) or the growth of plants (biology). Those tasks were limited to four independent variables (e.g. the distance between object and lens in physics or the amount of water in biology) in each of the two subjects. The videos were staged because we wanted to make sure that both versions (physics and biology) were fully parallel in structure. While working with the simulation, the participating pre-service teachers' task was to collect information about one specific student's scientific reasoning skills and to later compose a written diagnosis about his or her skills. In addition to the videos (displayed on the upper left hand side of the screen), the simulation featured a table containing information about the experiments conducted by the students in the videos as well as their observations (displayed on the upper right hand side of the screen), a note pad, offering participants the opportunity to write down individual notes (displayed on the lower right hand side of the screen) and a navigation area (displayed on the lower left hand side of the screen). In the navigation area, certain pre-formulated questions appeared and disappeared throughout the video. This was designed to give participants the possibility to interact with the students featured in the videos and collect additional relevant information. If a participant decided to ask a certain question (e.g. "What do you want to find out now?"), he or she had to click on the respective link and received the answer of the student via an additional video that was inserted in the main video. A limited overall amount of time was available for asking questions to ensure that participants would only ask deliberately selected questions.

Measurement of variables

After working with the simulation, participants rated their perception of the simulation on three different scales. All statements were rated on a 5-point Likert scale ranging from (1) disagree to (5) agree. *Realness* was measured by three items (e.g. "I think the learning environment is authentic") from an adapted scale (Schubert et al., 2001;

see also Seidel et al., 2010) with satisfactory reliability (Cronbach's $\alpha = .77$). *Involvement* was measured by four items (e.g. "I have immersed myself in the situation") from an adapted scale (Vorderer et al., 2004; see also Frank, 2014; Seidel et al., 2010) with acceptable reliability (Cronbach's $\alpha = .61$). *Spatial presence* was measured by three items (e.g. "I felt like I was actually there in the simulated situation") from an adapted scale (Vorderer et al., 2004) with satisfactory reliability (Cronbach's $\alpha = .79$).

For the purpose of quantifying participants' *diagnostic accuracy*, the written diagnoses were coded on the basis of the different sub-skills of scientific reasoning. Two independent raters coded for each of 11 specific scientific reasoning sub-skills (e.g. the skill to formulate specific hypotheses or the skill to manipulate the examined variable – while keeping all other independent variables constant) whether the sub-skill was mentioned in the written diagnosis and – if it was mentioned – if the sub-skill was diagnosed correctly. An additional coding variable captured whether the diagnosis noticeably indicated awareness of the difference between actual behavior and underlying latent sub-skill. The score for *diagnostic accuracy* was the percentage of the variables coded as "present" or "correct", respectively. Overall the two raters achieved a high agreement; $ICC_{absolute}$ (159,159) = .82. Averaged scores of both raters were used in the statistical analyses.

Results

The descriptive results indicated that on average participants perceived the *realness* and the *involvement* of the simulation as relatively high (see Table 1). The differences between these average ratings and the midpoints of the corresponding scale were statistically significant and amounted to a small effect in the case of *realness*; $t(159) = 4.04$; $p < .001$ (two-sided); $d = 0.32$ and a large effect in the case of *involvement* $t(159) = 10.32$; $p < .001$ (two-sided); $d = 0.81$. The ratings for perceived *spatial presence* were lower and below the midpoint of the rating scale (see Table 1). This difference was also statistically significant and amounted to a moderate effect; $t(159) = -6.75$; $p < .001$ (two-sided); $d = 0.54$.

Table 1
Descriptive statistics for perceived authenticity

	M	*SD*
Realness	3.29	0.92
Involvement	3.56	0.69
Spatial presence	2.47	0.99

In a multiple regression analysis with *diagnostic accuracy* as the criterion variable, *involvement* was found to be a statistically significant positive predictor ($\beta = .36$, $p < .001$), whereas *realness* ($\beta = -.08$, $p = .32$) and *spatial presence* ($\beta = -.12$, $p = .19$) were not statistically significant predictors.

Discussion

Pre-service teachers rated the authenticity of our simulation as rather high, as they stated that they felt involved during participation (*involvement)* and perceived the learning environment as a realistic depiction of a classroom situation (*realness*). Only the feeling of "being in the actual situation" was rated rather low (*spatial presence*). The results of the regression analysis only partially agreed with findings from previous research, as we found a statistically significant relationship between *involvement* and *diagnostic accuracy*. In line with the results of Fink et al. (2021), the relations between *realness* and *spatial presence* on the one hand and pre-service teachers' *diagnostic accuracy* on the other hand were not statistically significant. As the *involvement* ratings for the simulation were the highest among the three aspects of authenticity, these results further strengthen the validity of the developed simulation.

In summary, our findings suggest that it may be useful to take a more differentiated look at the role of authenticity, as our results point in the direction Henninger and Mandl (2000) suggested: It may not be sufficient to only increase the *realness* of simulations and therefore this aspect of authenticity perhaps should not be the sole focus of interest. Instead, it might be more important to get learners cognitively involved. Obviously, this does not mean that creating a realistic experience is not important as both facets are interconnected to a great extent; yet it may be useful to consider how increasing the degree of realness of a simulation can lead to more learner involvement.

Nevertheless, these findings stand in need of replication using more elaborated methods. In line with the idea of Norman et al. (2012), it may also be advisable to include additional measures of authenticity that also consider whether a simulation contains all critical elements of the corresponding real life situation. This may also require assessments by experts, since learners may not be able to evaluate respective critical elements themselves.

In conclusion, we still suggest that the statistically significant relationship between *involvement* and *diagnostic accuracy* provides some indication of what really matters when developing simulations for fostering diagnostic competences in pre-service teachers and that developers of simulations should focus more on inducing learner involvement than on maximally realistic simulations.

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Information Architecture as Theory: Sociotechnical Dimensions of Learning and Learning about Learning

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This paper looks at technological advances in the collection and use of information about learning. Updating earlier discussions on transcripts and videorecording, this paper draws on examples from a digital simulation and pedagogical approaches using videoconferencing as a post-pandemic alternative to table-base groupwork and then submitted transcripts of the meeting for evaluation and feedback. The transcripts were computationally analyzed producing visualizations of conversations. These data were combined with records of students working on collaborative documents and the learning analytics for a digital simulation. Congruent with prior reflections on transcription of recordings and the recording process, this paper highlights the ways, old and new, the inscriptional process is not theory-neutral, but privileges certain activities to play an agentive evidentiary role.

Education and educational research are richly semiotic practices

Education involves richly semiotic processes that are often inscribed for analysis or lost to the research process. Whether the indicators and information used to study what goes on in learning settings are proximal to the activities we see as consequential for learning—classroom activity, groupwork, engaging with digital tools, etc.—or distal activities including tests and surveys, our research is constituted in part by the records that are made of student work. Over the last fifty years, the tools used for recording details related to learning have advanced from audio tape to video recordings. Video has evolved from single general-purpose cameras to multiple and special equipment (Goldman, et al., 2014) all in search of better representations of what is occurring to enable learning. Today, these familiar approaches have been joined by digital platforms with new ways to collect information about student activity that these platforms often structure. This paper shows some contemporary methods of creating transcripts and other digital traces of student behaviors. These records show some things with clarity. Other things are less clear. Together these new inscriptional technologies provide important capacity to understand student actions over large numbers of individuals and events. In the past, advances in education and social science research have prompted reflections on the nature of these inscription/transcription processes and their impacts on researchers' epistemological/theoretical positions.

Research, Inscription, and Theory

This paper's intellectual lineage begins with Ochs' (1979) essay titled *Transcription as Theory* that provided a complementary perspective to technological optimism that recording equipment was dramatically reducing the filtering of researchers. Ochs focused on the transcription process and choices researchers and transcribers make to render the recorded event ready for analysis. Her work was drawn from studying language acquisition in small children. In 2000, Hall wrote *Videorecording as Theory* that expanded the discussion drawing on examples from educational research. Hall discussed issues of context and how contextual information is depicted through choices of camera placement, cropping, and editing. He looked at interactions between participants and each other and technologies. He considered the sharing of video records in datasets and how the use of those datasets align with the nature of the data collection and how sharing of video records may raise privacy and ethical concerns. This paper includes the concept of *Information Architecture* that has historically been visual where presentation choices impact comprehensibility (Wurman, 1995; Piety and Palincsar, 2006). This project includes several kinds of student interactions that have been recorded (transcribed) through automated digital methods. It extends Ochs' (1979) and Hall's (2000) work in four ways: 1) computationally derived data transcription streams with visualizations (Figure 1); 2) collaborative textual practices as students interact with shared documents (Figure 2); 3) integration of multiple data streams, including conversational and textual (Figure 3); and 4) multimodal discourse from students interacting in a digital simulation (Figure 4).

Teaching STEM career awareness and intent

The curriculum in both its document and its simulation portions uses a three-part pedagogical pattern where students were assigned some work to do with documents then meet and discuss the documents and produce an artifact for grading. The work the students do in the first part of the narrative is conducted on shared Google documents (Google Docs).

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Using recordings/transcripts of videoconference-based groupwork

Part of the implementation of this project was altered because of pandemic safety protocols. What was intended to be table-top groupwork was replaced with students working in videoconferencing sessions and submitting records of that meeting (video and transcript) for grading/analysis. This pattern was typically conducted over several days with the assignment on a Thursday and the students able to complete tasks for group submission on a Sunday night. By submitting their artifact, video, and transcript the students provide the instructional team information to grade and provide feedback (as well as automatically identifying participation for grading).

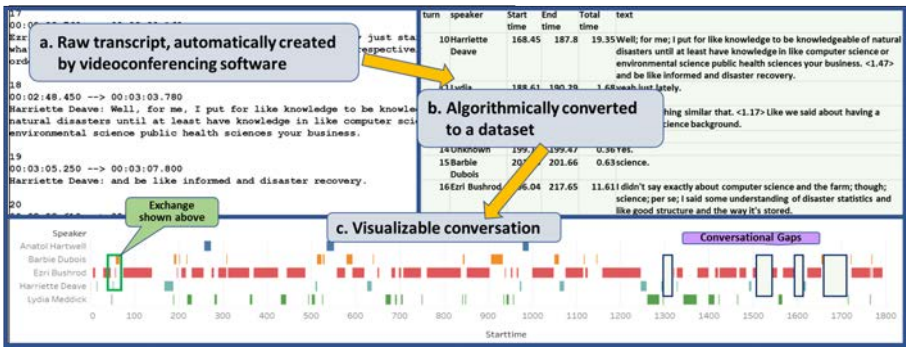

Figure 1 - From autogenerated transcripts to visualizing conversations

Computationally derived data transcription streams with visualizations

While creating a moderately accurate transcript of audio is commonplace. These generated transcripts have specific properties and affordances. As shown in Figure 1, a transcript with timings of speech comes from the videoconferencing software (a). The verbal interpretation is not always accurate, but the timing is. This file can then be converted into a dataset (b) that can be directly used in visualization software[2]. While the visualization (c) does not show specific detail about what is being said at different points in time, the information about who is speaking when and how much of the conversation is being produced by which participants is largely accurate. The depiction can be used to ask questions about the collaborative processes of the individuals present. The conversational gaps presented in the transcript files have generated new research questions for this project with various theories as to whether these gaps represent time the students are working on the collective artifact and whether there are any discourse patterns associated with the periods.

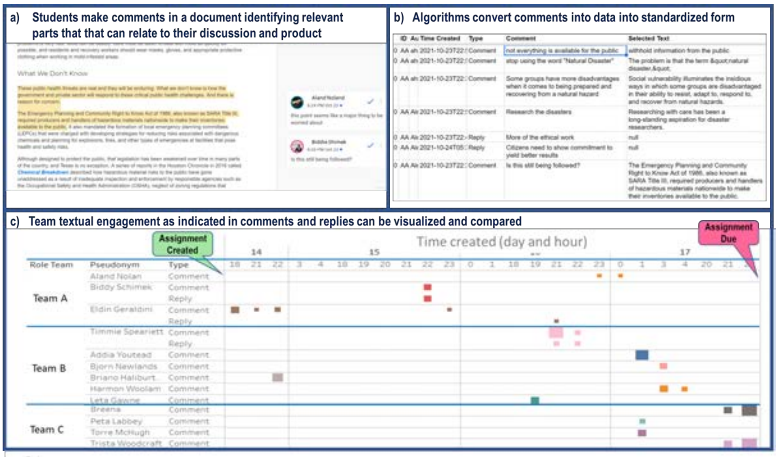

Figure 2 - GoolgeDoc comments showing team activity over days

A literature exists around collaborative document practices has largely been focused on direct observations of students working synchronously (Lowry, Curtis & Lowry, 2004) or in editing on collaborative web platforms (Stoddart, et al., 2016). Little work has shown how students work on shared documents asynchronously over time. Figure 2 shows the path that comments take from their state as students experience them in the margins of the document to a tabular format to then a data display like the one used for transcripts but showing activity over days. This visualization allows different team engagement patters to be readily seen and compared. The size of the squares is related to the number of actions (comment or reply) taken. Team B, for example works over the course of several days well in advance of the deadline. All members of Team B comment and two also reply. Team C, however, only does the minimum, right before the deadline.

In several the conversational transcript visualizations like the one shown in Figure 3, gaps appear in the conversation when no students are speaking. The research team speculated these gaps might be when the team is working to produce a shared document (see Figure 2). The research team further speculated that when there is an asymmetry in conversational time (as shown in Figure 3) that there might be a counterbalancing activity in editing. In other words, as one student is leading the conversation then other students are working on the

document. When the shared document is a Google Doc, it is possible to see when edits and are being made to the document. This information is limited to only knowing when edits were made and by whom rather than the details of the edits, including which material was added/changed by a person[3]. Rather, Figure 3 shows the same person making edits and speaking.

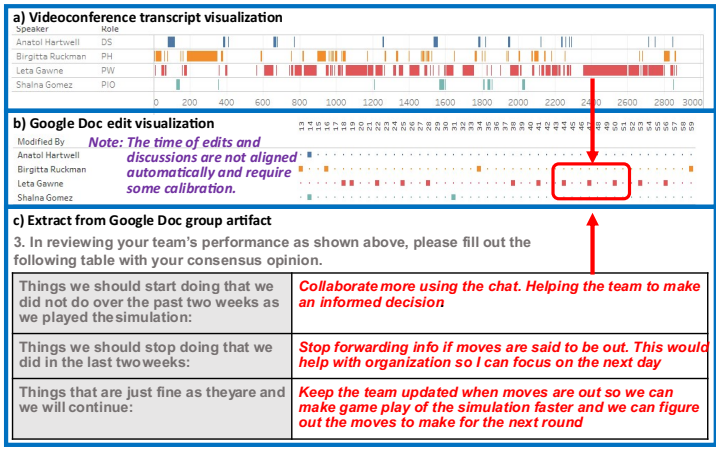

Figure 3 Document edits and conversations

The digital simulation embedded in the curriculum

The second portion of the narrative uses a digital simulation within a similar pedagogical pattern that was used with professional documents in the first portion. Rather than having a commenting activity that precedes the group discussion to develop a team artifact, the team plays a simulation. Data from the simulation is then used in asking the team to reflect on their group dynamics and understanding of collaboration in STEM careers.

Virtual emergency operations center with three intra-team communication options

The students engaged with a digital simulation of an emergency operations center (EOC) for a community. The EOC simulator presents each team has a different set of incidents and unique copy of a virtual world, but where all teams played simultaneously different variations. Players have three ways they can communicate with their teammates inside the simulation:1) a group chat that operates like other chat systems allowing direct text messaging within the team, 2) forwarding of notifications, and 3) placement of indicators (a digital pushpin). The simulation produces an activity log that shows the kinds of things that team members do and when. Figure 4 shows two different simulation teams' activity records. They show how the simulation unfolds and the kinds of actions different roles are taking. The technology produces 25 visualizations with the same effort to produce two enabling analyses on a large scale, albeit with less attention to nuance and detail. Many important factors may be less visible than with more focused methods. As with the prior visualizations, the game simulation representations show activity over time. With the first team in Figure 4, there is not much activity until the fourth member joins. The second team was able to begin much more quickly. There are then differences in how each team used the moves they are allowed. The first team spends more time moving on the map compared to the time they spend scoring. The second team is more efficient. These representations are shared with the students so they can reflect on who did what in their simulation.

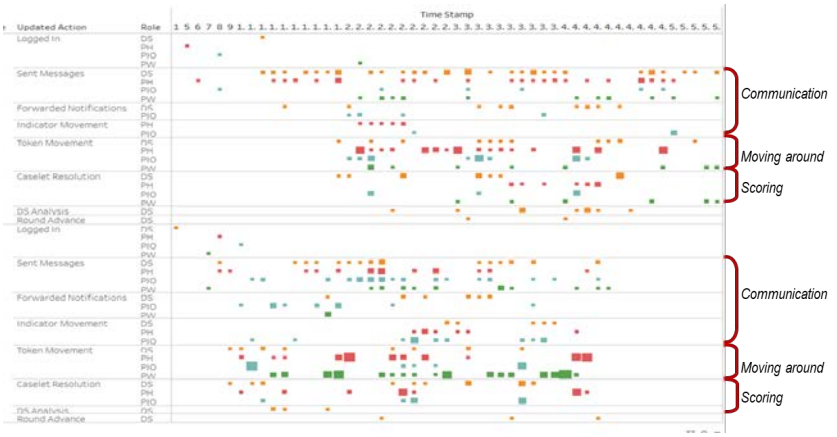

Figure 4 - Visualization of simulation activity for two different teams

How these visualizations are helping shape the research

An important part of this paper is the relationship between the depictions of human activity (formerly called transcripts) and research possibilities. The representations are computationally created and benefit from the ability to combine with other digital data. These new ways of seeing student activity in these group settings is supporting new ways to structure both teaching and research. They allow insights into asymmetric team member

participation in group activities. Instructors that assign groupwork, especially in some undergraduate programs, have become familiar with reports of how some students do less than others. as well as how some students dominate others. Understanding what happens is now more possible because of these data.

Discussion: Information architecture as theory

The world of social science and education research today is greatly changed from what it was just a few years ago. The advances in creating research artifacts from recorded activity are emblematic of broad changes that have occurred and are occurring with computational tools. These computational tools and their data streams are interconnected in a web of technologies that can operate instantaneously at great scale. The ability to collect information similar to that shown in this paper efficiently at scale suggests three areas for consideration.

1. **Reconsidering evidentiary classifications.** The kinds of data and visualizations presented in this paper do not fit neatly into quantitative or qualitative paradigms. The data and visualizations shown here are not specific to the research dimensions of this project. They are used for both grading and student support.
2. **Sociotechnical structuring.** As Hall (2000) indicated, the recording methods can structure what might appear to be naturalistic in edited video. In this research, Google Docs structures the comments and replies. Video conferencing software (Zoom) places participants in certain places and automatic transcriptions does not capture overlapping speech. The research adapts to these constraints.
3. **Automating surveillance.** The techniques used to collect traces of activity in meetings and from documents could be considered a form of surveillance. The meeting transcripts are required to show who was at the meeting, which addresses a common challenge with many undergraduate students: group project absenteeism. The technologies make this kind of surveillance easy and there are instructional situations where being able to pinpoint participation is helpful. However, it raises questions about ethics and privacy.

Researchers tend to work in comfortable patterns using techniques that have been successful before. This is especially true for emerging scholars who will use templates developed by those already established in the field. The kinds of approaches shown in this paper will likely become commonplace in the coming years. Researchers may be tempted to see in these new technologies a revolution in inferential possibilities. This paper like the ones it follows provide an optimistic, but cautionary perspective.

Acknowledgement

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International Society of the Learning Sciences

Can Mental Rotation Predict Performance in an Online Geometry Assignment?

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Abstract. Mental rotation knowledge has been linked to math performance, specifically in geometry, but it is unclear when, why, and how mental rotation affects achievement. We extend prior research by examining the relation between mental rotation skill and performance in two online geometry assignments on different topics (e.g., translations, rotations) and presented in two different ways to prime problem-solving strategies (e.g., analytic, visuospatial). Within each problem set, students completed four mental rotation problems, then an online problem set. The results indicated that: (1) mental rotation skill predicted assignment mastery speed regardless of topic; (2) problem presentation did not affect mastery speeds; (3) there was no interaction between mental rotation skill and problem presentation. We conclude that mental rotation skill may be more important in solving geometry problems than problem presentation and strategy use.

Introduction

It is well documented that spatial skills predict math achievement (e.g., Geer et al., 2019; Uttal and Cohen., 2012; Wai et al., 2009), specifically, in geometry (Pittalis & Christou, 2010; Weckbacher & Okamoto, 2014). However, arguments still abound as to when, why, and how spatial skills affect students' math achievements and later success in STEM disciplines (e.g., Wai et al., 2009).

Research has suggested that spatial skills are malleable (Uttal and Cohen., 2012), but one question is how transferable skills are from one domain to another or even within one domain on different topics. In their analysis of over 200 studies on the malleability of spatial skills, Uttal and Cohen (2012) reaffirmed the malleability of spatial skills, but their findings regarding the transferability of the learned skill were inconclusive. Not all problems involve the same steps or cognitive processes to solve. For example, in geometry, some problems, like rotating figures on a coordinate plane, might map better onto certain spatial skills, like mental rotation. Typical psychometric assessments might only test one specific type of spatial skill (e.g., mental rotation), so it is unclear whether mental rotation performance only impacts performance on geometry problems involving rotation or whether it would impact performance on other types of problems as well (e.g., translations; moving across a coordinate grid in a given direction). Here, we explore whether spatial skills are predictive of success across different topics within geometry (e.g., rotations and translations) and whether their impact extends beyond geometry rotation problems.

In addition, other studies have shown individual preferences for particular problem-solving strategies, visuospatial or verbal/analytic (Stieff, 2007). Prior work has shown that the use of different strategies, such as analytic as opposed to visuospatial, may mitigate the impact of individual differences in spatial skills (Stieff, 2007). Much work has been conducted in chemistry (Stieff, 2007), however, it is still unclear how spatial skills may influence different problem-solving strategies in geometry, and how the representation of the problem may influence the use of different strategies and ultimately impact performance.

The Present Study

In the current study, we explored whether mental rotation skills are predictive of performance above and beyond problem presentation and problem-solving strategies. We hypothesize that spatial skills may be more or less helpful depending on how problems are presented. Specifically, geometry problems can be presented in both visuospatial and analytic ways. [KR1]In a visuospatial presentation, students are prompted to solve the problem using visual perceptual cues and spatial reasoning. Conversely, in an analytic presentation, students are prompted to solve the problem with an analytic strategy using a coordinate grid and numeric coordinates. We also hypothesized that spatial skills may affect performance in geometry rotation problems that directly relate to mental rotation skills but may not in translation problems. We present a randomized control trial with eighth-grade

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students in ASSISTments (Heffernan & Heffernan, 2014), an online tutoring system. We asked the following research questions:

1. Does mental rotation skill predict math performance in online geometric problem sets?
2. Does problem presentation affect math performance in online geometric problem sets?
3. Does problem presentation moderate the effect of mental rotation on math performance within each problem set?
4. Does this relationship change depending on the topic of the problem set (e.g. translations, rotations)?

Methods

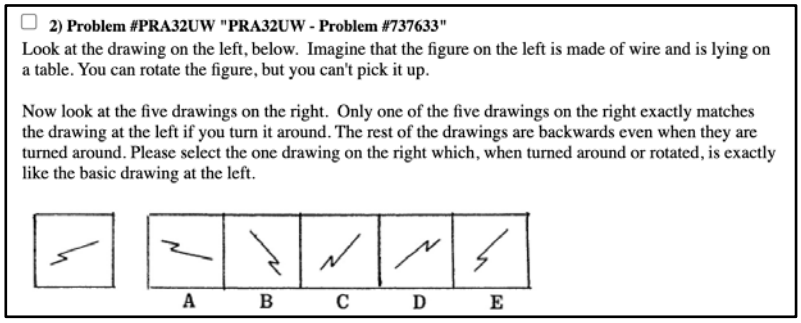
This study was an available problem set for 8th-graders covering translations and rotations within ASSISTments. The problem sets each consist of a pretest on mental rotation and a 10-problem skill builder. A "skill builder" is a problem set based on Common Core State Standards which present problems in a randomized order on one topic. The goal is for students to "master" a specific skill by answering three problems correctly in a row. Once they answer three problems in a row correctly, they are identified as having content mastery of that topic and are labeled as, "mastered". If a student answers a problem incorrectly, their count starts over, and they keep receiving problems until they get three correct in a row. A total of 398 students completed the translations set, and 942 students completed the rotations set and were included in analyses.

Procedure & Materials

First, students completed the mental rotation task (Hegarty, 2018), with four mental rotation problems (Figure 1). Then, they entered a skill builder, consisting of 10 problems, where they were instructed that they would complete the skill builder if they answered three questions correctly in a row. If a student failed to master the skill builder within 10 problems, they were given a skill builder score of 10.[KR2]

Figure 1.

An example of the mental rotation problems students saw



Within each skill builder, students were assigned to the visuospatial or analytic condition, differing in how problems were presented. The visuospatial condition presented the problems in a coordinate grid system without gridlines and with starting coordinates (Figure 2 left). The analytic condition presented the problems in coordinate grids with gridlines but without starting coordinates, which could easily be inferred by counting squares (Figure 2 right). We used the following two measures: (1) mental rotation score: how many questions a student answered correctly out of the 4 questions; 2) mastery speed: how many problems it took a student to complete the skill builder (e.g., answer 3 problems correctly in a row). A lower mastery speed indicates they mastered the problem set in fewer attempts.

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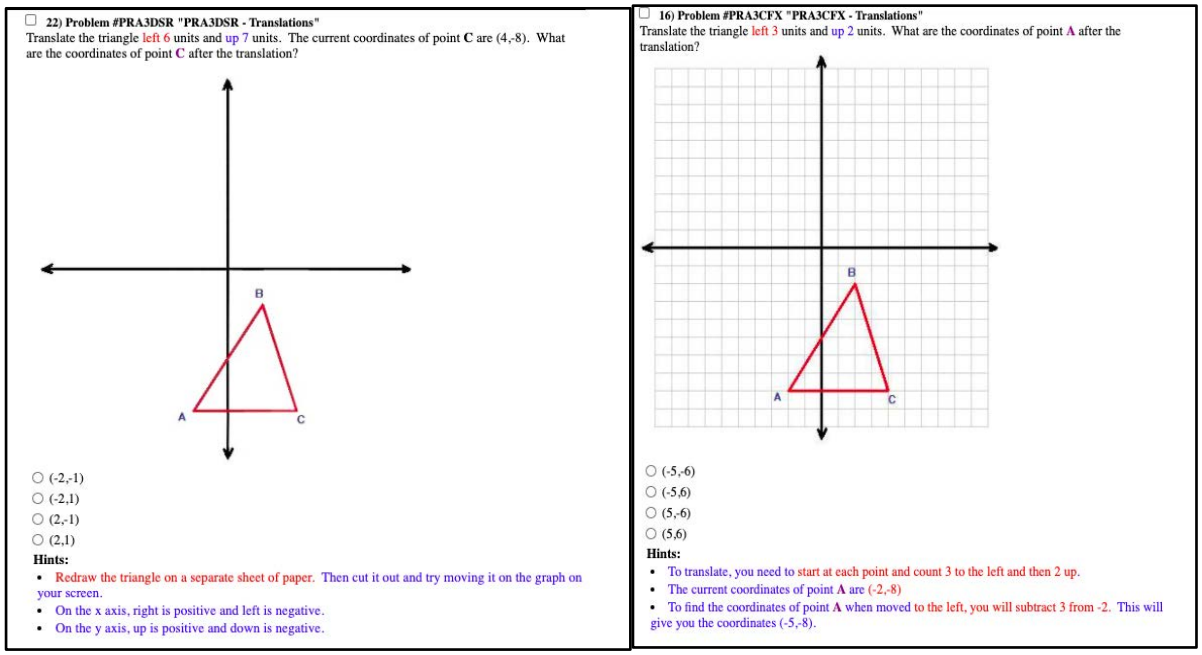
Figure 2.

An example of a translation problem and hints in the visuospatial (left) and analytic (right) condition

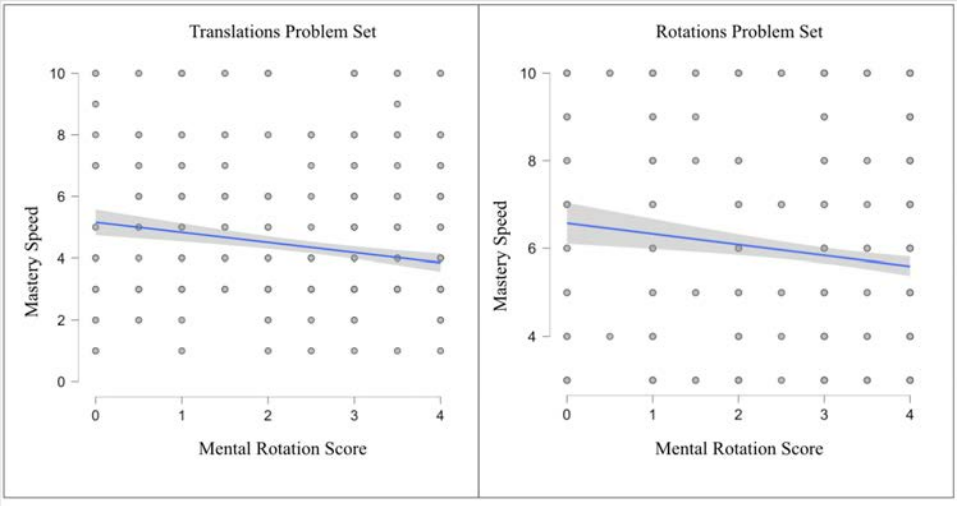


Results

For our first research question, we ran two linear regressions predicting mastery speed based on mental rotation score. Within both problem sets, we found that mental rotation score significantly predicted mastery speed; translations, $F(1, 397) = 28.91$, $p<.01$, $R^2 = .068$; rotations, $F(1, 941), = 11.60$, $p<.01$, $R^2 = .012$. A higher mental rotation score led to a lower mastery score (Figure 1), meaning that participants who performed better on mental rotation mastered the problem set in fewer attempts.

Figure 1.

Mastery speed based on mental rotation score for the translations and rotations problem sets



For our second research question, we ran two independent samples t-tests comparing mastery speed between the analytic and visuospatial conditions for each problem set. For both problem sets, there were no significant differences between conditions; translations, $t(1,396) = 1.28$, $p = .20$; rotations, $t(1,940) = .27$, $p = .79$. Students in both conditions and across problem sets had similar mastery speeds (Table 1).

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For our third research question, we ran two linear regressions predicting mastery speed based on condition and mental rotation score. Within both problem sets the condition X mental rotation score interaction was not significant, *ps* >.05. However, mental rotation score remained a significant predictor of mastery speed across both problem sets.

Discussion

The results replicate the effect that spatial reasoning skills have on math performance. We found that higher mental rotation scores predicted assignment mastery speed among both problem sets in Geometry. Importantly, this association held across both conditions (spatial and analytic), indicating that problem presentation does not impact the effect of mental rotation skill on geometric problem solving. It is also important that mental rotation scores predict performance not only on the rotation problem set but also on translation problems, as this suggests some transfer or domain generality of spatial skills. In addition, we were able to extend prior research into an online environment, suggesting that spatial skills still matter while learning geometry online.

While we hypothesized that spatial skills may be more or less helpful depending on how a problem is presented, we were unable to find differences in performance based on problem presentation. While we found no differences in performance, there may have been strategy differences we were not able to detect with our measures. It is also possible that our specific problem presentations did not sufficiently direct students toward one strategy over the other. Therefore, future studies should look into the specific strategies students employed while solving these problems and possibly iterate on aspects of problem presentation to further support or constrain particular problem-solving approaches.

In conclusion, we showed that mental rotation skill predicted performance above and beyond problem presentation and that the effect of mental rotation skill is consistent across two types of geometry problem sets. This has important implications for math instruction, as it suggests that students' spatial skills are more important than problem presentation. This reaffirms the importance of engaging students in activities to build their spatial skills and suggests that math teachers' and curriculum designers' time and energy might be better spent designing those sorts of spatial skill-building activities than on designing problems in specific ways to elicit spatial versus analytic strategies.

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Promoting Cognitive Strategies for Processing 360° Videos in History Learning Contexts

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Abstract: 360° videos can be characterized as immersive representations that may cause an illusion of reality. This illusion can be overwhelming or lead to a lack of distancing while processing the contents presented, which is exacerbated when learning with history-related 360° videos containing emotionally charged content. One way to counter these dangers could relate to the use of cognitive strategies. Cognitive strategies could help students to use a structured approach for processing the immersive and emotionalising videos and, thereby, to focus on aspects that are fundamental for reflective interaction with the content. Cognitive strategies can be promoted through self-regulated learning (SRL) trainings. Thus, the present study investigates whether a SRL training can promote school students´ acquisition of cognitive strategies for processing history-related 360° videos. The results of our quasi-experimental study ($N = 164$) suggest positive effects of the training on both students' use of and knowledge about cognitive strategies.

Introduction

In recent years, 360° videos have been developed to intensify learning processes in history learning contexts. These videos can be characterized as immersive representations that may cause an illusion of reality (Cummings & Bailenson, 2015). This illusion of reality might be particularly problematic in history learning contexts. Specifically, history-related 360° videos may not only create immersion, but are also often characterized by highly emotional content. This emotionalized and immersive presentation of the content could overwhelm the recipients or lead to a lack of distancing, whereby they may not realize that the content shown in the video is only a representation of the past (Bunnenberg, 2020; Brauer, 2019). Thus, the impression of actually experiencing history could hinder a cognitive and critical engagement with what is being presented. Consequently, watching immersive videos with emotionally charged content in history learning contexts requires recipients to critically analyse the contents presented (Gautschi, 2015). Therefore, in history classes, students need to be supported in applying dedicated methods for analysing the videos, for instance, by using cognitive strategies.

Cognitive strategies refer to learning techniques for taking up, identifying, classifying, memorising, elaborating as well as critically examining and storing information (e.g., Schiefele & Wild, 1994). If students learn to use cognitive learning strategies adequately, they can use a structured approach for processing the immersive and emotionalising history-related 360° videos and, thereby, focus on aspects that are fundamental for reflective interaction with the video content. In research on history education, it is also assumed that activities, such as summarizing, elaborating and contextualizing the learning content, aid students' reflective and critical processing of history-related content. While these activities are denoted as competences or skills in research on history education (e.g., Gautschi, 2015), they are conceptualized as cognitive strategies in research on self-regulated learning (SRL). SRL research on how to be acquire such strategies has revealed that students need to *know* how and why to use them, and they need to be able to *apply* them (e.g., Wischgoll, 2016). Moreover, we can learn from SRL research that both cognitive and metacognitive processes should be trained together (e.g., Dignath & Büttner, 2008; Stebner et al., 2015).

SRL trainings may be a promising way to promote the cognitive as well as metacognitive strategies required when learning with 360° videos in history education. However, while ample research has investigated the effects of SRL trainings in the context of the *natural sciences* (e.g. Stebner et al., 2015), there are barely any studies on such trainings in history education and, more specifically, for learning with history-related 360° videos. To the best of our knowledge, only one study has investigated self-regulated learning in museum sites (Dold, 2020), but this study did not focus on learners' processing of immersive and emotionalising 360° videos.

Against this background, the present study aims to investigate the effect of a SRL training on students' knowledge about and use of cognitive strategies when examining history-related 360° videos. Building on relevant characteristics of SRL trainings uncovered by previous research (e.g., Stebner et al., 2015), we developed a SRL training that combined cognitive and metacognitive strategies. To examine the effects of our training, we conducted a quasi-experimental study comparing two conditions: *explicit SRL training* (experimental condition)

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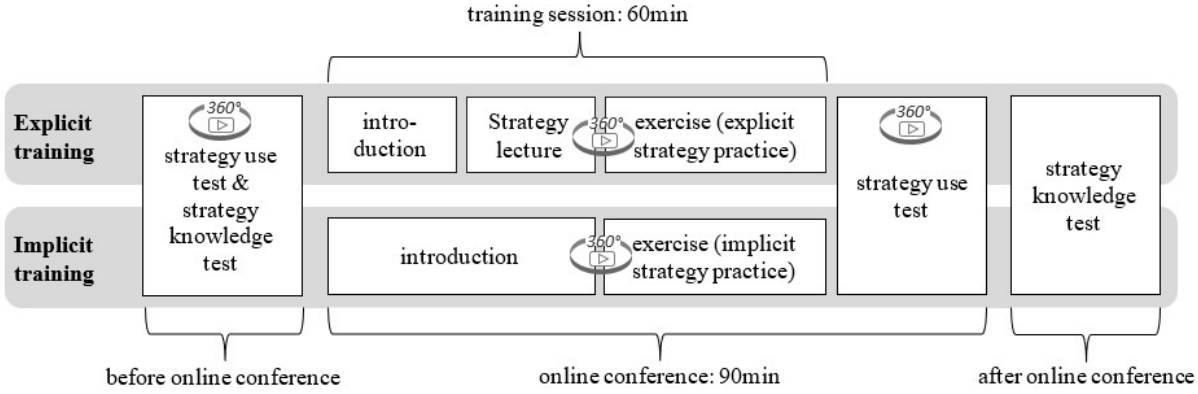
with explicit instruction on the functionality of cognitive and metacognitive strategies and explicit guidance on using these strategies for analysing history-related 360° videos, and *implicit SRL training* (control condition) without instruction on the names and functionality of cognitive and metacognitive strategies and implicit guidance on the use of cognitive strategies for analysing history-related 360° videos. In the analyses presented here, we focus on examining the effect of our SRL training on students' use of and knowledge about *cognitive* strategies. We hypothesize that students who receive an explicit SRL training will – in contrast to students who receive an implicit SRL training – improve their *use of* cognitive strategies (H1a) and their *knowledge about* these strategies (H2a) when examining a history-related 360° video. Consequently, we further hypothesize that – after the training – students of the explicit training condition will use (H1b) and mention (H2b) more cognitive strategies for analysing a history-related 360° video than students of the implicit training condition.

Method

Design and Sample

164 9th to 13th graders (52% female) from 10 classes of 10 German secondary schools participated in our study that took place in the form of an online video conference due to the pandemic situation. The 10 classes were randomly assigned to either the explicit training condition (n = 70) or the implicit training condition (n = 94). Figure 1 depicts the procedure of the present study.

Figure 1
Procedure in both conditions



In the *explicit training condition*, students first received a brief introduction to historical terms and then participated in a strategy training that is based on a SRL training from previous research (see Stebner et al., 2015) and includes a strategy lecture and an explicit strategy exercise. During the strategy lecture, the supervisors discussed the definition and usefulness of the following five strategies in history-learning contexts with the participating students: (1) summarize content, (2) check medium, (3) check perspective, (4) check mood and (5) formulate conclusions. Afterwards, the participating students practised to analyse 360° videos with the help of the supervisors. This exercise explicitly included guidance on the use of cognitive strategies. In the *implicit training condition*, students received a more detailed introduction to historical terms than students in the explicit training condition. Afterwards, in contrast to the students of the explicit training condition, the students of the implicit training condition did not receive explicit instruction on cognitive and metacognitive strategies (i.e., no strategy lecture) and only indirectly practised to analyse 360° videos with the help of cognitive and metacognitive strategies. Specifically, the supervisors did neither explicitly name the cognitive and metacognitive strategies nor explain their functionality during the exercise.

In addition to the 360° video that students watched and analysed during the exercise, all participants watched – as part of the strategy use tests – a 360° video before and after the training session (see Figure 1). We administered a strategy use test as well as a strategy knowledge test before and after the training session in order to assess the number of cognitive strategies used when analysing a 360° video (strategy use test) as well as the number of cognitive strategies mentioned when explaining how to analyse 360° videos in general (strategy knowledge test) as our dependent variables.

Measures

The strategy test is based on the multi-strategy test by Stebner et al. (2015) and measures spontaneous recall as well as the intended use of cognitive and metacognitive strategies. In our study, we adapted the test to the history-related context and divided it into two parts: The strategy use test measured the *use* of cognitive strategies by asking the participants to watch a 360° video and to examine its presentation of the past. The strategy knowledge test measured the *knowledge* about the cognitive strategies (indicated by students' mentioning of the cognitive strategies) when examining a 360° video in general. The instructions in the strategy use test differed slightly depending on the video content between pre- and posttest, but included the same type of task. In the pretest, we used the video "A VR journey to the Middle Ages". In the posttest, we used the video "What did they [member of the German State Security Service] want in Berlin?!". The videos are available on YouTube.

We coded the student answers in the strategy tests by using a system of categories that builds on the definition of historical deconstruction competence (Gautschi, 2015), elements of film analytics (Kühberger, 2013) and processes of self-regulated learning (e.g., Schiefele & Wild, 1994). For example, *applying* the strategy *check the medium* in the strategy use test was defined as describing the medium and its influence on the representation (example of a respective student answer: "The whole situation is presented as a 360° video, which means that the viewer can look around and has an all-round view during the event."). In the strategy knowledge test, *check the medium* was defined as mentioning that the medium and its influence on the representation have to be taken into account when analysing 360° videos in general (example of a respective student answer: "It´s very important to look at the video critically and to recognise interpretations. With these videos it´s very important to get an all-round view of the situation and also to pay close attention to the sounds."). We coded the answers in a binary way. Thus, we only coded whether one of the strategies occurred (1) or not (0), and did not analyse the frequencies of the occurrences of the individual strategies within a student answer. Two independent raters coded 30% of the pretest and posttest datasets and reached, on average, a satisfying agreement ($\kappa = 99{,}88$). To test our hypotheses, we calculated the sum of the coded strategies, leading to a total number of 0 to 5 strategies that students could use or mention in the strategy tests.

Results

To test H1a and H2a, we investigate the pre-post differences within each of the two conditions by conducting Wilcoxon tests. To test H1b and H2b, we compare students' use of and knowledge about cognitive strategies after the training between the two conditions by conducting Mann-Whitney U tests.

Prior to the interventions, students' performance in the two pretests did not significantly differ between the two conditions, neither with respect to the total number of applied strategies in the strategy *use* pretest (explicit training condition: $M = 0.91$, $SD = .93$; implicit training condition: $M = 0.93$, $SD = .79$) nor with regard to the total number of strategies mentioned in the strategy *knowledge* pretest (explicit training condition: $M = 0.36$, $SD = .61$; implicit training condition: $M = 0.27$, $SD = .56$).

With respect to our H1a, the results of the Wilcoxon test show a significant pre-post difference in the total number of strategies *applied* by students of the explicit training condition ($n = 44$, $r = .56$, $p < .001$, M(pretest) = 0.89, M(posttest) = 1.73) and, as expected, no significant pre-post difference in the implicit training condition ($n = 50$, $r = .25$, $p = .07$, M(pretest) = 0.98, M(posttest) = 1.28). Thus, in line with our H1a, while students of the explicit training condition improved their use of cognitive strategies for analysing a history-related 360° video by the end of the study, students of the implicit training condition did not improve their use of these strategies. Consequently, in line with our H1b, the results of the Mann-Whitney U test show a significant difference ($U = 2092.00$, $Z = -2.70$, $r = .22$ $p = .007$) in the number of used cognitive strategies between the students of the explicit training condition ($n = 66$, $M = 1.62$, $SD = 1.21$) and their counterparts of the implicit training condition ($n = 83$, $M = 1.07$, $SD = .85$). Thus, students who received the explicit SRL training used significantly more strategies for analysing 360° videos than students who received the implicit training.

With regard to our H2a, the results of a Wilcoxon test show a significant and large-sized pre-post difference in the number of *mentioned* cognitive strategies in the explicit training condition ($n = 26$, $r = .75$, $p < .001$, M(pretest) = 0.42, M(posttest) = 2.42), but also a significant and medium-sized pre-post difference in the implicit training condition ($n = 30$, $r = .69$, $p = .000$, M(pretest) = 0.37, M(posttest) = 1,63). Thus, against our H2a, students in both conditions increased their knowledge about cognitive strategies by the end of our study. However, looking at the differences in participants´ knowledge about cognitive strategies between the two conditions (H2b), the results of the Mann-Whitney U test show a significant and small effect of condition ($U = 543.50$, $Z = -2.26$, $r = .25$, $p = .024$) on the total number of mentioned cognitive strategies after the training. Thus, in line with our H2b, students who received the explicit SRL training ($n = 32$, $M = 2.28$, $SD = 1.75$) mentioned significantly more cognitive strategies than students who received implicit training ($n = 48$, $M = 1.4$, $SD = 1.44$).

Discussion and conclusion

The present study investigated the effects of an explicit SRL training on the knowledge about and use of cognitive strategies when watching 360° videos with history-related content.

We found that students who participated in the explicit SRL training used (H1a) and mentioned (H2a) a higher number of cognitive strategies in the posttest than in the pretest. However, against our hypothesis, students in the implicit training condition also improved their *knowledge* about (but not their *use* of) cognitive strategies. This finding may be due to the fact that, at the time of the pretest, students did not exactly know what they were supposed to do in the task. During the intervention, however, students in both conditions got at least an impression that the examination of 360° videos requires some kind of analysis. Consequently, students with implicit SRL training might have activated relevant prior knowledge they had previously gained by performing similar tasks (e.g., film or text analysis) in school. Nevertheless, students of the implicit training condition were seemingly unable to transfer this knowledge to their actual video analysis, as they did not *use* these strategies for analysing the history-related 360° video. However, although students of both conditions improved their knowledge about cognitive strategies by the end of the study, our further results suggest that students of the explicit training condition acquired more cognitive strategies than students of the implicit training condition. This finding is supported by both the total number of strategies that students used in the strategy use posttest (H1b) as well as the total number of strategies that students mentioned in the strategy knowledge posttest (H2b). This finding is particularly interesting in light of the fact that we designed the training in a greatly reduced form due to the pandemic situation. The duration of an intervention can be crucial for its effect on learning outcomes, or in other words, the effectiveness of an intervention can be affected by the number of training sessions and the number of months one participates in it (Dignath & Büttner, 2008). But as our study indicates, a 60-minute training can already evoke beneficial effects on especially the use of cognitive strategies. Future research on SRL in history education could build on this finding, for example, by providing students with multiple lessons in a history learning project in which students practice the use of strategies for examining different forms of presentations of the past.

To conclude, our results are in line with previous studies on the effectiveness of SRL trainings (e.g., Stebner et al., 2015, Dignath & Büttner, 2008), and may provide a new impulse for empirical history education research on learning with 360° and virtual reality media. Moreover, our study demonstrates the potential of interdisciplinary research in this area, as we attempted to build a bridge between history education with its mainly theoretical approaches on how to teach historical competences on the one hand and empirical research in educational science with well-researched approaches for promoting cognitive strategies on the other hand.

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International Society of the Learning Sciences

Organizational Co-design: Triggering Science Teacher Sensemaking to Support Recognition of Varied Forms of STEM Learning

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Abstract: Co-design has become an important resource in supporting instructional reform in science education. Various studies of teacher learning in co-design have focused on the outcomes of this work, including teacher content learning and use of co-designed resources in their practice. In this study, we focus on how the co-design process created opportunities for teachers to develop their interpretive power of students' STEM learning to identify varied forms of participation and learning in STEM activities through the co-design of an afterschool STEM program. We found that observations of students engaged in out-of-school STEM activity supported teachers to view STEM learning in varied ways and that the organization of students' activity mattered for what they paid attention to in relation to student learning.

Introduction

Science teacher co-design has emerged as an important tool in support of science instructional reform (Penuel, Roschelle, & Shechtman, 2007). In this work, science teachers engage with researchers to design instructional resources that align to science reform and take into consideration the localized expertise of science teachers. Research on science teacher co-design has demonstrated a variety of learning outcomes of the co-design process, including teachers' greater use of resources they have designed alongside researchers (Furtak & Heredia, 2014), supporting teachers' engagement in reflection of their instructional practice (Matuk, 2016), and a focus on teacher learning of content knowledge for teaching (Kelter et al., 2021). In this paper, we seek to understand how the co-design process supported science teachers to identify multiple forms of student learning in STEM activity. To do so, we explore the initial phases of the co-design process as science teachers work to design an afterschool STEM program for their schools as part of a larger STEM ecosystem (National Research Council, 2015). In what follows, we introduce the design problem related to teacher recognition of various forms of student learning in STEM environments and a conceptual framework used to organize the co-design process.

Design Problem

In this project, science teachers were supported to co-design a STEM afterschool program organized as part of a STEM ecosystem designed to support students to develop varied STEM identities and interests. However, fostering variety in students' STEM identities is not necessarily a key feature of formal classroom instruction (Tan et al., 2013). Rather, science teachers tend to focus on standardized curricula, geared toward local and state-level accountability measures, including high stakes testing contexts (Settlage & Meadows, 2002). Such curricula generally offer a narrow conception of learning in science that emphasize evaluating student learning of discrete facts and vocabulary (Otero & Nathan, 2008), rather than the myriad ways students can demonstrate growth and learning in science, such as increasingly sophisticated forms of participation in science practices over time (Rogoff, 2003). Therefore, science teachers need opportunities to build their interpretive power to learn to recognize the varied ways that students make sense of science content and phenomena to support multiple pathways to develop interest and identities in STEM (Roseberry et al., 2016).

Conceptual Framework

Guiding our work is the recognition that when teachers engage in learning of new practices, they do so as actors in complex organizations, enmeshed in their day-to-day work practices (Spillane & Hopkins, 2013). Therefore, we leverage constructs from organizational sensemaking (Weick, 1995) to guide our approach to co-design. Organizational sensemaking is the process by which individuals interpret changes to their work environment and make decisions about how and what to change in their work practices (Weick, 1995). Teachers' sensemaking can be supported through intentional opportunities for them to see what's new or different about a

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reform instruction, and then have access to resources that support their design and implementation that make the integration of new practices feasible, given their local expectations (Allen & Heredia, 2021).

In this study, we anticipated that science teachers' interpretive power in student activity aligns with accountability systems and that they would privilege students' correct use of science vocabulary in science activity, which would cause some ambiguity when observing student learning in out-of-school settings that work to develop a variety of ways students can engage with science. Therefore, we intentionally designed their learning activities to surface this ambiguity through observations of students engaged in out-of-school science activity. Then we provided opportunities for teachers to make sense of students' learning and to recognize the ways in which science learning can be organized to support varied pathways in STEM.

Methods

We used a design-based approach (Barab & Squire, 2004) to develop and study our work with teachers in co-design. Here, we focus on early phases of this co-design process and explore how anticipated sources of ambiguity about student learning surfaced and how designed activities in the professional development triggered science teachers' sensemaking about student STEM learning beyond conceptual understanding.

Participants and professional development context

Participants included six middle school teachers from three schools who worked in teams (two teachers were each from the same school). The teachers ranged in teaching experience from 4 - 27 years in the classroom. They were all certified science teachers and have degrees either in science or elementary education.

The teachers chaperoned students from their school to the university for an out-of-school STEM program called Saturday Stormwater Investigations (SSI). The SSI program engaged students in STEM activities that were designed to support them to understand local problems related to stormwater and how to use best management practices to solve these problems. While students participated in the SSI program, the teachers engaged in professional development learning in parallel with their students. The primary focus of the professional development was to support science teachers to design and implement an afterschool program that extended students' engagement in the campus-based SSI program. In the professional development, the teachers learned about the design of the SSI as a pedagogical model for their afterschool STEM clubs. Professional development activities included applying the pedagogical framework to the designed activities for the SSI, observing students as they engaged in the activities (facilitated by university staff and faculty) and then reflecting on their observations.

Data sources

Each of the six teachers participated in a total of 45 hours of professional development over the course of three years. We collected video and audio recordings of the professional development meetings with teachers. Here, we focus on data from the first year of the professional development when teachers participated in a total of 20 hours of professional development. Additionally, we interviewed teachers prior to the start of the project and again after their first year in the program. The initial interview asked teachers to describe their educational background, their teaching practices, and experience with afterschool programs. The second interview happened over the summer to support teacher reflection of their learning, as well as to provide feedback to the research team about student programming.

Data analysis

We sampled conversations from the professional development meetings that asked teachers to debrief and reflect on their observations of students' activities during the SSIs (Table 1). We transcribed these conversations and coded teacher utterances according to the nature of student activity they noticed and discussed with the group. Codes included teacher discussion of student conceptual understanding of science (right/wrong, conceptual sensemaking, scientific language), student's social and emotional learning, students' cultural resources (asset-based and deficit-based), and student identity work. We coded each transcript independently and discussed how we applied codes, refining, and adjudicating differences in our discussions. We wrote short research memos about the nature of the teacher post-observation conversations. We similarly coded and wrote memos for teacher interview responses to questions about student learning in the SSIs. Finally, we organized these memos into a time-ordered matrix (Miles & Huberman, ?) to look for changes over time.

Table 1
SSI activities observed and discussed by the teachers

Date	SSI activity observed
Meeting 1	Students walked to a wetlands on campus and they looked for aspects of stormwater management. At the wetlands, they were given a variety of science tools to explore the living and non-living aspects of the wetland environment.
Meeting 2A	Students traveled with their teachers on buses to the university for the SSI program.
Meeting 2B	Students self-selected into different activities: science activity - monitoring biotic and abiotic indicators of water health at the wetlands, engineering activity - exploring permeable pavement, and technology - exploring various tech tools for advocacy.

Findings

The data revealed shifts in the ways in which teachers recognized and noticed different aspects of students' science learning in the out-of-school setting as compared to their descriptions of student science learning in their classrooms. In initial interviews, teachers highlighted the importance of school growth data to inform if and how their students were learning science. While they initially focused on the use of science vocabulary in student activity during the SSIs, they also noticed other aspects of students' learning, including student affect during the activity, their collaboration and interaction with students from other schools, and student science identity work.

Not surprisingly, all six teachers focused on students' conceptual understanding of science as a measure of growth at the on-set of the study. In their pre-interviews, they discussed a variety of methods and tools to assess student learning in science, including quizzes, technology, end of year state assessments and benchmarks, and students' explanations of science content. For example, one teacher described how he makes teaching decisions based on students' scores on assessments: "I then also analyze my data ... really the best place to get it is that test, and I can look at the tests I give them or the quizzes I give them, because I use Schoolnet, and I get instant data." Each of the teachers focused on data related to content understanding, with some attention to students' behavior and general engagement.

During the first year of professional development, the teachers had multiple opportunities to share their observations of student activity in the SSI. The focus of those conversations related to students' engagement with the activity and with each other and their science content learning. The teachers made connections to their observations of students in their classroom or at the school and their modes of participation in the SSI activities. For example, after observing students engaged in a creek and wetland exploration on the first day of the SSI, one teacher noted, "And not knowing how they were going to interact and be so happy about...the different interactions you saw between your own students that you didn't expect and then how they also interacted with others. It was really good, really good reinforcement." The teachers also recognized the lack of access that their students have to this kind of science activity and were excited they had an opportunity to explore a creek in a disciplinary way.

While they did recognize other forms of learning, they also paid attention to the ways in which students were developing science conceptual understanding. For example, in a debriefing conversation after teachers observed students in breakout activities in computing, science, or engineering, the teachers focused more on students' conceptual understanding as they engaged in the activities and expressed frustration at the lack of science vocabulary. One teacher noted that the students described the concept of permeability and talked about it, but never named it. "They didn't directly make the connection immediately, so when the kids- she was asking them about what did you see, about the different materials they were using. They were giving all of the words that are permeability, but no one said it until later." Here he was focused on their conceptual understanding that was being developed during the activity and expressed frustration that the students did not use scientific vocabulary in their explanations.

During their interviews following the SSIs, teachers mentioned that in the SSI program, students learned science, but also how to communicate and interact with different people and about the college campus. One teacher talked about how youth gained sensitivity and an awareness of the environment around them and they learned to use science to solve problems. When asked about what they noticed during student activity in the SSI program they talked about students' interactions with one another, the conversations they were having and the questions they were asking, and the connections they were making between the content and the real world. The shift evident in their interviews suggests that the teachers' experiences observing students in the SSI supported them to move beyond simply did my students get the science content to recognizing other forms of learning, such as developing identities to care for the environment and their interactions with other students.

Discussion

This study presents an initial analysis into the ways in which observations of student activity in out-of-school science settings can support in-service teachers to build their interpretive power to see varied forms of student learning in STEM activity. We found that teachers identified students' content learning in the SSIs, but they also paid attention to how students interacted and collaborated with other students, how the activity supported (or not) students' STEM identity development, and student affect as they engaged in SSI activities. Similar to research on pre-service teacher learning in informal settings (Jurow et al., 2012), we found that observations of students in the informal setting are productive sites for learning for in-service teachers as well. Next steps would be to collect data on science teachers' classroom practices after participating in the professional development to see if and how they are applying these varied views of student science learning in their classrooms. This study provides evidence that science teachers have the capacity to see other forms of learning. However, our understanding of the role of context suggests that it's possible that teachers may not apply different lenses for recognizing student science learning in their classrooms given the organizational focus on content learning.

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Artificial Intelligence (AI) in Education: Addressing Societal and Ethical Challenges in K-12 Settings

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Abstract: Artificial intelligence (AI) incorporates the applications of algorithms, machine learning, and natural language processing within automated assessment and facial recognition systems, personalized learning tools and microblogging systems. These AI applications have the potential to increase capacity within education by supporting the social and cognitive development of students. Despite these affordances, AI applications pose critical ethical and societal drawbacks which are rarely considered in K-12 education. Integration of these algorithms in education may amplify societies' existing systemic biases and discrimination, perpetuate privacy, autonomy, and surveillance concerns for students from marginalized and underserved groups. In this paper, we interrogate applications of AI in K-12 education, highlighting their ethical risks. We introduce instructional resources to help educators navigate the challenges of integrating AI and advance students' understanding of AI and ethics. The paper concludes with recommendations for research.

Keywords: artificial intelligence (AI) in education; AI and ethics; teacher education

Introduction and purpose

Artificial intelligence (AI) and its applications have become an inseparable part of our lives as we perform Google searches, read articles and emails, or join online tutorials and courses (Iman et.al., 2020; Regan & Jesse, 2019). During the COVID-19 pandemic, AI systems became even more important to everyday functioning; it is now nearly impossible to live in a modern society without using the applications powered by AI (Iman et.al., 2020). AI leads the fields of science, engineering, and technology, but also is actively present in education through machine-learning systems and algorithms (Ali et. al., 2019). AI has a variety of algorithmic applications in education, such as through automated assessment systems to lessen teachers' workload and support them in evaluating what students know; facial recognition systems to bring insights about student behaviors; and personalized learning systems to cultivate students' learning experiences (Remian, 2019). Algorithm systems are also dominant in education through various social network sites and social media outlets, especially within mobile applications and microblogging systems. Therefore, AI applications have the potential to increase capacity within education by leveraging the cognitive and social development of students (Murphy, 2019).

Despite this promise, these applications also pose critical societal and ethical drawbacks in education. In essence, AI algorithms do not occur in a vacuum; rather, they shape and are shaped by society's ever-evolving historical and institutionalized systemic biases, which ultimately transform into algorithmic bias (O'Neil, 2016). The biggest risks of integrating these algorithms in education (particularly in K-12 contexts) are: (a) amplifying societies' existing systemic bias and discrimination, (b) perpetuating privacy, surveillance, and autonomy concerns for students from mostly marginalized and disadvantaged groups, and (c) amplifying exiting gender bias, racism, xenophobia, and other forms of inequity and injustices (McMurtrie, 2018). As Ruha Benjamin's (2019, p.15) points out that: "New technologies reflect and reproduce existing inequities, but they are promoted and perceived as more objective or progressive than the discriminatory systems of previous era."

Considering these pressing concerns, we argue that it is our responsibility (as learning scientists, educators, and teacher educators) to educate teachers and students to recognize, critique and challenge the ethical and societal implications of algorithm use in education. To create a future generation where an inclusive and diverse citizenry can participate in the development of the future of AI, we need to study and develop AI- and ethics-based curricula and professional development opportunities for teachers and K-12 students as they engage with AI and apply a critical perspective (Akgun & Greenhow, 2021).

Toward this end, in this paper, we synthesize existing literature on how applications and ethical dimensions of AI takes place in K-12 education. We first unpack the definition, benefits, and drawbacks of AI applications. Then, we provide strategies for practitioners to reap the benefits while navigating the ethical challenges of AI use in K-12 settings. Toward this end, we introduce different instructional and pedagogical resources, such as MIT Media Lab's "*AI and Ethics*" curriculum for elementary schools (Payne, 2019) and Code.org's "AI for ocean" investigation for elementary and high schools. We conclude with suggested directions for learning scientists seeking to build on such resources in future design studies.

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Applications and benefits of AI in K-12 settings

Considering its capacity and affordances in fields of science, engineering, and education, we define AI as a form of technology that constructs systems to think and act like humans with the capability of solving problems and achieving goals (Iman et. al., 2020; Remian, 2019). Powered by algorithms and machine learning systems, AI takes place in education in the forms of a) personalized learning systems, b) facial recognition systems and predictive analytics, c) automated assessment systems and d) social networking sites and chatbots.

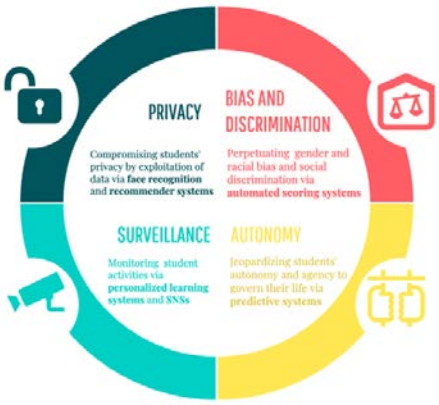
More specifically, ***personalized learning systems***, are one of the most common applications of AI in supporting students during their individual learning process. These systems provide students with access to various learning resources by considering each students' individual learning needs and based on specific subject area goals (McMurtrie, 2018). For example, rather than engaging in ideas and solving problems in physics on a worksheet or reading a textbook, students can use an interactive, multimedia space to help them progress toward learning objectives in their subject matter (McMurtrie, 2018). Microsoft's recent report (2018) from Singapore, the U.K., the U.S., and Canada shows that such personalized learning platforms promise to identify gaps in students' prior knowledge by offering different learning tools to promote students' growth. With the drastic shift to online education during the COVID-19 pandemic, personalized learning systems have become one of the promising distance learning options for students (Remian, 2019). Second, ***facial recognition systems*** are used to monitor and capture students' facial expressions. These systems aid teachers in recognizing and evaluating students' behaviors during the learning process. They also provide teachers with a space to intervene, which, in turn, can support teachers in developing student-centered classroom environments by increasing students' participation and engagement (Dishon, 2017).

Another prevalent tool powered by AI: ***automated assessment systems,*** can help meet the need for scoring students' exams, essays, and assignments, which are usually assessed by teachers. Assessment algorithms offer course management tools to decrease teachers' workload by increasing their productivity and capacity. For example, a scoring tool called "Gradescope" has been used by several universities to improve and streamline the assessment process (Blank et al., 2014). These systems have the potential to support students' learning process by giving them feedback and offering guidance to develop and revise their writing. Finally**, *social networking sites*** (SNSs) monitor students' well-being, provide space to deepen teacher-student relationships, and widen learning opportunities for students beyond the formal classroom setting (Asterhan & Rosenberg, 2015). Different scholars point out that the integration of social media can promote students' collaboration skills, active learning, and connections with their communities (Asterhan & Rosenberg, 2015; Akgun & Greenhow, 2021).

Ethical and societal risks of integrating AI applications in education

In addition to their affordances, AI systems pose serious ethical risks and challenges. In essence, the risks become visible as AI systems are introduced and marketed as value-neutral and objective tools. In contrast, algorithms carry the values of their builders who hold positions of power (Holstein & Doroudi, 2021). In the process of building algorithms, society's systemic and historical biases are represented within the codes, which ultimately transform into algorithmic bias. Even though the biased code is not integrated into the algorithmic model with an explicit intention, such representation can perpetuate existing racial and gender biases in different AI platforms (Benjamin, 2019). In the sections below, we focus on four major concerns in relation to privacy, autonomy, surveillance, and bias and discrimination (see Figure 1).

Figure 1. Ethical and Societal Challenges of AI applications in Education (Akgun & Greenhow, 2021)



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One main ethical issue raised in AI use in K-12 education relates to ***privacy*** concerns for teachers and students (Remian, 2019; Kang, 2021). As people expose an intensive amount of personal data (their language, location, biographical data, racial identity) in different online platforms, privacy violations can occur. Although legislation has been created to protect sensitive personal information, tech companies' violations (such as the privacy lawsuit aimed at Facebook (Kang, 2021)) with respect to security and data access, escalate concerns about privacy and human agency as independent and introspective individual thought is reduced (e.g., AI users may not realize the extent to which personal data is being shared) (McMurtrie, 2018). ***Surveillance*** is another notable ethical concern which relates to tracking preferences and actions of students and teachers. AI-based surveillance or tracking systems not only monitor activities but also determine the future actions of their users (Regan & Jesse, 2019). Patrolling and monitoring students' actions can be interpreted as part of a teacher's role and responsibility (e.g., to intervene in cases like exposure to sexual content or cyber-bullying). However, these systems may limit students' learning by making them feel uncomfortable and unsafe. How can students feel secure and safe to take ownership for their ideas when they realize the AI systems are policing and surveilling their actions and thoughts?

Connecting to these surveillance concerns, concerns about ***autonomy*** also stem from limiting and diminishing people's ability and freedom to act based on their own values and interests. For instance, predictive algorithms' predictions in relation to people's future actions based on their metadata raise serious questions about amplifying existing bias and prejudices of social stratification (Murphy, 2019). Finally, ***bias and discrimination*** concerns introduce another critical issue for AI ethics in K-12 education (Asterhan & Rosenberg, 2015). For instance, gender bias and gender-specific stereotypes become one of the visible forms of this problem. As just one example, when students in language learning courses use Google Translate, they see the Turkish equivalent of "S*he/he is a nurse*" translated into the feminine form, while the phrase of "*She/he is a doctor*" translated into the masculine form (Johnson, 2020). Racial bias against non-dominant groups is also present in voice-based assistants Murphy, 2019). Similarly, racial bias is present in facial recognition systems towards darker skinned people that has led to wrongful arrests (Murphy, 2019).

Teaching ethical and societal dimensions of AI in K-12 settings

The four major concerns above illustrate the need to introduce students and teachers to risks of AI use in K-12 education. To meet this need, nonprofits, and research groups (e.g., IBM's Educator's AI Classroom Kit, Google's Teachable Machine, and Machine Learning for Kids) have created open-access instructional resources related to AI and ethics. Next we highlight two such resources: the MIT Media Lab's *AI and Ethics* curriculum and Code.org's *AI and Oceans* activity.

The MIT Media Lab provides an open-access AI and ethics curriculum for the middle school level. Through lesson plans and activities, the curriculum aims to support students' in learning the terminology of AI systems and their ethical implications (Ali et al., 2019). The curriculum includes learning objectives, such as introducing students to basic components of AI (supervised machine, datasets, and algorithms) and helping them to figure out the process of creating bias in algorithms. For instance, through the "Algorithms as opinions" investigation, students consider algorithms as recipes. First, they write an algorithm to make their **"**best" jelly sandwich and peanut butter. In doing so, they raise the question of what it means to be **"**best." They see how their thoughts and definitions are reflected in their algorithms. Thus, students engage with the idea that algorithms can have various goals and motives. Following this investigation, students also build their own "Ethical matrix." They refer to their "best" jelly sandwich and peanut butter algorithms. They further discuss what counts as the "best" sandwich for themselves (most practical, healthy, delicious). Using the ethical matrix (chart), they identify different stakeholders (their parents, friends, teacher) who care about their jelly sandwich and peanut butter. In this way, stake-holders' opinions and values are also embedded into their algorithms. These investigations assist students and teachers in realizing a) the role and agency of different stakeholders in a society (or system), and b) how they can build their values and biases into the algorithms in the ethical matrix.

Another resource for practitioners is provided by Code.org, a nonprofit organization focused on increasing students' participation and involvement in computer science. Sponsored by tech companies like Microsoft and Google, Code.org aims to bring opportunities for students (grades 3-12) to learn about machine learning systems, algorithms, and algorithmic bias (Code.org, 2020). Through their online activity called "AI for oceans," students build their own machine learning models by exploring how to train, classify and model data**,** as well as how personal bias takes place in machine-learning systems. Students initially classify the objects as either "not fish" or "fish" to remove trash from the ocean and develop their data set by adding other sea creatures.

Creating such instructional and curricular resources are extremely crucial to support teachers and their students a) in negotiating the meaning and role of AI systems within the machine learning applications and b) in figuring out the potential risks, limits, and ethical risks of AI applications in education to reap the benefits and minimize the costs of AI use.

Conclusion and implications

In this paper, we emphasize four potential ethical and societal drawbacks of using AI applications in education. To highlight these risks, we focused on several instructional resources and strategies for practitioners who are seeking to incorporate AI applications and their ethical issues in K-12 settings. These instructional strategies might help students and teachers to reap the benefits of AI while criticizing and disrupting the ethical challenges related to privacy, autonomy, surveillance, and bias.

Existing research on how best to support practitioners in teaching AI and ethics is still in its infancy; it is critical to conduct future research on designing professional learning opportunities for teachers as well as on the integration of ethics-focused curriculum where AI is adopted in schools by centering culturally responsive and relevant pedagogies. In other words, centering students' funds of knowledge (Bang et. al., 2012) and family and community background are important to addressing the concerns of surveillance, privacy, autonomy, and bias within the AI systems. More specifically, further research is needed that focuses on questions of a) how existing AI curriculum materials and activities on AI and ethics are developed and taught and b) in what ways do professional learning sessions support teachers in coming to understand and teach the risks and benefits of using AI in K-12 classrooms are needed. In such collaborative research projects, students might have a space to voice their own contextual and cultural experiences while trying to critique and disrupt existing power structures (Ladson-Billings, 1995).

We believe that this work is essential for learning scientists and teacher educators to understand and build on existing instructional materials and resources with respect to AI and ethics. It would also contribute to the work of the Learning Science community by increasing awareness and action on the critical use of AI and algorithms to create more inclusive, fair, and equitable AI education in K-12 settings.

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International Society of the Learning Sciences

#WhiteRibbonAgainstDictatorship: Youth participation in Thailand's 2020-2021 political movement

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Abstract: A large number of Thai high school students participated in pro-democracy protests on all levels: from organizing rallies to small symbolic actions such as wearing white ribbons during 2020-2021. We engaged 691 Thai students from diverse backgrounds to write a letter to a recipient on the other side of the political divide to examine this phenomenon. Participants were asked to reflect upon their hopes and fears for Thailand's political future and explain why their civic engagement is personally, socially, and politically important. Utilizing the ladder of youth participation and other succeeding frameworks in the field, we explored the high school students' perception of their youth participation: their aspirations, justification for their participation, and responses from the adults in their lives. We find that while the students have clear and well-articulated reasons for their participation, they are hindered and resisted by their parents or teachers who disagree with their political views.

Introduction

Current Thai youth (aged 12-18) have grown up in this political change and polarization. Resentment towards the junta government had been brewing for almost a decade. This dissatisfaction exploded in protests, many at university campuses ('Student Flash Protests,' 2020). Student-led protests revived not only at the university but also at the high-school and middle-school levels. These students expressed their solidarity with anti-government protests creatively, such as wearing white ribbons and raising the three-finger "Hunger Games" salute during the national anthem (Wongcha-um, 2020). A hashtag that translates as #WhiteRibbonAgainstDictatorship was used nearly 1 million times on Twitter in August 2020 (In Pictures:'Thai Students "Hunger Games" Protests,' 2020). The situation escalated after a mass rally on October 14, 2020, when the government declared a state of emergency in Bangkok. A series of warrants and arrests of student leaders inflamed youth anger and pushed high-school students to be more politically active ('The names of 15 student protest leaders', 2020).

While the United Nations (UN) has fully recognized young people's right to freedom of expression in the 1991 Convention on the Rights of the Child and scholars have developed theoretical models for youth participation, there is a paucity of research that focuses on Thailand and its current political insurgency. This study examines youth participation in Thailand and embeds their experience within the conceptual framework of youth participation and the broader scholarship on youth and politics in Asia. We assigned a non-graded homework called "A Letter to Bridge the Divide" to approximately 700 high school students representing Bangkok and three regions in Thailand. These students were asked to write letters to friends, teachers, or adults with different political views. We have worded the assignment's prompt so that those who disagree with the protests can also write to fellow students to explain their views. Participants' students will reflect upon their hopes and fears for Thailand's political future and the reason why the movement is vital to them. These key experiences may involve but are not limited to past and current political turmoil, social inequality, generational gaps, and students' future aspirations.

Literature Review

Youth Participation

Checkoway (2011) defines youth participation as a process of involving young people in the institutions and decisions that affect their lives. It requires active engagement and the real influence of young people, not a passive presence or a token role under adult agencies. This study utilizes Hart's (1992) "Ladder of Participation" framework to determine how much adults in Thai society engage with young people, classifying participation hierarchically across eight levels using each rung of a ladder as a representation. Hart (2008) later emphasized that framework is about the degree to which adults and institutions enable children to participate (p.23). Thus, the ladder portrays different degrees to which children are allowed, enabled, and supported (often by adults) to initiate civic actions and make decisions in carrying them out with others. In addition to Hart's original ladder, we also utilize Reddy and Ratna's (2002) work which extends Hart's ladder framework beyond the "Model of Non-participation'. They suggest two additional bottom rungs of non-participation to Hart's model: "Hindrance" when

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adults intentionally or unintentionally undermine children and discourage them from participating, and "active resistance," in which adults actively work against children's participation. The reasons for active resistance resonate with Checkoway and Richards-Schuster's (2006) argument that young people are too often displaced and disengaged from the process by adults, even in their schools and communities, because adults may feel that young people should not be involved in decision-making processes because they cannot do so. "It is difficult when adults view young people as deficits rather than resources or show 'adultism' which flows from the assumption that adults are better than young people, and entitled to act upon them without their agreement because of their age" (Checkoway, 2011, p. 342). Adultism can lead young people to question adults' legitimacy and suppression. Moreover, viewing young people through a deficit lens can stifle their potential to change.

Thailand 2020-2021 Youth Participation

Much research remains to be conducted on Thailand's 2020-2021 youth participation in politics. McCargo (2021) has conducted one of the first scholarly surveys on the current wave of youth participation. More in-depth studies by Sinpeng (2021) and Lertchoosakul (2021) shed light on different aspects of the movement. Sinpeng (2021) analyzes the use of Twitter in the current political movement. She argues that social media is mainly used to air grievances and categorizes the tweets into six topics: democracy, youth rights, education, government opposition, the economy, and the Thai Monarchy. On the other hand, Lertchoosakul (2021) interviews university and high school students at protest sites. She finds that dissatisfaction with the authoritative and conservative education systems, corruption, and inequality in Thai society are the main reasons driving the protests. Lertchoosakul (2021) also emphasizes that Thai youth participation is motivated by grievances against political institutions, particularly the monarchy. Our study extends previous scholarship by engaging Thai students at schools--not the protest sites nor Twitter, whose opinions may not represent all students. It highlights Thai high school students' political participation and embeds this experience within the conceptual framework of youth participation and the broader scholarship on youth and politics in Asia.

Methodology

This study was a qualitative research project. We reached out to six teachers from six different public schools in various parts of Thailand, who agreed to participate in the study and assigned "A Letter to Bridge the Divide" as non-graded homework to their high school students. The assignment asked participating students to write a letter to teachers, parents, adults, or peers who hold different political views while reflecting upon their hopes and fears for Thailand's political future and why the movement is vital to them. The teachers were responsible for disseminating and collecting the assignment in their classrooms. The students have the right to opt-out of the research or leave the homework blank without consequence. Students' names, genders, and protected characteristics were anonymized, and thus the recruitment process did not exclude participants based on gender, class, or race. The homework was assigned to roughly 1,200 students from the six schools. Since the homework was non-graded and anonymized, 691 students turned in the assignment.

To analyze the letters, document analysis was employed to examine the specific language used by the participants in the study to understand their hopes and fears for Thai political insurgency (Creswell, 2002). We addressed the coding based on the conceptual framework used for the study (Saldana & Omasta, 2017). Specifically, we used behaviors and characteristics of Hart's (1992) Ladder of Participation and Reddy and Ratna's (2002) Adult-Children Engagement as initial codes to develop themes. We looked closely at segments of the letters related to the participants' 1) self-perception of current political situations, 2) experience with civic engagement, 3) experience with generational clashes and adult engagement, and 4) hopes and fears for the Thai political future.

Findings

This section investigates how Thai high school students perceive their political participation. It is important to note that not all students support the protests. Roughly around 27% of the letters indicate their neutral stance by writing: "I'm not taking sides;" "I'm neutral and reasonable;" "I understand that a lot of my friends want to express their stances. I think it's their right to do so. I don't think we can always agree, but we have to respect each other. It's natural in a democratic society." Less than 3% are supportive of the government.

Thai high school students view their freedom of expression as one of their inalienable rights. Two hundred nine students (30%) explicitly mention their "rights" and "freedom" to political expression. For example, a student from eastern Thailand argues, "FREEDOM OF SPEECH [capitalized by original source] is a human right by law and international standards. It means that we can express or communicate our thoughts and opinions through words, action, or writing." Since freedom of expression is their fundamental right, the students just want

the space to speak their minds. For instance, a Bangkok student states, "We are not asking for very much. What we're doing is exercising our rights. And I believe this right is not causing anyone any trouble."

Moreover, the students believe that the policymakers should listen to their concerns because they are taxpayers and thus can hold politicians accountable for their actions. Though most young people do not yet pay income taxes, they point to VAT (value-added tax) to contribute to the country's economy. Forty-three students (6%) explicitly mention taxes in their letters. According to these students, since they pay taxes, they have a right not only to question how the government spends public funds but also to demand better infrastructure and welfare from the state. The students believe that their taxes should be used to improve people's well-being. Still, the current government is not spending these funds transparently or effectively.

Since young people are almost universally denied the right to vote, Thai high school students believe they can exercise their rights through symbolic actions, such as the Hunger Games three-finger salute or wearing a white ribbon. Since their civic participation is primarily symbolic, the students feel that they are not harming anyone and are well within their rights. For example, a student writes, "Wearing a white ribbon and the three-finger salute have no physical effect, do not break any rules or laws, do not hurt anyone, involve no weapons."

Many students expressed dismay at the resistance to their political participation and what they feel are violations of their fundamental rights by adults in their lives. Three hundred five students (44%) experienced generational clashes and/or misunderstandings with their parents and teachers. At the fundamental level, Thai students feel that it is only "natural" to have a variety of political opinions. A student from Bangkok asserts, "Having different political opinions is normal because everyone has different ideas and viewpoints." Similarly, a student from the Northeastern region writes, "It is normal that even when [people] are brought up in the same environment, they can have different views only in different periods." Some students have cited a rule from the Ministry of Education that allows political expression in schools and question why their teachers are not abiding by these regulations. In their letters, the students recount how teachers and school administrators have infringed upon their rights to political expression. For example, some teachers reportedly threaten to deduct grades or have explicitly banned the three-finger salute in school. A teacher from eastern Thailand even allegedly slapped a student for wearing a white bow to class. While the students are demanding real changes from the government of General Prayut, their expectations of their families and teachers are different: the students are not trying to change their elders' minds. Instead, young people want the adults in their lives to keep an open mind and listen to what they have to say. For example, a student writes, "We want the people who disagree with us to understand us. Not for them to switch sides, just to understand what we are protesting."

Discussion and Conclusion

The students' beliefs in their unalienable rights and their criticisms of the Prayut regime motivated and justified their political participation. Our findings underscore that the students were not merely acting out or misled into holding rallies or wearing white ribbons. We thus argue that Thai students were operating at high levels of Hart's (1992, 2008) and Reddy and Ratna's (2002) youth participation models - despite adult resistance and unwillingness to communicate (further discussed below).

The students can be placed on one of the highest levels of Hart's (1992, 2008) model of engagement: "children initiated and directed." The contents of the letters indicate that Thai students' beliefs in their fundamental rights and experiences fueled their actions - meaning that they were initiated by the students themselves. The students believe strongly in their freedom of expression and rights as democratic citizens. Therefore, they should voice their opinions and concerns against what they perceive as inappropriate, whether corruption, ineffective use of tax money, or unjust democracy. As mentioned above, this political participation was also by students in many forms: from large protests, such as the ones outside the Ministry of Education in August 2020 (Lertchoosakul, 2020), to everyday symbolic actions, like raising the three-finger salute and wearing white ribbons.

We thus gain insight into students' political participation beyond traditional forms. Studies in various countries have challenged the dichotomy between "apathetic" teenagers and activists (Fisher, 2012; Harris et al., 2010). These scholars find that young people in Australia and the United States engage in "everyday participatory practices" that reflect their political views - such as recycling, signing petitions, and supporting or boycotting businesses. Our findings concur with these arguments. Thai students wearing white ribbons to schools or raising the three-finger salute during the national anthem have incorporated their political participation into everyday life. They have found a new way to participate in Thai politics. Those who participated were not all passionate activists who organized rallies and gave speeches at protest sites but were not politically apathetic. The different forms of participation further substantiate that the students were operating at the "child initiated and directed" level. These political actions weren't something mandated by an authority figure. Students had the independence and decision-making abilities to take action in ways that were within their limits and means, regardless of the economic situation, availability, and comfort level.

Though Thai students had taken the initiative and were already operating at high levels, we believe that the students are facing a combination of "hindrance" and "active resistance" on Reddy and Ratna's (2002) extension from Hart's model. A high number of students writing of misunderstanding and generational clashes (44%) are made to feel inadequate and/or unfit to voice their political opinions by the adults in their lives, thus being "hindered" from participation. According to the students' letters, adults viewed them as "children"; therefore, their role was to study, not solely participate in political movements. This resonates with Reddy and Ratna's (2002) findings when some adults believe that children don't have the capacity to participate and hence cannot make informed choices for their actions. Adults under the "active resistance" category tend to hold a strong position against youth participation and mobilize their resources to lobby against it. This is seen in the cases of teachers deducting marks from politically active students or even going as far as being verbally and physically abusive. Overcoming this resistance will be a necessary step toward bridging the generational gap. A 16-year-old student nicely sums up solutions for the current generational clashes, "We should talk with facts and reasons that would lift the country up. Both sides should listen without bias. Reasons should come before feelings. [...] Age shouldn't be a factor. No matter how old you are, we should be able to express our opinion freely."

Our study holds significance in showcasing the motivations of student political participation, particularly in Thailand. The messages from the Thai students' letters are universal and almost too apparent. These young people find issues with the status quo, believe that their rights to express their discontent are irrefutable, and are driven by their aspirations to secure a better future for themselves. Therefore, those in power everywhere should at least heed, if not welcome young people's political opinions and let them truly have a voice in society.

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Participation and Success with Optional Self-Explanation for Students in Online Undergraduate Chemistry Courses

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Abstract: The benefit of self-explanation in learning has been well researched, but the extent to which students engage with such activities in a real-world course setting is often overlooked. To investigate how students participate and perform on such a task, we embedded an optional self-explanation activity into an introductory online chemistry course consisting of 129 students. We analyzed their participation and performance in the course, and how it relates to the quality of their self-explanation. We found that 53% of students participated in the optional self-explanation activity and 25% of their self-explanations were reviewed by experts to be sufficiently specific and detailed. Our results suggest that students are willing to engage with an optional self-explanation activity; however such interventions may be targeting the already high performing students in the course.

Introduction

As a constructive learning activity that fosters deep learning by encouraging students to generate inferences to themselves while they engage with the learning material, self-explanation acts as a medium for developing students' thinking and is specifically important for fostering transfer between concepts (Margulieux & Catrambone, 2017; Wylie & Chi, 2014). In a variety of domains, prompting students to self-explain while learning has been shown to positively impact the development of both conceptual and procedural knowledge (Rittle-Johnson, 2006). Understanding the structure and the quality of students' self-explanations can provide a foundation for examining their learning progression and their ability to communicate science (Sandoval & Millwood, 2005). Self-explanation can occur through different modalities, such as explaining out loud to a person (e.g. Jacob et al., 2020), selecting an explanation from a list of options (e.g. Asano et al., 2021), and constructing your own via an open-ended prompt (i.e., self-explanation - Rittle-Johnson & Loehr, 2017). This set of previous work has shown that it is effective for both in-person instruction in the classroom and online in a digital environment. Oftentimes students are required to perform self-explanation as part of their coursework or participation in a study, so claims can be made in relation to the quality of the student explanation and their success in class (Menekse et al., 2011). Additionally, systems are sometimes developed and deployed specifically to engage students in the self-explanation process (Williams et al., 2016). As a result, the participation and success of self-explanation activities may be inflated, as students in online courses often lack motivation and have low participation rates when the material is not required (Shapiro et al., 2017). This is not necessarily reflective of what occurs in the classroom or online, where students often make use of more low-stakes learning opportunities intended to give students feedback that are not required for the students to complete.

As prompting students for self-explanation has been proven to be an effective instructional intervention, garnering the participation of students that are struggling and could benefit the most from it is critical. While often neglected by previous work around self-explanation, identifying which students are engaging in the task, particularly when it is optional, can improve understanding of how self-explanation is leveraged by students. As stated in Asano et al. (2020), optional open-ended prompts to self-explain can readily be applied into many courses without the need of additional grading or ed-tech systems. However, we need to first understand how students will interact when the self-explanation activity is optional and for those that do interact, what the quality of their self-explanation is like. We addressed these questions in the current work through including an optional self-explanation prompt in an online chemistry course taken by over a hundred students. Specifically, in this study we present students with an optional self-explanation prompt embedded in their online coursework. We then utilize a 5-item rubric to assess the quality of students' self-explanations. The two research questions we address are: (1) How often do students engage with an optional self-explanation activity in the context of their online chemistry course? and (2) How do students respond to optional self-explanation prompts in an online chemistry course?

Methods

Study context & students

The present study takes place in a digital courseware platform known as the Open Learning Initiative (OLI). OLI is an open-ended learning environment that offers courses from a variety of domains (such as chemistry, biology,

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statistics, economics, etc.) and consists of interactive activities and diverse multimedia content (Bier et al., 2019). OLI activities are presented in two distinct categories: low-stakes/formative, providing students with feedback, or high-stakes/summative, used to evaluate student learning at the end of a structured unit. The low-stakes formative assessments in the system are all optional, allowing the students to scroll by them and focus purely on the instructional content. These assessments consist of a variety of question types such as MCQs, short answer, and dropdown style questions. Each question in OLI is broken down into one or more problem steps, where each step corresponds to an opportunity for student input. For instance, if a question asks a student to set the value of three dropdown boxes, then it consists of three unique steps that each have their own set of feedback and correct or incorrect responses. This distinction between a problem and its steps is important, since students may work on a problem, but not complete all of the steps due to a number of reasons such as not knowing the answer to some of them, wanting to skip them to save time, or getting distracted (Chen et al., 2018).

We used data collected from a week-long unit in four instances of an introductory chemistry course taught at a community college in the western United States. The course is geared towards freshman and sophomore undergraduates from varying degree backgrounds, with a majority of the students pursuing a chemistry-related degree. Our data comes from the fall semester of 2020, when the introductory chemistry course was offered in the OLI system. In total, our data consists of 129 students, with 68 of them participating in the self-explanation activity.

The OLI content the students used for the course covers the topic of elements and compounds and consists of thirteen separate modules. Each module consists of several topic headers, containing paragraphs of instructional text and low-stake activities embedded throughout. There are a total of 35 low-stakes and completely optional problems embedded throughout the thirteen modules of the course. These problems include multiple choice questions, selecting the correct option from a dropdown, drag-and-drop exercises, and submitting a short answer to compare against an expert response. Each of these problems is broken down into steps, depending on the components of the activity, for a total of 178 unique steps. For instance, if a problem has three fill-in-the-blank boxes, then that problem would consist of three unique steps. Additionally, students have unlimited attempts to answer these questions, so they can continue until they are correct or choose to advance, regardless of a correct or incorrect response. Additionally, all the instructional materials in OLI were optional to the students; there was no requirement for them to access or complete the materials outside of the summative quiz that was also accessed and implemented in the OLI platform. Previous research using the OLI platform has found that students have varied participation levels with the optional activities found throughout the material (Moore et al., 2021). However, students were assessed on the concepts covered by the OLI materials elsewhere in the course, so it was beneficial for the students to utilize them.

Data collection

We focus on an activity that was added to the course that involves each student generating a self-explanation as to why they chose their answer to a particular problem in the course. In the chemistry course, this activity is found in the second module of the content for this section of the course. This module provides several paragraphs of instructional text, two worked examples, and several low-stakes multiple-choice and short-answer questions on the topic of atomic mass. The self-explanation activity is presented in the same low-stakes and optional format as the other activities found throughout the course. In the activity (1), students are prompted to self-explain why they chose their answer to the short answer question above the prompt. The instructions for the self-explanation come from a related study by Asano et al. (2020) and are worded in a way to maintain the motivation of the student and briefly explain the concept of self-explanation. We intentionally wanted to keep this low-stakes and optional, to examine the students' participation with the task and the quality of their contribution.

Analysis

The student-generated explanations were coded by two experts to assess their quality and specificity. The two experts had content knowledge in chemistry and had ample previous experience coding qualitative student data. The inter-rater reliability was calculated and the Cronacbh's alpha value was .98, as the raters only disagreed on the rating of four self-explanations. These discordant explanations were discussed among the two raters until they reached a consensus on the categorization of them using the coding schema. This coding schema was adapted and used from Menekse (2020), which has also previously been used in several studies (Asano et al., 2020; Menekse et al., 2011). Explanations were assigned scores from the rubric ranging from 0 to 4. The exact coding schema that was utilized by the two expert reviewers can be found at (2).

A score of 0 "No Submission" means that the student left the self-explanation text box blank, they did not submit anything. Explanations received a score of 1 "None" if the student submitted something, but it was not relevant to the problem or the course content in any fashion. For example, a student wrote "I had no idea what to

say, but I had to say something". While the student did input a self-explanation, it has no relevance to the context of this course and it appears as if they were just submitting text to have something input for this question. A score of 2 "Vague" was assigned to explanations that were not specific to the current problem, but were still relevant to the context of the course and potentially borrowed some language from the question's text. One example submitted by a student was "they have to be within range of the isotopes". While part of the problem does involve isotopes and they are mentioned in the text, this explanation only mentions the isotopes and does not reference how the isotopes impact the outcome of the problem. Additionally, it is not clear what the "they" is referencing in this explanation.

Explanations received a score of 3 "General" if they discussed the topic of the problem, but did not provide enough details. For example, one student wrote "It is the number closest to 39.098 amu." for their explanation. This explanation directly relates to the problem and even a number used in calculating the correct answer, but does not mention specifics on how to use the amu number or the isotopes to determine the correct answer. Finally, a score of 4 "Specific" was given to explanations that were both detailed in nature and specific to the problem, for instance "The atomic mass is the average mass of all the isotopes present in a naturally occurring sample of this element. If the amu for K is 39.098, then that means that K-39 is more abundant since it is the closest to the atomic mass". Note that this explanation is also much longer than the previous, which was a trend for the explanations scored in this category. The explanation, in sufficient detail, clearly demonstrates how the student used their knowledge of atomic mass and isotopes to determine the correct answer.

Results

Student participation and self-explanations

We found that over half of the students in the four courses wrote responses to the self-explanation task. In total there were 129 students in the instances of the course and 68 (52.71%) of them made a contribution to the self-explanation activity. The chemistry course used by all four instances consisted of 35 problems that were composed of 178 total steps. On average, students completed 22.66 problems (*SD = 14.67*) and 112.96 steps (*SD = 78.54*), meaning a majority of the activities were worked on by the students, despite being completely optional. A t-test showed a significant difference in the number of completed problems, $t(127) = 9.369, p < .0001,$ and steps, $t(127) = 9.319, p < .0001$, between students that did the self-explanation activity and those that did not do it.

The self-explanation task was in reference to a short-answer question found towards the beginning of the course that was completed by 83 (63.34%) of the 129 students. Even though 83 of the students completed the short-answer problem, only 68 of those students contributed to the self-explanation task. This means 15 students did the problem, but chose to not participate in the self-explanation. Additionally, students on average spent 99.82 (*SD = 82.99*) minutes actively working on the problems found in the course, meaning they were typing or had their cursor somewhere present in the activity box. The average time spent by students on the self-explanation activity was 103.58 seconds, with the least amount of time being 17 seconds and the greatest being 433 seconds.

Description and quality of student self-explanations

The self-explanations students provided were input into a multiline textbox that had an adjustable size, capable of fitting any length of text. On average, the student-provided self-explanations were 107.5 characters long, with the shortest response containing 1 character and the longest 363 characters. There was a significant and positive correlation between the amount of time a student spent on the self-explanation task and the length of their explanation, $r(67) = .28, p = 0.019$. This might suggest that students spent their time thinking and typing the explanation out for the task, rather than having their cursor idly on the activity. A Spearman's rank-order correlation test indicated that the time students spent working on the self-explanation task was also positively correlated with the rubric score they received for their explanation, $rs(67) = .26, p = .032$.

A summary of the rubric scores for the student self-explanations can be found in Table 1. There were 61 students (47.29%) who did not submit a self-explanation response. For the 68 self-explanations provided by students, a majority (66.18%) of them were scored as a 3 or 4, indicating they were relevant to the problem; some were general (score 3) while others were sufficiently detailed and specific (score 4) to the problem. The highest percentage of score 4 was found in the c2 course at 19.23% across all students in that instance of the course. However, a one-way ANOVA revealed there was no significant correlation between the four courses and the distributions of rubric scores in the range of 0-4 for student self-explanations, $F(3, 125) = 1.309, p = .274$.

Table 1 Distribution of the rubric scores assessing the quality of the self-explanations that students received across the four instances of the chemistry course.

	Rubric Score					
Course	0	1	2	3	4	**Total Students**
c1	30	3	2	15	7	57
c2	9	1	3	8	5	26
c3	12	3	3	2	3	23
c4	10	4	4	3	2	23
Total (%)	61 (47.29%)	11 (8.53%)	12 (9.30%)	28 (21.71%)	17 (13.18%)	129

Endnotes

(1) https://github.com/StevenJamesMoore/ICLS2022/blob/main/ICLS_2022_Figure_1.png
(2) https://github.com/StevenJamesMoore/ICLS2022/blob/main/ICLS_2022_Figure_2.png

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Future Selves in STEM: An Epistemic Network Analysis of Past and Present STEM Minority Program Participants

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Abstract: STEM minority participation programs have been widely implemented in higher education institutions to diversify and expand the U.S. STEM workforce. Research highlights the potential of targeted exploration of STEM roles and careers, and of intentional reflection on the self in relation to STEM (identity exploration). This work examines how engagement in a federal-funded STEM minority participation program shaped these processes in current students and alumni. Epistemic Network Analysis visualized connections between inductive identity themes in interviews, highlighting differences between interviewees at different stages of their careers and identity work: students discussed action-taking as they explored less-certain possible future STEM roles, while alumni integrated more diverse and holistic identity facets when conceptualizing their futures. Results offer insights into the identity-related impacts of STEM minority participation programs and longer-term trajectories of minoritized students working toward STEM majors and careers.

Identity and STEM participation

Shortages in the science, technology, engineering, and mathematics (STEM) workforce have been a persistent issue in the U.S., exacerbated by a representation gap in terms of minority participation (Camilli & Hira, 2019). Programming is needed to encourage URM youth to declare STEM majors and work towards degree completion. To address this, STEM minority initiatives that foster facets of identity exploration have been highlighted as a tool to broaden participation in STEM education. Research on STEM minority participation emphasizes identity work as supportive of student self-efficacy (Syed et al., 2019), self-authorship (Morton & Parsons, 2018), and motivation to persist in STEM (Hernandez et al., 2013). Reflection on *future possible selves* in STEM, or the roles and characteristics an individual hopes or expects to one day embody (Markus & Nurius, 1986) has been shown to play a key role in student's STEM learning, academic development, and career certainty (Syed et al., 2019; Verdin et al., 2018).

Identity exploration (Flum & Kaplan, 2006) is grounded in the idea that self-reflection in one moment is meaningfully built upon prior experiences and conceptualizations of self. Learners craft future possible selves as an awareness of what they might, would like, or fear of becoming based on an understanding of current and past roles (Markus & Nurius, 1986). Despite affirmations of the value of identity-focused interventions on institutional outcomes (Crawford et al., 2018), identity exploration research has found mixed results. While large-scale studies on the impact of university STEM programming connect current science identity (feeling part of the scientific community) to beneficial outcomes such as goal-setting and academic achievement, others suggest having a current science identity and values may not be predictive of STEM career success beyond four years post-graduation (Estrada et al., 2018). This disconnection could be representative of research that emphasizes reflection on the "current self" as a science community member, but not on a future possible self in STEM. Existing longitudinal studies of URM STEM identity exploration also tend to be survey-based (Habig et al., 2020), which may not elucidate how URM participants engage in identity exploration at different stages. This work adds to knowledge about long-term outcomes of higher education STEM minority programming through an examination of how participants at different stages of their STEM trajectories engage in identity exploration around future possible selves. The research question asks, "What patterns of identity exploration emerged when students and alumni discussed their future possible selves in STEM?"

Research methods

This work is a part of an NSF-funded project through the Louis Stokes Alliance for Minority Participation (LSAMP), which supports underrepresented students earning degrees in STEM. We examined individual interview data with eleven current and ten former LSAMP participants. The sample represents four LSAMP participating institutions,

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various STEM disciplines, and different stages within the STEM pipeline. Semi-structured interviews were conducted via zoom where participants discussed identity exploration processes as they related to their future possible selves as they participated in LSAMP programming. A priori themes/codes were selected using an inductive thematic analysis; however, codes were broadly framed based on the theoretical positioning of identity exploration and future possible selves research discussed above (See Table 1).

Table 1
Codes Related to LSAMP Participants' Future Selves in STEM

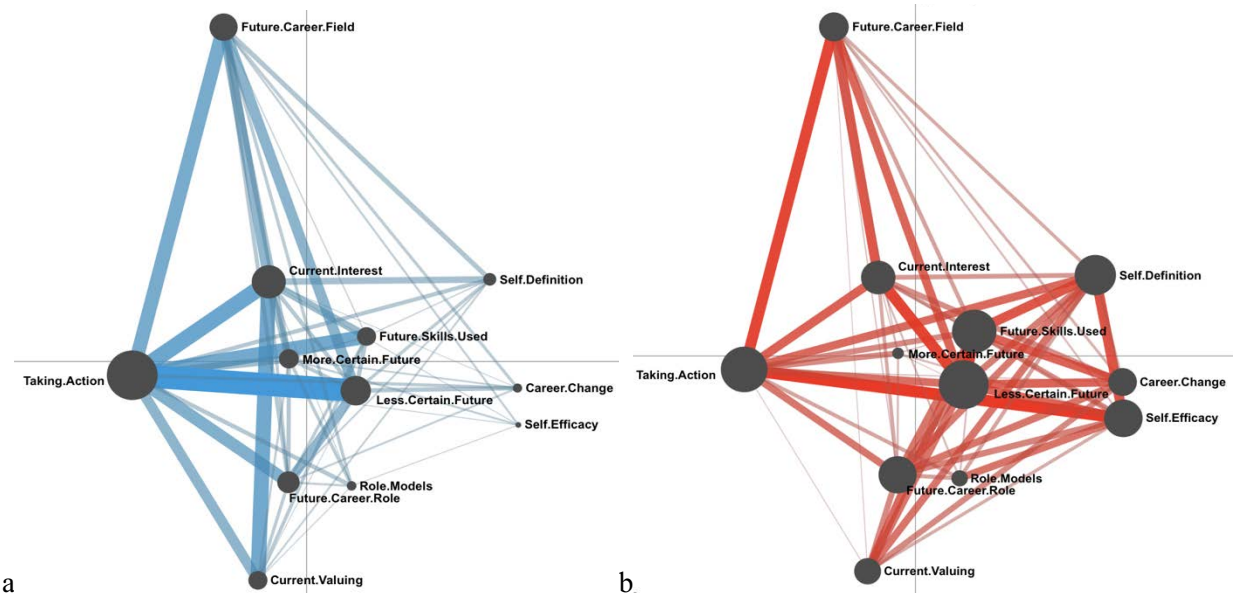
Code	Definition
1. Career Change	Expected change in STEM major or career
2. Current Interest	Describing liking or enjoyment of a STEM topic
3. Current Valuing	How a topic, domain, etc. is personally valuable
4. Future Career Field	Expected field or discipline in which participant may work
5. Future Career Role	Expected role or position which participant may hold
6. Future Skills Used	Expected skills to have and/or use in future
7. Less Certain Future	Lack of certainty or specificity in discussions of the future
8. More Certain Future	Expressing certainty and/or specificity in future career, role, field, or skills
9. Role Models	Describing individuals who inspire future major or career choices
10. Self-definitions	Descriptions of current identity labels and features; self-concept
11. Self-efficacy	Expressing confidence in one's ability to achieve desired results or goals
12. Taking Actions	Describing actions or steps taken to achieve desired results or goals

Once identified, codes were deductively applied to the interview data, with each sentence coded for occurrence (1) or non-occurrence (0). Interrater agreement was reached using social moderation (Herrenkohl & Cornelius, 2013). To understand differences in the ways that current LSAMP students and alumni conceptualized future possible selves, we applied epistemic network analysis (ENA) (Shaffer, 2017), a quantitative ethnographic technique used to model the relationships between codes in discourse. ENA generates network visualizations of the co-occurrence of codes within a moving stanza window, which means that code connections are determined and measured when they co-occur in the same sentence or a few sentences from each other (in this case 3 sentences). To generate the epistemic networks, units of analysis were set as the alumni and student groups, subset by each participant. Conversations were segmented by each interviewee and any breaks (i.e., off-topic discussion) in their interview. Nonparametric Mann-Whitney U tests were conducted to test whether differences between student and alumni discourse were statistically significant. Network findings are supplemented with qualitative findings.

Results and discussion

The epistemic network model had strong goodness of fit across the first (0.97 Pearson, 0.97 Spearman) and second dimensions (0.99 Pearson, 0.99 Spearman). The alumni network (Mdn=0.81, N=10) was also statistically significantly different (alpha<0.05) from the student network (Mdn=-0.54, N=11, U=108.00, p=0.00, r=-0.96), suggesting meaningful differences in their patterns of connection-making across identity themes. Figure 1a shows the epistemic network of associations that students made across the 12 identity constructs, while 1b shows the network for alumni.

Figure 1
Epistemic Networks of Associations Between Identity Themes for Student (left) and Alumni (right) Interviews.



Student discourse was driven by connections between "taking action" and codes such as (1) a "less certain future" (.24), (2) discussions of "current interests" (.17), (3) a desired "future field" (.14), and (4) an expected "future career role" (.13). A robust connection manifested between students' current interests and their current values in STEM (.15). Interpretive examination confirmed a pattern where students would detail STEM-related steps they were taking as part of an academic program, followed by a discussion of general or "less-certain" roles for which these actions were intended. One student alternated discussions of her current activities with potential, less-certain roles:

> I was trying to do a gap year at [company], they might have semiconductor research [actions taken]. This was going to depend on COVID, you know, kinda set all of this stuff, so I want to keep my options open [less certain future]. I'm even considering, you know, working as a professor, and I recently participated in a faculty exploration in [place] [less certain future, actions taken].

Relationships between "interest" and "taking action" manifested as students exploring multiple roles, such as the student who described looking for research positions in biomimicry to satisfy her passions. Some students knew the actions they took were working toward future participation in a general STEM field but had not yet settled on a specific career. These findings illustrate how engagement in STEM-focused programming may have at least tacitly encouraged students to take actions to explore facets of different STEM interests and career fields, but that student conceptualizations of their future selves in STEM had often not coalesced around concrete future roles or careers.

The alumni epistemic network reveals a more balanced pattern of association across identity themes, rather than centering around any single code. Alumni discussed "taking action," but were more likely to connect it to self-efficacy (.13) in their STEM career. Alumni often described a "less certain future" regarding careers and STEM identities but were more likely to connect this to a discussion of the "future skills used" (.13), as well as to "current interests" (.12). Other stronger connections included discussions of "taking action" in relation to "future career field" (.12). A visual examination shows "taking action", "less certain future", "self-definition", "future skills used" and "self-efficacy" as the most heavily connected constructs. Interpretive examination confirmed that alumni were more likely to integrate different facets of their identity exploration processes in interviews. Trajectories of reflection tended to be more diverse across alumni, with different participants making different connections in unique ways. Compare the following interview examples from two different alumni:

> Career goals... I would like anything that could pay me well and keep me using my engineering brain and my lawyer brain [current valuing, self-definition, future skills used]. I'm an engineer, a lawyer, a problem solver and a critical thinker and that's what I want to do [self-efficacy, self-definition]. It's kind of general, but I've

> no plans on leaving my current employer unless I found a better deal…that still allows me to do what I'm doing [current valuing, future skills used, less certain future].
>
> I'm trying to get hired with a process or a scale-up commercialization sort of role, because I want primarily to be able to get a couple of years of industry experience [taking action, future career role]. The positions that I'm really looking at and working with, let's say sustainability units within chemical manufacturers or working with the more - [future career role] I've recently started to understand this space a little bit more [self-efficacy].

Not only are alumni discussions more likely to integrate different facets of the self in a more complex and detailed way, but each pattern of reflection may be more conceptually distinct in terms of their socio-cultural situation; alum 1 and 2 differ in terms of the specific job they currently have, their STEM experiences since graduation, the skills they use, and the amount of time that has passed since they engaged in LSAMP programming. These features place them not only on unique STEM career paths, but also at different points in their distinct STEM trajectories.

Conclusion and implications

Results highlight the distinct discourse patterns and conceptual connections that emerged as current and former LSAMP participants discussed their future identities in STEM. While students were more likely to describe the current actions they were taking in relation to their exploration of more diverse and nebulous STEM interests, roles, and topics, alumni reflections revealed more holistic discussions of self that diverged into unique career and context-specific trajectories. As alumni move further along their increasingly unique STEM trajectories post-graduation, whole-group claims may start to obscure their socio-culturally distinct yet contextually valid patterns of growth and self-reflection they enact over time. This work contributes to research on STEM identity and minority participation by highlighting patterns of connection-making enacted by past and current participation and suggesting how and when individual trajectories might start to diverge post-graduation. Future work may extend this exploratory application of ENA to larger student and alumni datasets and secondary sources to understand identity exploration with greater nuance.

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Visualization and Reflection to Scaffold Time-Management in a Computer-Based Learning Environment

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Abstract: Facilitating practice of time-management skills in education is imperative due to its impact on short and long term academic achievement. By bringing tacit processes into students' conscious awareness via visualizations, computer-based learning environments offer unique opportunities to enhance such practice. Nonetheless, there is a dearth of knowledge on how this impacts students' learning and time-management, especially when it comes to secondary vocational education. Therefore this study explores how visualizations of performance combined with guided reflection impact students' (N = 40) time management accuracy and their knowledge acquisition. Technical vocational students who worked in a computer-based learning environment that included a visualization of estimated time accuracy combined with guided reflection, were compared to students who worked in the same environment without this support. Results indicated that higher accuracy and learning gains align, that the added support may have induced an adaptation in time-management, but that learning was not affected.

Introduction

Training of processes needed to acquire academic skills -often referred to as self-regulated learning skills- in education, can have direct as well as indirect effects on students' academic achievements (Ifenthaler, 2012; Palalas & Wark, 2020; Viberg et al., 2020). But teachers are uncertain how to properly support such training, especially within the practical-oriented secondary vocational training programs (e.g., Christoffels & Baay, 2016; de Bruijn & Leeman, 2011; Eshuis et al., 2021). And research addressing support for this population is rare (Viberg et al., 2020). An example is the process of time management, a key factor of self-regulated learning (Khiat, 2019; Winne & Hadwin, 2013), but to date an underdeveloped and underexamined topic (Wolters & Brady, 2020).

In the context of education, time management is the process of scheduling time to complete the learning tasks that are tied to the desired learning goals (Claessens et al., 2007; Khiat, 2019). Researchers established that *good* time-management has both direct and indirect effects on students' learning effectiveness (Khiat, 2019). A key component in good time management is the accuracy of the estimated time required to achieve the desired goals (e.g., Claessens et al., 2007; Landy et al., 1991). Experience combined with a continuous cycle of adaptation is needed to achieve this. Providing instructional guidance, like prompts that trigger students to plan and reflect, can help students to successfully engage in the required cycle of adaptation and improve their time management.

Prompts are instructional directions that stimulate and support students to carry out specific actions (Bannert, 2006). They are widely studied, often in the context of reflection, and their effectiveness is generally endorsed (Davis, 2003; Kori, et al., 2014). Though prompts can trigger and support students' planning and reflection, the outcomes of these activities is subject to many factors. One of these being that students tend to underestimate the time they need(ed) to complete their tasks (König & Kleinmann, 2007). This impacts the benefits of reflecting; when students start from inaccurate information their reflection is probable to result in wrong conclusions, even when all steps (i.e., collection of information, evaluation of information, goal setting) are carried out successfully (as also described in Eshuis et al., 2019). Here, computer-based learning environments can provide valuable support. Digital tools can track students' performance in learning environments and provide timely feedback for reflection, for instance via a visualization of students' estimated time in comparison to their actual time spent. Studies have demonstrated that such 'comparative feedback' (feedback that offers a comparison source) is a promising instructional means that can serve as a promoter of reflection (Eshuis et al., 2021).

This paper explores such a digital tool. The tool employed visualizations (comparative feedback contrasting students' estimated time with their actual time) and guided reflection prompts, in order to support students' time management (see Figure 1). Two groups of students were compared. All students worked in a digital environment that required self-regulated learning. Only one group of students had access to the time management support tool. Because self-regulated learning processes play an essential role in students' success in computer-based learning (e.g., Broadbent & Poon, 2015; Lehman et al., 2014; Wong et al., 2021) and time-management is a key component in self-regulated learning (Winne & Hadwin, 2013), it was expected that more effective time management would positively impact students' success in the computer-based learning environments. More specific, it was expected that more successful time management would relate to better

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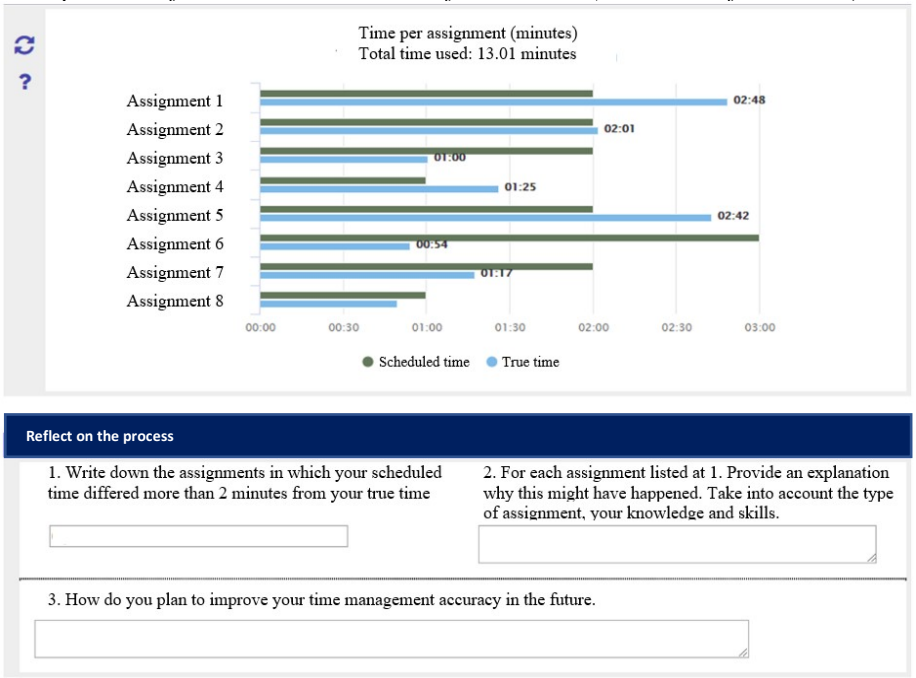
performance on domain knowledge tests (1); that students' time management accuracy would improve over time (2); and that the support would improve time management and consequently improve learning (3).

Figure 1

An Impression of the Visualization and Reflection Tool (Translation from Dutch)



Method

This study utilized an experimental pretest (domain knowledge test) - intervention (two sessions in a digital learning environment) - posttest (domain knowledge test) design with two conditions. All students completed two online learning environments (copies of the environments used by Eshuis et al. (2021)). They contained two online labs, eight assignments each, and instructive multimedia material related to electricity and electric power transmission. For the experimental condition, the time management reflection support was added to both learning environments. This was a digital tool which consisted of three steps: planning, evaluation, and reflection. The planning step was carried out at the start of each learning environment. Here students were invited to check the learning goals and the tasks in the environment and schedule how they would spend their 60 minute lesson. After students spent 60 minutes working on their assignments (or when they were done) they completed the second and third step: evaluation and reflection. Here, the tool presented the students with 'comparative feedback'. This comparative feedback comprised an overview of students' scheduled time per assignment and the actual time they spent on it (see Figure 1). Via a series of prompts students were invited to check the overview and reflect on their findings. More specific, the prompts requested students to 1) indicate significant differences between their scheduled time and their actual time spent, 2) explain this difference while taking into account the type of assignment, their prior knowledge, and skills, and 3) think of ways to improve their time management.

Measurements

Students' *domain knowledge* was assessed with two parallel versions of a paper-and-pencil test. To avoid order effects counterbalancing of the two versions as pre- and posttests was employed. Each test consisted of 11 constructive response items that aligned with the learning objectives lined out in the learning environments. Each item had two sub questions: one assessed factual knowledge (i.e., recalling a definition or formula) and one assessed procedural knowledge (i.e., applying a formula or explaining a principle). A sub question was awarded one point when answered fully correct. Three scores per test were calculated: total knowledge (all items), and factual and procedural knowledge separately. Cohen's Kappa for both pre- and posttest was >0.9.

Students' *time management inaccuracy* (i.e., the average deviation in time from the scheduled time) was calculated using the differences between students' scheduled time and their actual time spent per assignment. Where a positive score indicated an overestimation of time needed to complete the assignments, a negative score indicated an underestimation of this. A score of 0 indicated perfect time management.

Results

The data comes from 40 students (all male, M_{age} 17.3 years, SD_{age} = 8 months) of secondary vocational education (in Dutch: MBO) who completed all four sessions of the experiment. Participants were first-year students from three classes divided over two schools in the Netherlands. Students were enrolled in a technical training program preparing them for a vocational profession (e.g., car mechanic, electrical engineer).

Table 1
Descriptive Statistics

	Experimental condition (n=17)		Control condition (n=23)	
	mean	SD	mean	SD
Domain knowledge pretest (max 22)	5.14	3.47	4.96	2.58
factual (max 11)	2.37	1.41	2.53	1.21
procedural (max 11)	2.20	1.53	2.30	1.61
Domain knowledge posttest (max 22)	6.89	4.52	7.12	3.54
factual (max 11)	3.28	2.19	3.46	1.74
procedural (max 11)	3.17	2.31	3.22	1.83
Total time spent (minutes)				
learning environment 1	56.03	8.36	58.74	8.58
learning environment 2	52.31	10.05	50.01	14.66
Time management inaccuracy (minutes)				
learning environment 1 (TMI-1)	-0.45	1.84	n.a.	n.a.
learning environment 2 (TMI-2)	0.44	1.50	n.a.	n.a.

Pearson correlations demonstrated significant relations between pretest and posttest ($r(15) = .812$, $p < .001$), TMI-1 and TMI-2 ($r(15) = .505$, $p = .039$), and TMI-2 and posttest ($r(15) = -.617$, $p = .008$). There were no significant correlations between students' domain knowledge pretest score and TMI-1 ($r(15) = -.294$, $p = .252$), nor TMI-2 ($r(15) = -.481$, $p = .051$). Furthermore, from the descriptive statistics of the experimental condition it seems that students in learning environment 1 were more likely to underestimate the time they needed, while in learning environment 2 they seemed to be more likely to overestimate the time they needed. A paired sample t-test demonstrated a significant difference between these two average levels of inaccuracy, $t(16) = -3.93$, $p = .001$. Though there was a significant change from learning environment 1 to learning environment 2 it should be noted that the deviation from 0 in each appears about equal.

Mixed-design multivariate analyses with 'condition' as between-subject factors, and 'time' as within-subject variable demonstrated significant learning effects overall, but no effect of support. The within-subject variable represented the students' multivariate scores on the domain knowledge pre- and posttest with the factual and procedural scores as underlying univariate measures. Results showed a multivariate main effect for time, $F(2,36) = 10.11$, $p < .001$ (Wilk's $\Lambda = .640$, $\eta_p^2 = .360$), no multivariate main effect for condition, $F(2,36) = 0.097$, $p = .908$ (Wilk's $\Lambda = .995$, $\eta_p^2 = .005$), and no multivariate interaction effect, $F(2,36) = 0.36$, $p = .965$ (Wilk's $\Lambda = .998$, $\eta_p^2 = .002$). Univariate effects demonstrated that there were no significant univariate interaction effects underlying the insignificant multivariate interaction.

Discussion

The findings of the current study add to our understanding of how digital tools designed to support time management can impact students' behavior in an online learning environment. Specifically the focus group of the current study (i.e., students from technical secondary vocational education) makes this a unique contribution; as Viberg et.al. (2020) justly noted in their review, research often addresses higher education and only rarely addresses secondary education (in their review only 4% of the studies did so). Despite the moderate sample size, the current study provides some evidence that a relatively simple and short intervention has potential to foster adaptation. A change was established, but it should be noted that the change is not yet completely in line with what was desired. When looking at the average time, students were off by a similar time in both environments. It could be that a longer intervention is necessary to move from mere adaptation to adaptations with higher accuracy, or maybe added instructional support is required. The same goes for the transfer of higher accuracy to higher learning gains. The results of the current study corroborate the general assumption that more accurate time management aligns with higher learning gains. Nonetheless, the intervention in the current study was unable to elevate students' accuracy to such a level that significantly higher domain knowledge scores would be achieved. Also here a longer duration of the intervention might be necessary to establish substantial effects that translate

into a difference on this indirect level. It should be noted that the result is not unusual; Viberg et.al. (2020) concluded in their review there is little evidence of self-regulated learning support tools that manage to significantly improve learning outcomes. It could be that differences within the population impact the effectiveness of tools (as also discussed by ter Vrugte & de Jong, 2017) and that certain design choices, like the comparative feedback, may only benefit certain students.

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International Society of the Learning Sciences

Instructional Landmarks: Describing a Novel Intermediate Knowledge Structure for Physics Learners

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Abstract: Mapping the intermediate stages of developing knowledge structures is a critical endeavor for educational researchers. The influence of formal education on knowledge structures is particularly relevant to instructional designers. During an exploration of intermediate physics learners' knowledge of the Coriolis force, a novel knowledge structure was observed as the students discussed isolated systems, frictionless surfaces, and the law of inertia. We call these structures "instructional landmarks" as they appear to emerge from classroom instruction and serve to orient students in conceptual spaces and resolve conflicts during problem-solving. These structures, if found in other physics domains, could be useful for describing and modeling the cognition and development of intermediate physics students.

Introduction

Participating in formal instruction can help students construct more elaborate mental models for making sense of the physical world. In response to educational interventions and experience, novices reorganize their prior knowledge to construct higher-order structures that can meet the increasing functional demands of more complex problem-solving (Vosniadou & Brewer, 1987). During this restructuring, novices can build intermediate structures which act as a sort of conceptual bridge between their previous, naïve understanding and the rigorous, methodical, mathematical operations that are exemplified by experts (Niedderer, 2001). Identifying and describing these intermediate structures can help instructors develop alternative teaching approaches, which can further develop these intermediate conceptions into productive expertise (Brown & Clement, 1992).

In the course of developing a conceptual teaching approach for the Coriolis force for undergraduate physics, our team conducted a series of task-based interviews with intermediate physics students in order to observe how their prior knowledge, both intuitive and from their introductory physics education, played a role in their sense-making. We observed patterns in student reasoning, which may implicate a new category of intermediate knowledge structure in physics learning. We call this category of knowledge *instructional landmarks*. The role of instructional landmarks in learning could inform instructional design across multiple domains of physics.

Theoretical framework

This work builds on a theory of knowledge and learning called Knowledge in Pieces (KiP; diSessa, 1993). KiP postulates that knowledge is a complex web of atomized knowledge elements with context-dependent connections. The connections which exist within the knowledge structures of novices are highly localized and sparser in general than those employed by experts. Novices also tend to lack the higher-level, abstract schemas that govern large-scale cognitive organization in the minds of experts. Part of the transition from novice to expert involves reorganizing and repurposing existing knowledge elements to align with accepted scientific understanding. As the knowledge network becomes more reliable, clusters of related elements fuse into more developed structures which can be used productively in sense-making. By examining learners at various stages of development and across a broad range of topics, researchers can catalogue the various available resources, understand the relationships and interactions between them, and explore their evolution and development over time. This would allow for the creation of adaptive educational materials, which utilize the students' cognitive resources to their fullest extent.

Methodology

In order to get a sense for the conceptual resources undergraduates bring to their learning of the Coriolis force, our team interviewed eleven undergraduate students from a large university in the U.S. Intermountain West. All participants had finished the university's Introductory Physics course, which covered basic physics concepts that were necessary to understand the Coriolis force. Six of the participants had also completed the Classical Mechanics course that included traditional instruction about the Coriolis force. During each one-on-one interview, students were presented with a series of thought experiments, which explored the motion of a puck as it moved across the surface of the earth under various circumstances.

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Interview transcripts were analyzed using Knowledge Analysis, which focuses on the structure, genesis, and evolution of knowledge within an individual's mind (diSessa et al., 2015). Specifically, we used a microanalysis to identify participants' resources for reasoning about Coriolis force phenomena. Knowledge Analysis is a grounded approach, meaning it allows patterns and interpretations to emerge from the data rather than looking at the data to find evidence of existing components of a theory (Corbin & Strauss, 2008). After transcribing the recorded audio from the interviews, the students' responses were analyzed to identify the ideas they featured. Similarities in student ideas were then compared to previously documented knowledge elements and structures to identify the existence of previously documented resources and highlight ones that were novel.

Results

Among the data, three patterns in student reasoning stood out. They shared enough similarities with each other that they appeared to be instances of a common structure and the three together offered enough detail to form a rudimentary outline of the structure. They appeared to be heuristics that the students relied upon as they interacted with intermediate physics concepts, which had strong roots within the students' formal education. Their primary function seemed to be orienting the students within a conceptual landscape during problem solving. We named these structures "instructional landmarks" and began documenting their common traits:

1. *Central Node:* Instructional landmarks have a focal point that is a common physics term, phrase, or rule (e.g., "Newton's 2nd Law"). The highlighted term is one that would have little importance to a lay person but is instantly recognizable to anyone with an introductory level of physics education. This demonstrates that instructional landmarks are not intuitive knowledge elements, but rather are constructed in the same environment where novice physics learners are introduced to the technical terms of physics.
2. *Loose Organization:* Concepts which share an association to the central node are cued when learners activate the instructional landmark. The strength of cuing is proportional to the frequency at which the concept was relevant to problem solving involving the central node during physics instruction. The connections surrounding the central node are still unrefined; students may mistakenly use the wrong term when describing the central node even when their understanding of the central node is correct.
3. *Authoritative:* Instructional landmarks form around central nodes which were taught in an axiomatic manner: within a specific context, the rules imposed by the central node are assumed to be of the highest priority. Due to this assertion, students grant these structures an enormous amount of trust, rarely questioning them. The reliable nature of the central node also allows students to confidently and repetitively cite the central node to demonstrate the validity of their own arguments.
4. *Orientation:* When exploring the cognitive space around a landmark, students will use the central node to orient themselves as they attempt to determine the range of acceptable solutions and weed out irrelevant ideas. Before brainstorming, students will try to verify that the problem space is within the central node's conceptual boundaries. Once confirmed, they branch outwards from the central node, working through related concepts while maintaining their view of the central node. The students may reiterate the central node during the cognitive exploration to assure it has not been neglected, and if they get lost or become unsure, they will try to reestablish their view of the central node before continuing.
5. *Conflict Resolution:* Students will measure potential solutions against the central node to determine if the suggested answers are acceptable; in cases where multiple instructional landmarks are relevant, the rules of all visible central nodes will be applied. If the solutions disagree with the postulates of any relevant central node, they must be relinquished (even if the solution is supported by the students' intuition). When multiple ideas clash, preference will be given to whichever best aligns with the nearby landmarks. If the students fail to discover a solution which meets these requirements, they will abandon the search rather than suggest an answer which knowingly conflicts with the central node.

Some landmarks exhibited certain traits more strongly than others, and in some cases did not exhibit a trait at all (though this was usually because the interview did not provide an opportunity for the trait to be demonstrated). During our observations, we noted three distinct instructional landmarks built around the central nodes: isolated systems, frictionless environments, and the law of inertia.

The isolated systems landmark

At the start of the interview, each participant was asked to give a simple description of the laws of conservation of energy and conservation of angular momentum. These concepts were covered as part of the Introductory Physics curricula and are fundamental to describing the Coriolis force. As part of their explanations, six of the eleven participants stated that these conservation laws were only applicable in isolated systems. The language of

isolation was not prompted by the interviewer, yet it was included by more than half of the participants, sometimes repeatedly. The repetitiveness of the statement indicated that the participants viewed the rule as extremely important, one that must not be neglected when interacting with any conservation problem. The participants were practicing a routine of delineation which is taught to every introductory physics student; it is imperative to clarify the boundary of your system at the start of most physics problems. Without this step, it becomes impossible to know which rules or precepts will apply to which objects.

Our team was unable to resolve the finer details of this landmark, primarily because the conceptual approach did not incorporate scenarios in which the isolated system of the earth is intruded upon by outside forces. Without those conflicts, there was no reason for the students to utilize the landmark beyond its initial mentioning when explaining the general rules of the conservation laws. Further study would be necessary to confidently identify the internal structure of this landmark, explore other contexts in which the landmark might be cued, and determine the manner in which students rely upon it during conceptual problem-solving.

The frictionless environments landmark

Our conceptual approach, like many thought experiments in physics, made use of an idealized frictionless surface. The participants were familiar with frictionless surfaces as they play an integral role in Introductory Physics. Throughout the intervention, several participants regularly stopped to verify with the instructor that the frictionless environment was still in effect, asking questions like "You said it's frictionless, right?" for clarification. As the participants began to vocalize their own predictions, they commonly cited the frictionless environment before they offered their answer. This manifested in statements like "Because there's no friction, there's not going to be a force that inhibits the motion," and "With the planet being frictionless, the rotation underneath shouldn't matter." This habitual reiteration seemed to a) ensure that the frictionless state was not being neglected or forgotten and b) lend credence to their proposals by showing that they were obeying the rules of the scenario.

It was clear that the participants were treating the impositions of the frictionless state as an essential component of the problem-solving process, but the greatest utilization of the landmark came when the students realized that their current intuition was at odds with the frictionless assumption. The students would immediately abandon their idea and search for an alternative that would adhere to the frictionless ruleset:

> Interviewer: *Why would the puck be moving…?*
> Student: *Because the earth is rotating … and because the puck is on the earth... Actually, if we're still negating friction, I would say the puck still is in the same stationary spot.*

With very little pushback, the participants discarded ideas that were incongruent with what they had been taught about frictionless surfaces. These real-time corrections exemplify one of the primary functions of instructional landmarks: because the rules associated with each landmark can be reliably assumed to be true within a conceptual space, they can serve as a litmus test for detecting flawed ideas or uncovering contradictions. Interestingly, the frictionless landmark encompasses a ruleset that does not exist in the real world, but the usefulness of an instructional landmark is specific to the problem-solving contexts in which it can be applied. The students appeared to have a great deal of experience navigating using the frictionless landmark, and we predict that the Introductory Physics classroom would be a perfect environment for exploring students' use of the frictionless landmark in greater detail.

The inertia landmark

Throughout the interview, the participants were asked to make predictions about the motion of a puck subjected to a variety of initial conditions. Within these predictions, the participants expected the puck to move if it was pushed and to remain stationary otherwise. At this stage in their instruction, the participants were well acquainted with kinetic physics problems: a significant amount of the introductory curriculum involves enumerating and analyzing the forces acting on an object in order to calculate the resultant motion. We refer to the structure which arises from these practices as the "inertia landmark," although the central node of this landmark had a far weaker association with proper terminology than any other observed landmark. In fact, across all eleven students, not one used the word "inertia" when predicting the motion of the puck (even though they were using the concept to inform their predictions). Despite the weaker jargon, the landmark still proved decisively useful: the students tended to vocalize which forces were (or weren't) present as they started to formulate their predictions, saying things like "there's just gravity pointing down, there's no friction keeping it in place," and "there's no force that is changing where the puck is, other than gravity and the normal force." Even though the word "inertia" wasn't being offered as a part of these propositions, it was clear that the students had formed a habit of enumerating forces as a preliminary step when predicting motion during their introductory physics education.

What's more, this structure appears to have been refined further in the students who had completed Classical Mechanics: three of the advanced students mentioned the term "inertia" when centrifugal forces came up in their discussions. Interestingly, the inertia mentioned in these contexts activates the same landmark as before: the students recognized that a state of motion will remain unchanged according to an inertial observer unless acted upon. The strong contextual association of inertia with the centrifugal force (which is covered in Classical Mechanics but not Introductory Physics) demonstrates that the connection has been developed further during the advanced instruction; the same conceptual framework that applied in kinetics is now relevant in the new territory of inertial forces. To put it another way, the conceptual landscape from which the inertia landmark was visible had been increased as a direct result of additional instruction. This is a prime example of the continuous nature of knowledge as it is refined from a naive state to expertise: existing knowledge elements and structures are repurposed and expanded to facilitate complex understanding and enable more advanced problem-solving.

Discussion

All three landmarks had a strong central conceptual node, though the association of that node to specific terminology or neighboring concepts varied. The connections displayed by all three landmarks bear a significant resemblance to traditional instruction methods and practices, suggesting that the refinement of these structures rely on student-teacher interactions. These landmarks occupy an elevated status in the students' minds, where they are given priority over other intuitive or instinctual knowledge. Once built, the landmarks serve the students during conceptual problem solving, providing a yardstick with which the students can measure possible solutions, eliminate erroneous suggestions, or differentiate among competing hypotheses. The landmarks display a wide range of applications which vary in specificity from broader physics topics to specific problem-solving scenarios.

Given the similarity in traits between the trends documented here, the construct of instructional landmarks could provide education researchers with an interesting perspective from which we can deconstruct and analyze intermediate knowledge structures in physics learners. The three landmarks documented here are merely those which were relevant to discussions about the Coriolis force and are not at all a comprehensive list. We expect to find similar landmarks built on other conceptual nodes throughout physics. The nodes will most likely be those which have high experimental confirmation (which are taught in an axiomatic way) or wide-reaching conceptual utility (such as idealizations or simplifications). The high degree to which context determines activation will mean that instructional landmarks will most easily be identified by examining students' cognitive decision-making within specific conceptual neighborhoods. Instructional landmarks should also develop into more refined models as the students pursue deeper and more complex guidance from physics experts throughout their formal education. Ultimately, these instructional landmarks could prove to be a precursor to larger, more systematized structures that provide support across domains for experts.

Describing and investigating intermediate knowledge structures such as instructional landmarks will be a critical step in advancing toward a computational model for conceptual physics understanding. Expanding the vocabulary for describing intermediate structures will not only empower the communication between students and teachers, but among educational researchers as well. The intermediary stages that exist between novices and experts are among the most crucial to understand, as they have the potential to redefine priorities and revolutionize strategies within classrooms, workspaces, and academic communities.

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In Pursuit of Creativity in *Minecraft*: A Mixed-Method Approach

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Abstract: Despite *Minecraft*'s incredible popularity, we know very little about how the game might enable creativity. To assess and support the creativity of the structures that players create in *Minecraft*, we need to understand how Minecrafters describe creativity in their communities, and how similar or different those descriptions match the creativity literature. In this study, we used a modified rubric for creativity and investigated if we could find evidence for this rubric in how *Minecraft* builds are being evaluated in YouTube. We also used natural language processing (NLP) to develop automatic coding algorithms for future use. Insights here would inform the literature, research, and educational practices of creativity.

Introduction

Creativity is one of the essential skills for success in life in the 21st-century (Gray, 2016; Glaveanu et al., 2020). In our ever-changing world, we need people to think, feel, and act creatively to solve new or unexpected problems (Resnick, 2018). Since the beginning of the COVID-19 pandemic, creativity has been quintessential to designing effective vaccines (e.g., Tan et al., 2021) and sustaining economic infrastructures. For instance, restaurants, schools, and businesses have had to come up with creative means to remain open. Because creativity is valuable to society, attention has been placed on understanding the various ways creativity manifests in everyday life, the so-called *little-c* creativity (Kaufman & Beghetto, 2009; Richards, 2010)—the focus of this study. To assess little-c creativity, researchers use divergent thinking to examine creative thinking or creative potentials (Runco & Acar, 2012). Guilford (1956) operationalized divergent thinking using its four facets: *flexibility* (e.g., the number of categories or themes used when solving a problem or the ability to come up with relevant ideas from different categories or themes); *fluency* (the ability to produce a large number of relevant ideas); *originality* (the ability to produce statistically rare ideas); and *elaboration* (the ability to implement and expand on an idea in detail and high quality).

One promising medium to assess and enhance creativity is video games (e.g., Rahimi & Shute, 2021a; Shute & Rahimi, 2021). This is because video games, in their ubiquity, reach broad audiences all around the world (Rahimi & Shute, 2021). Through the often-repeated practices, people obtain creative skills that may transfer to other parts of life, thus enhancing their overall creativity in life (Green & Kaufman, 2015). Well-designed video games may enable people to practice being creative (Rahimi & Shute, 2021b). To support creativity in video games, one must first accurately assess it, however, assessing creativity is challenging. For instance, assessing creativity could be subjectively in the eyes of the beholder. Some researchers have even suggested we need to drop the idea of objectively assessing creativity (Amabile, 1996). However, others have used new assessment techniques such as stealth assessment to objectively (i.e., automatically) assess creativity (Shute & Rahimi, 2021). Stealth assessment uses log files generated in an immersive environment (e.g., digital games) to make inferences about learners' level of competency on the skill at hand (e.g., creativity). Before a stealth assessment is designed and embedded in a digital game environment, it is essential to find appropriate indicators in the assessment or learning environment (e.g., a digital game) to provide evidence for the competency of interest (e.g., creativity).

One of the most popular games of all time is *Minecraft* (Gilbert, 2018). *Minecraft* has shown promising results in improving people's creativity (e.g., Blanco-Herrera et al., 2019). *Minecraft* includes five modes of gameplay: creative, survival, adventure, spectator, and hardcore. In the creative mode, players usually create various structures (e.g., a recreation of real-world buildings, creating fantasy worlds). These structures has been showcased online via various platforms such as YouTube which consistently ranks *Minecraft* as one of the most popular terms searched on the platform globally (Hardwick, 2020). In fact, others have fruitfully leveraged YouTube to examine *Minecraft* productions (Walker et al., 2019) to find out how they are represented and constructed at scale. Therefore, YouTube content about *Minecraft* has a lot of potential for creativity researchers to investigate how creativity is manifested in this video game.

To assess and support the creativity of the structures that players create in *Minecraft*, we need to understand how Minecrafters describe creativity in their communities and how similar or different those descriptions are compared to the classical creativity definitions in the literature. Among the YouTube videos about *Minecraft* are some videos created to showcase and evaluate top *Minecraft* constructions created by others that

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could be classified as creative (e.g., top 10 constructions in *Minecraft*). These videos usually have a voice-over describing why those 10 builds, for example, are among the top *Minecraft* constructions. The evaluators' descriptions could potentially include the language used to describe creativity discussed in literature. In this study, we will focus on analyzing the evaluative videos' transcripts to address the following research questions:

1) *To what extent the YouTube-based Minecraft evaluators' comments are consistent with our rubric of creativity (see Table 1; adapted from Rahimi, 2020)?*
2) *Are there new facets of creativity emerging in how Minecraft content evaluators describe creative structures on YouTube?*

Insights here would extend our understanding about the ways creativity manifests in online, sandbox video games such as *Minecraft*; thus, enhance learning-interventions and assessment of creativity in the future.

Method

The current study uses a combination of traditional deductive and inductive qualitative coding (Ravitch & Carl, 2019) and natural language processing (NLP) to examine the transcripts of a set of evaluative *Minecraft* videos hosted on YouTube. We specifically looked for patterns of common descriptions of creative constructions in the video transcripts and categorized them into the seven categories defined in Table 1. We also looked for new emerging categories if any.

Table 1
The Initial Codes for Creativity in Minecraft

Code	Description
Elaboration	The amount of detail. Any time the evaluator remarks on a Minecraft build in terms of the level of detail regarding the materials, mechanics.
Originality	How rare is the building? Any time the evaluator refers to the construction being unique, rare, or states something similar referring to the building being novel.
Aesthetics	Is it aesthetically pleasing? Well-thought-out designs, symmetrical elements, great choice of color?
Surprise	Was there any sense of surprise in the evaluator's narration? If the narrator was amazed, impressed, wowed.
Humor	Was there any laughter in the evaluator's narration? This the evaluator used words such as "funny" or even laughed like "hahahah" or "hilarious"
Complexity	refers to ideas from different categories. If the narrator referred to Variation of shapes, colors. Combining different elements in the building.
Novel use of materials	If the narrator refers to the use of a material in an unusual way.

Selection of videos

To find the most appropriate YouTube videos, we first consulted with two *Minecraft* experts (with more than three years of experience in *Minecraft*), and then we came up with appropriate search terms and video selection criteria. The search terms included "Minecraft builds" "top Minecraft buildings" "best Minecraft constructions" "top ten" "top five" "Minecraft" and "creative." Our search terms and inclusion criteria yielded thousands of results on YouTube. After several iterations, we developed the criteria to only include videos that had narrations. In addition, we included videos evaluating *Minecraft* builds and excluded videos about competitions or about the other *Minecraft* modes (e.g., survival). With the criteria, each author created a list of videos with the YouTube links they found. After individual screening and consulting with our *Minecraft* experts, we collectively selected a sample of 61 videos. Then, three authors went through an additional screening to determine the duplicates and apply the inclusion/exclusion criteria until 100% consensus was reached. The final data set included a collection of 36 videos (about 360 unique builds in our analysis). Next, we briefly explain how we extracted the transcripts.

Extracting the transcripts

Using YouTube's publicly accessible application program interface (API), we wrote a code to read the YouTube URLs from a Google spreadsheet, extract each video's transcript, and generate a dataset with all the transcripts

for each video in it. The variables in that dataset included: video ID, caption (as they would appear on the screen), time stamp, and duration for each caption. Our final dataset included 14,860 lines of caption.

Coding process

For this study, which is a work-in-progress, we chose the first two videos in our dataset (20 builds), created three separate spreadsheets for each of the authors, and applied the codes in Table 1 to this unit of analysis. Codes were applied deductively to the transcripts. We also inductively reasoned on parts of the transcripts that could be coded as a new category but were not captured in our existing codebook. In doing this we identified themes that were then consolidated into a formal code (see Table 2). Codes were not mutually exclusive and could co-occur in each excerpt. In the first round of coding, three authors independently coded a subset of the transcripts and met to compare and resolve code application disagreements until 100% consensus was reached. To get a sense of code distribution for each build and across the entire sample we generated descriptive statistics in the form of frequency counts per code. In addition, we invited another author, who has expertise in learning analytics to help us understand and focus on connecting human codes with NLP and machine learning classification algorithms. Developing an NLP model can help us automatically code transcripts of similar videos in the future at scale.

Results

In the process of coding, we developed two new codes: (1) *effort* referring to how much effort it seemed a build took to be created. For example, "almost a full year of work was put into bringing this creation to life" was coded as evidence for effort. We found ten incidents for effort in the ten builds we coded; and (2) *realism* which refers to how real the build was in evaluator's view. It is hard to create real-looking constructions using blocks in *Minecraft* because the scales should be accurately estimated, and it takes a lot of detail. Therefore, when a building resembles a real building, the evaluators found it as doing something creative. We found 28 incidents for realism in the ten builds we coded. The rest of the codes' appearance are listed in Table 2. The most frequent codes were elaboration, aesthetics, surprise, and complexity. We have not found any explicit statements to be coded for humor in the ten builds that we coded. However, it is too soon to decide if we need to drop these codes as we still have about 34 videos to code.

Our preliminary analysis using NLP and machine learning classification algorithms revealed insights about the possibility of automated creativity evaluations. We achieved close to 70% accuracy (using 5-fold CV) to distinguish the sentences that showed evidence of creativity. Similarly, close to 90% accuracy was acquired to categorize the sentences based on the proposed dimensions of creativity. We used a logistic regression algorithm and a multi-label adapted kNN classifier with the term-frequency inverse document-frequency vectorization.

Table 2
The Initial Codes for Creativity in Minecraft

Code	Frequency	Example for the Captions
Elaboration	39	"Wow look at the details" "this is a very dense design"
Originality	15	"I have not seen something like this before" "This is a unique built"
Aesthetics	30	"Wow, this is beautiful, look at the colors!" "Such a symmetrical shape"
Surprise	44	"Wow, this is really unexpected!!" "Can it get even more complicated?"
Humor	0	"Wow, this is funny!" "This looks really hilarious" "Hahahaha this reminded me of…"
Complexity	13	"This is a complex design as the builders combined multiple materials"
Novel use of materials	3	"Look, they used a torch as the eyes of the devil"
Effort	10	"Almost a full year of work was put into bringing this..."
Realism	28	"... a highly detailed recreation of The Lord of the Rings."

Discussion & Conclusion

In this study, we used a modified rubric for creativity and investigated if we could find evidence for this rubric in how *Minecraft* builds are being evaluated in YouTube. Due to lack of time for this proposal, we have so far coded the caption related to 20 builds. We found evidence for most of the codes or sub-facets of the rubrics we used except for humor and novel use of materials. We also found two new codes: effort and realism. These codes are significant because they highlight how platform-specific features shape how creativity manifests itself. In other

words, creativity codes can in many ways be generalized, however, video games and their diverse context may manifest creativity in different terms. Because of our small sample of builds so far (only 20 builds) we cannot make a conclusion about which code has appeared more compared to the other codes. However, it is noticeable how often surprise, elaboration, aesthetics, and realism appeared in the captions from those 20 builds.

Moreover, our NLP analysis and classification algorithms could successfully identify the syntactic and semantic differences among the creativity dimensions. However, the analysis was conducted with a relatively small set of sample sentences for both training and evaluation, which may limit the generalizability of the findings. Hence, we encourage a future focus on expanding the labeled dataset to evaluate the capacities of our algorithms for automated coding.

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International Society of the Learning Sciences

"With statistics, that's supposed to take bias away": Divergent teacher views on engaging students with race in data sets

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Abstract: This study examined what pedagogical potential teachers see in data sets that include race as a variable. Through interviews with 11 secondary teachers, we show a range of views about the role race plays with respect to students' opportunities to engage with data analysis. From analysis of teachers' noticings of pedagogical potential and justifications for what data sets they would prefer in a constrained choice task, we identify areas where the learning sciences can support teacher learning and curriculum design with race-inclusive data sets.

Introduction

Recently, there have been a number of urgings for youth to learn more about data science as part of their K-12 education (e.g., Bargagliotti et al., 2020). Our concern is to explore how teachers whom we anticipate are among the most likely to be enlisted in teaching data science – namely, secondary statistics and mathematics – think about the pedagogical potential of various data sets (Lee & Delaney, 2021). As data sets are already abundant but also being continuously generated, we are examining how teachers judge the suitability and usability of data sets in their teaching. Developing a model of teacher thinking about the pedagogical potential of different data sets could help inform future efforts to design curricula, curate data for pedagogical use, recommend possible uses of data in the classroom, and enhance teacher professional learning experiences. In the early stages of research shared in this paper, our aim has been to explore how teachers think about teaching with data sets that prominently feature race. In the United States, where we are based, race is a complex social construction that is deeply connected to longstanding issues of power, privilege, and injustice. These are topics that the learning sciences, particularly in North America, are actively discussing (Booker & Esmonde, 2016). While our work directly speaks to challenges in the US, we believe it still has implications for other nations as matters of equity and injustice are concerns that transcend geopolitical boundaries. Our primary question in this paper is: What considerations are statistics teachers making regarding matters of race when appraising the pedagogical potential for quantitative data sets?

Theoretical Perspectives

This work is based on the premise that, while popular discourse would suggest otherwise, data are not objective. They are the product of human decisions, subject to their own biases. They are markers of the social world rife with matters of unevenly distributed power, injustice, and oppression. Enthusiasm about what the potential of data science is rooted in "imagined objectivity" of data (Benjamin, 2016).

With respect to race and data, learning scientists have observed important opportunities where teachers can engage students. Philip et al. (2016) proposed the field attend to racial-ideological micro-contestations as a space for conversations about race with data. These are social interactions where the meanings and consequences of race are raised, contested, and negotiated. In Philip et al.'s work, this took the form of dialogue in a class viewing data about movie rentals in different regions of a large, segregated city. Their analysis showed how a specific classroom teacher needed to make immediate decisions on how to respond to the topic of race as it was raised in classroom discussion and was unable to use that moment to navigate students through a potentially powerful discussion involving both data and racial literacies.

This is a challenge noted by other learning scientists. Enyedy & Mukhopadyay (2007) described a design experiment to provide students with culturally-relevant mathematics pedagogy. Students were intimately familiar with inequities represented in the geospatial data that Enyedy & Mukhopadyay brought to a high school classroom such that the utility of the mathematics being taught was unclear. The design experiment made prominent the tensions in goals and norms of their intended culturally-relevant pedagogy and those of their mathematics pedagogy. Reconciling those tensions is complex design and teaching work. Some cases model promising potential new approaches (Rubel et al., 2017). Still, there is much to be examined, especially as it relates to the prospect of high school statistics teachers taking on the work of teaching data science.

Methods

Research Participants

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Eleven high school mathematics and statistics teachers from public, private, charter, and magnet schools were recruited for this exploratory study through existing contacts and snowball sampling. All teachers taught in 'majority minority' schools where White students consisted of less than 50% of the student population. These teachers had an average of 16 years' experience, ranging from 4.5 to 35 years, and some taught other courses (e.g., computer science) or held other professional roles (e.g., coach, administrator). 3 of the 11 identified as teachers of Color, and 5 of the 11 identified as female.

Procedure

Teachers participated in 60-minute interviews that were videorecorded on the Zoom conferencing platform. During the interview, teachers were presented two pairs of publicly provided side-by-side data sets (Figure 1) regarding the same topics. Of the two pairs of data sets presented, one set was on policing and the other set contained technology company employment data. Teachers viewed four data sets in total, and all contained racial variable columns, with some mixing race and ethnicity. Teachers were asked to think aloud and comment on what they noticed when viewing them. Then the interviewer posed a series of questions, designed to target teachers' perceptions of student interest in the data, potential elements of student struggle with or about the data, authentic appearance of the data, and pedagogical affordances of the data. Each viewing session concluded with the teacher's decision and explanation as to which data set they would choose to teach with, and why.

Figure 1. Partial Representations of Policing Data Sets 1 and 2

Data Set 1

Year	Race	Population	Statewide Population (%)	Stops	Disparity Index	Searches
2018	White	3914998	82.76	1177844	0.92	71168
2018	Black	515828	10.9	296065	1.76	26448
2018	Hispanic	139109	2.94	34769	0.77	2933
2018	Asian	80677	1.71	14849	0.56	431
2018	Am. Indian	19168	0.41	2016	0.32	120
2018	Other	60721	1.28	13934	0.71	571
2017	White	3914998	82.76	1189744	0.93	69995
2017	Black	515828	10.9	288851	1.72	25616
2017	Hispanic	139109	2.94	34068	0.75	2904
2017	Asian	80677	1.71	14438	0.55	370
2017	Am. Indian	19168	0.41	2096	0.36	98
2017	Other	60721	1.28	12558	0.63	458
2016	White	3914998	82.76	1212726	0.94	67546

Offense charged	Race: Total	Race: White	Race: Black or African American	Race: American Indian or Alaska Native	Race: Asian
TOTAL	7,710,900	5,319,654	2,115,381	164,430	92,737
Murder and nonnegligent manslaughter	8,957	3,953	4,778	105	94
Rape	18,776	12,794	5,376	267	289
Robbery	66,789	29,025	36,187	676	641
Aggravated assault	298,040	184,527	100,393	6,736	5,078
Burglary	134,542	91,581	39,617	1,590	1,422
Larceny-theft	669,983	448,193	201,086	11,987	7,324
Motor vehicle theft	69,002	44,512	22,305	1,151	818
Arson	6,946	4,938	1,740	137	101
Violent crime	392,562	230,299	146,734	7,784	6,102
Property crime	880,473	589,224	264,748	14,865	9,665

Data analysis

The interviews were transcribed and subject to multiple coding passes, parsed into two analytical phases. The first phase focused upon which data set was selected and why. Here, we analyzed teachers' expressed preferences toward a particular data set, observed when and how teachers referred to race as a rationale for selection (pedagogical or contextual), and identified a set of 12 rationale-based codes across teachers (e.g., "Opportunities for inquiry about race," "Examine a trend over time,"). The second phase examined in what ways teachers conceptualized race when the data sets were presented. Specifically, we explored the degree to which race was framed as a pedagogical concern for students' inquiry of data and learning about contemporary issues of power and injustice. The authors met for joint data review sessions, focusing on what was being discussed in a data set and how social phenomena were being evoked by the teacher in relation to their learning goals for students.

Results

How do teachers engage with matters of race in their judgments of data sets?

Teachers varied in the extent to which they centered race in their noticings and its role in student learning. Some articulated the importance for students to learn about contemporary social issues while others expressed pedagogical affordances provided by race (for example, the ability to make statistical comparisons by racial subgroupings). Others expressed hesitation or resistance toward the centrality of race within the data. The following sections represent teachers' divergent responses toward race and pedagogical potential of data sets.

Race as essential to consider

For three teachers (one Black, one Latinx, and one White), their final choice of a data set was supported by their perception that data could better enable race to be a discussion topic informed. For the two teachers of color, this appeared for only the policing data. For the other teacher, who is White, it appeared across both policing and employment data. As was the case across teachers' judgments about data sets, there was much complexity in what

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pedagogical value was recognized. To illustrate, we provide an excerpt from Gavin, a Black male teacher in an urban school, who elaborated upon his preference for selecting policing data set 2:

> "So, if I had to pick one, I think once again, the one on the right [data set 2] is just more interesting. I think it's more mature, and I would definitely do it with a mature set of students. But I think the conversation doesn't have to be White versus Black. I think it's important that we do talk about Native Americans, that we talk about Hispanics, that we talk about Asians. I feel like our society is so Black and White sometimes that's what we focus on." (Gavin, interview transcript, p. 22-23)

Key aspects of this portion of Gavin's comment that we noted include: the data pertained to a topic that would be more interesting to students, (perhaps relatedly) they engaged topics requiring certain levels of maturity, and that they would support the teacher's desire to have students develop expansive, rather than dichotomous, recognitions of how race is present in society. Gavin further expanded on his preference for data set 2 with:

> "But here, we have a diverse amount of crimes, we have a lot of data about different groups of people, and, murder, rape, prostitution, sex offenses, we don't talk about these things, but these things are real. And when are you ever going to talk to kids about these things?" (Gavin, interview transcript, p. 23)

Here, we noted that Gavin was attending to breadth and diversity in the data. The data had exploratory possibilities with numerous possible categorical values to examine. Being under-engaged as a topic ("we don't talk about these things") and relevant "these things are real" also factored into Gavin's justification. As will be illustrate below, this quality and its use for teaching varied. Several other teachers in our study cited the association between race and crime as a reason to *avoid* data set 2 because such topics featured prominently could unknowingly trigger some students or reinforce specific negative discourses regarding race and crime. However, with teachers like Gavin in mind, we could envision that valued data sets would have a breadth of categories to consider, would not shy away from complex social concerns, and might be made even more helpful if they were coupled with some recommended analyses and variable selections that Gavin could use with his students to explore and challenge assumptions and narratives that might exist around the topics of race and policing.

Race as a useful variable

While Gavin's statement that data set 2 provided affordances toward necessary classroom discussions about race as a general societal construct, far more teachers in our study (6 of the 11: 2 for policing, 2 for employment, 2 for both) emphasized pedagogical opportunities the race variables provided with respect to data inquiry more than the underlying matters of injustice that can appear in the data. In these teachers' purview, race as a variable might lead students to better query the data and make comparisons between subgroups. The following utterance by Brent (White male teacher) illustrates one such instance:

> I think what you have a great opportunity here to look at running your conditionals two ways. Which is, let's say I have side-by-side pie charts. Do I want to compare White people to non-White people? Or, do I want to compare the ethnicity breakdown of murder versus, what's a non-violent crime...property crime? … So, I think in that way, there's two different types of questions you could ask. You could compare one ethnicity to another, versus comparing one crime to another." (Brent, interview transcript, p. 19-20).

As Brent describes, the provision of two categorical variables (race and offense) affords students the opportunity to examine conditional variables, data displays of conditional variables, and appropriate graphical representations of conditional variables. In addition, a deeper investigation could be conducted by "running your conditional two ways," permitting students to learn various strategies and interpretations of data arrangements in association to statistical questions. Brent seemed comfortable seeing the ways in which common statistics topics could be engaged, yet this utterance did not show active consideration of the challenging history and the emotional dimensions of race. Teacher educators may see this as illustrating a need to help Brent and others learn how to recognize matters of injustice and how to thoughtfully and sensitively engage students so that they can see statistical ideas without disconnecting from the more complex social injustices reflected in the data.

Race as too sensitive to be paired with student learning

One other judgment of racial variables came in the form of anticipating students' sensitivities. Two teachers described words within data sets, or more broadly, the presence of race paired with offenses in policing data set 2, with negative valence as they envisioned how their particular students might feel about data. Acknowledging race was something teachers cold envision as being too uncomfortable. For example, when Iris (White female teacher) was asked where her students would struggle, she explained:

> "Every person has a different story and perspective and background, and is maybe triggered by this information more than others. When you're talking about sensitive topics like this, I think that people are going to be triggered. How do you come at this from an unbiased perspective? Biased. I think your bias...does bias have an effect on how we look at data? So yeah, can you totally take your bias out? With statistics, that's supposed to take bias away, you're just looking at numbers. But is that something we need to look at...this could be sensitive to a person or group of people." (Iris, interview transcript, p.19)

Iris suspected that "people are going to be triggered" with the policing data. Iris's utterance and justification reflects tensions regarding bias and objectivity in our thinking about data. According to Iris, data – "just looking at numbers" - should take bias away. At the same time, Iris is aware human bias does exist. Her statement seems to suggest that the bias may not be within the data but rather in the interpreter. Recall that our perspective is that data are social constructions that are made by humans with biases. This view that data are objective may be the type of issue that needs to be explored more deeply with teachers. Seeing bias as residing only on the side of the human who views data runs the risk of delegitimizing the experiences and concerns of students and limit teacher supported classroom examination of why the data look the way they do, both in their creation and in what may be inferred. At the same time, productively engaging with data (while also recognizing that bias exists within data) is another matter that teachers need support to explore.

Discussion

While it is a modestly-sized study, this examination of teacher judgments about data sets where race is a prominent variable suggests there is visible variation in how teachers think about race and data. The variation among even our small sample of teachers regarding if and how race should be engaged in data sets invites questions about how to best support teacher growth – through professional learning and with designed curriculum.

Notably, the teachers in this study were attending to both their conjectures of data science instruction and perceptions of race within data sets simultaneously. Our findings do not yet take teachers' uncertainties of data science (Manz & Suárez, 2018) into consideration. Future analyses will develop a more nuanced coding scheme that considers the interaction of race, data science, and teachers' inherent uncertainty when making in-the-moment judgments. Yet, our work thus far offers preliminary insights to how teachers consider race in data sets in relation to their students' opportunities to learn. In the learning sciences, important learning interactions such as racial-ideological micro-contestations are beginning to be recognized. The work here may help us identify means to ensure that teachers can make such moments thoughtful and informative about the nature of data and the social world of which they are a part.

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The Emotional and Corporeal Dimensions of Belonging to STEM Education

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Abstract: This paper explores the politics of belonging in STEM education contexts by foregrounding emotions as an analytical lens. We show how political projects of belonging are constructed/resisted *affectively* in two different STEM postsecondary contexts, within a technical college and a university in Canada. Belonging is examined along two interrelated dimensions: having the 'right' kind of body and emoting in the 'right' kind of way. Those dimensions reveal subtle and pervasive practices of exclusion and marginalization as science students experience their belonging to STEM fields and to Canada. We discuss how a multi-scalar analysis of bodies and emotions in relation to various spaces and various social relations could reveal more layered understandings of how bodies become distributed/valued within STEM fields.

Theoretical background and purpose

Research on emotions in science education have been garnering increased attention (e.g., Bellocchi et al., 2016). This is in response to a cognitivist bias in science education, that has been attributed to "a long-standing Newtonian–Cartesian tradition of separation, prizing apart the mind and body, divorcing and polarizing reason from feeling" (Alsop & Watts, 2003, p. 1044). Various methodological, theoretical, and empirical approaches have highlighted how emotions are part and parcel of social practices of teaching and learning in science learning environments (e.g., Tobin & Llena, 2014). For instance, inquiries into classroom's emotional climate take situated and sociocultural perspectives when studying emotions and as such "overcome the limitations of examining emotions as individual psychological constructs" (Tan, 2013, p. 553) that could naturalize emotions and fixate learning within individuals. Other similar research traditions have examined how emotions are not just passive impulses that happen to us but are "fabrications manufactured and maintained through corporeal and discursive means" (Butler cited in Chubbuck & Zembylas, 2008, p. 279). Drawing on poststructuralist thought, researchers have argued that analyses of emotions from socio-cultural traditions have been limited to micro-processes of interaction without addressing how emotions are discursively and materially constituted and constituting. Focusing on the performative nature of emotions (Zembylas, 2015), responds to calls from within the learning sciences to develop "theories of power, to explain how power circulates in contexts, how it aligns with structural oppression, how it challenges oppression, how it is subtle, and explicit, pervasive, and yet often invisible" (Esmonde & Booker, 2017, p. 2).

Notions of belonging elicit emotional attachments to collectives and imaginaries and are especially relevant when considering institutional practices of exclusion and marginalization within STEM education (Nxumalo & Gitari, 2021). Avraamidou (2019) argued that emotions could be a valuable lens for studying experiences of inequalities and othering and what it means to 'become' a science person in relation to various systems of oppression and recognition. This paper explores the politics of belonging in STEM education contexts by foregrounding emotions as an analytical lens. We demonstrate how political projects of belonging are constructed/resisted *affectively* in two different STEM postsecondary contexts. We examine emotionality in students' lived experiences not only as *reflective* of the "dirty work of boundary maintenance" (Crowley, 1999) but as *constitutive* of how particular collectivities are made to belong. We draw from Sara Ahmed's work who looks at what emotions *do* and less on what they *mean*. A performative view of emotions examines how emotions work "through signs and on bodies to materialize the surfaces and boundaries that are lived as worlds" (Ahmed, 2013, p. 191).

Inspired by Sara Ahmed's various writings including but not limited to the *Cultural Politics of Emotions* (2013), this paper attempts to release belonging from its self-referential associations and positive undertones (sense of belonging and feeling 'at home') to consider the political landscapes of belonging (see also Yuval-Davis, 2006) as they are formed and reformed through daily affects and emotions experienced by Black, Indigenous and People of Colour (BIPOC) in postsecondary STEM programmes. 'Positive' emotions are not necessarily positive, as they might be connected to narrow conceptions of happiness (Ahmed, 2008) and lives of normativity (Berlant, 2011), inherited from within Western, colonial, capitalist, middle class societies. This helps to situate the

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micropolitics (of lived/bodily experiences of racialized bodies) in relation to macropolitics (of racialized and racializing systems) (Mulcahy & Healy, 2021). Political views on belonging allow us to explore how STEM educational contexts extend the "political and affective economies of normativity" with the "production of a collective will to imagine oneself as a solitary agent who can and must live the good life [read also happy life, Ahmed, 2008] promised by capitalist culture" (Berlant, 2011, p. 167). This has particular significance to contexts of postsecondary STEM, that prepare future workers to enter in relationship with the economy and places of labour and livelihood.

Methodology

To explore the corporeal and emotional dimensions of belonging we bring together two data sets; one is from an ethnographic study of a college microbiology laboratory at a Canadian technical college and another data set draws from BIPOC students' responses to an exploratory survey of their experiences in postsecondary STEM university programmes in a university setting in Western Canada. The ethnographic study comes from the first author's doctoral research whereby notions of belonging to Canada via STEM education became salient through her various interactions with international students from India. The other data draws from an exploratory survey of BIPOC students' lived experiences navigating STEM institutional structures, the first author's postdoctoral work alongside the second author. Together, these data sets allow us to view how students' emotions work "to create the very distinction between the inside and the outside" (Ahmed, 2004, p. 28), vis-à-vis STEM as a disciplinary space and STEM as connected to nation-belonging.

Data sources from the ethnographic study included video recordings accompanied by fieldnotes of laboratory practices (e.g., students testing the effect of different products on bacterial growth), semi-structured interviews with the students at the beginning of the course related to their experiences coming from India and living in Canada and ongoing discussions with the instructor about their emerging observations. For the purposes of this paper, we only draw on those data sources to focus on data excerpts where themes of belonging were particularly apparent. For our analysis, we combined thematic coding with collage as a data analysis practice (Morgaine, 2018) involving a juxtaposition of fragments of data, arranging and rearranging them together to enable an analysis of the micropolitics (Bazzul, 2017) of belonging in relation to different scales (to STEM as a belonging to discipline or STEM as belonging to a nation) and in relation to students' actual practices in the lab at the college level alongside students' reflections on their general STEM experiences at the university level. Hence, this study takes a space-sensitive approach to the study of intersecting social relations to examine how "different aspects of belonging such as class (socio-economic), gender and race (body or corporeal aspects), ethnicity, and ethical/political value systems (representative and performative aspects) assemble in certain locations and situations" (Youkhana, 2015, p. 15-16) and how emotions work to constitute and reconstitute those assemblages.

Discussion of findings

Our analysis of the data from the two data sets enabled us to examine political work of belonging being exhibited along two interrelated dimensions: Belonging as having the 'right' kind of body and belonging as emoting in the 'right' kind of way. We present those two dimensions separately to examine how political projects of belonging circulate and are enacted/resisted through bodies and emotions.

Belonging as having the 'right' kind of body

Most of the students in the college microbiology lab were international students from India. In various interviews with students, they discussed their experiences of being channeled into this program by college recruiters and agents back in India as their only entry ticket to Canada. Intersecting with students' ethnic and immigration status, another noteworthy observation was that women formed the majority of students in this lab, constituting 17 out of 18 students. Nived, the instructor, commented how this is not surprising since "most students will become biotechnicians, following protocols". This comment demonstrates how the program extends women as docile and compliant, doing what they are told, by 'following' protocols. In this sense, what it means to have a body in this particular context is configured along racial and gendered lines, reducing bodies to "their working parts" (Kimmerer, 2013, p. 49) through tedious and repetitive lab practices and an overemphasis on performing the 'right' techniques (as was evident through observations of pedagogies of the lab). STEM college programmes along with formal and informal channels of migration contribute to differential valuations of bodies, perpetuating gendered and racialized allocations of labour (Vora, 2015) for Western economic gains. This helps to complicate what it means to belong to STEM beyond acquiring the right bodily dispositions of a biotechnician to consider how learning/belonging in this context are situated within larger gendered, racial, and capitalist formations. We

juxtapose this analysis with an undergraduate student response on a survey describing his experiences of marginalization and discrimination as a South Asian inside a university lab setting:

> Often in science labs, sometimes when paired with people who are Caucasian, I have experienced lab partners who would disregard my physical being and *turn towards other white people* with whom they prefer to talk with. I don't think that was an intentional racist instance, I just have found that often when I am paired with Caucasian males in particular, that they *don't know how to converse with me, want to converse with me or know how to relate to me*. Feel somewhat lesser than them.

In this case, we witness how practices of exclusion take place through bodily orientations that reinforce the idea that to belong to the lab, one needs to have the 'right' kind of body (in this case, a Caucasian male body). Those self-reflective and narrated experiences of marginalization could be equated with the subtle and pervasive practices of inclusion/exclusion, evident in the context of the college microbiology lab. These analytic examples gesture at how material places (the college lab vs. the university lab) intersects with social relations to produce the ways that belonging to STEM is encountered/experienced. They both center belonging through corporeality as particular instances of having the right kind of body in STEM places, though each data segment is more nuanced in how different STEM bodies become constituted as 'less'; this might happen in the moment (in transient bodily orientations of turning towards/ away) or in more pervasive and infrastructural arrangements (with the prevalence of particular bodies in specific places).

Belonging as "emoting in the right kind of way"

When students were working in the lab, they often turned to each other or to their instructor to discuss their plans for working and living in Canada. Hence, accompanying their ordinary lab practices, appears to be a spectral presence (with its associated fears, anticipation, anxieties, and hope) of wanting to belong with Canada through their labour in STEM. Such 'positive' and hopeful outlooks for the future work to further normalize precarious conditions (Veldstra, 2020) faced by international students as they experience their belonging to Canada. Asked to project themselves five years into the future, many mentioned having emotional and financial stability in Canada:

> Anushka: After 5 years, either I am working in my pharmaceutical industry, or I will clear my pharmacy test and become a pharmacist here, *I don't want to go back to India.* In between I will get married and have 2 babies. I just need the perfect husband for me.
> Nisha (jokingly): Don't worry, we will *find a Canadian husband* for you.

Careful not to downplay international students' visceral dreams and hopes for a better future, for Anushka, STEM was a pathway for belonging to Canada. However, becomes quickly gendered and racialized through becoming a wife to a "Canadian" man and mother. Juxtaposing the positive with the negative, emoting "wrongly" works to reproduce exclusionary boundaries, as evident in a student's response in the survey data:

> I am constantly seen as *an angry person when I am outspoken about my mistreatment*. Sometimes it feels as though my value is to entertain white folks in STEM, something to make fun of, something to tokenize.

This student self-identifies as Korean and, in this statement, we could see how anger turns to a technology of racism (Zembylas, 2015) that produces bodies in opposition to other 'composed' bodies, the white folks in STEM. But also, anger serves to disturb and challenge the "ordinary affects of racialization" (Mulcahy & Healy, 2021). Being an angry person is likened to a "kill-joy" (Ahmed, 2008), someone who disturbs belonging to/of whiteness in STEM education contexts. Reading students' practices in the microbiology lab alongside students' responses to the survey, we notice how students in STEM "acquire certain subject positions based on regulatory norms of social and political affect" (Zembylas, 2016, p. 206), that delimit/resist imaginaries of belonging at multiple intersecting scales, spaces of STEM education and Canada.

Conclusion and implications

Attending to the *work* of emotions enables an appreciation of how constructs of belonging conceal non-innocent relations with possible implications for justice-oriented efforts in STEM education. Our study also showed the possible merits in analytically attending to the affective and corporeal aspects of belonging within situated practices and discourses in STEM contexts to examine how micro-meso-and macro levels of analysis are co-

constituted (Philip & Gupta, 2020) and to better highlight and along with that, imagine pedagogical possibilities within microlevel interactions, where agentic individuals "improvise with ideologies and practices that may otherwise appear static and inevitable" (p. 196). This is an area that we hope to keep expanding on. Our analysis also showed how a multi-scalar analysis of bodies and emotions in relation to various spaces and various social relations might reveal more layered understandings of how bodies become distributed/valued within STEM fields.

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Using Design-Based Research in a computational thinking and programming course with Pedagogy students

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Abstract: In this paper we approach the importance of Design Based Research (DBR) as a tool for redesigning learning architectures in extension courses aimed at the continuing education of Basic Education teachers in order to improve professional learning and promote the development of Technology, Pedagogy and Content Knowledge (TPCK) and its subdomains. Therefore, we present a qualitative research carried out during an extension course on computational thinking and programming language aimed at future teachers who will work in the early years of Basic Education promoted by the Federal University of Alagoas (Brazil). The research results showed that the DBR made it possible to redesign the course activities in a collaborative way, observing the participants' difficulties, which led to the beginning of the development of the TPCK by the researched group, requiring that skills in computational thinking and programming language evolve to that TPCK is fully developed and manifested in pedagogical practices.

I. Introduction

The Common National Curriculum Base (2018), BNCC, a new guiding document for Brazilian Basic Education, places as one of its general competences the insertion of digital culture in schools, as well as citing the use of technologies in the specific competences of the different curriculum components, teaching and learning process. In the characterization of the area of Mathematics and its Technologies, BNCC recommends for Basic Education that topics such as robotics, automation, artificial intelligence, programming and digital games be addressed.

Although the BNCC brings these curricular innovations related to technology and its themes, there are other factors that directly influence the implementation of these proposals in Brazilian public schools, such as the lack of equipment and teaching resources and lack of teacher training to apply the proposal in your classes. This issue is basically due to the lack of more effective public policies in relation to the insertion of technology in public schools of Basic Education, which implies a huge investment and generally the justification is that the existing resources are not sufficient, and in view of that, little is invested, which does not generate large-scale effects. On the other hand, it is necessary to reflect on the didactic resources that are used in these technological proposals aimed at Education in Brazil. In general, we have few technological didactic resources for teaching programming language that are genuinely Brazilian, that is, that are developed for the profile of Brazilian students and teachers, and thus, adapted foreign didactic resources are used. Thus, it is necessary to invest in software development considering the characteristics of the student and Brazilian education, considering the assumptions of Design Based Research and Learning Sciences - areas that have not yet been consolidated in Brazil as a field of research - which are fundamental to contribute to improve the teaching-learning process of topics such as computational thinking and programming language. Therefore, in this paper we present the results of a research that addresses Design Based Research (DBR) as a tool for redesigning learning architectures in an extension course on computational thinking and programming language aimed at the continuing education of Basic Education teachers of the State of Alagoas, Brazil, to improve professional learning and promote the development of Technology, Pedagogy and Content Knowledge (TPCK) and its subdomains.

II. Preparing teachers to work with technology and the importance of Design Based Research in teacher training courses

It is important to plan the training of Basic Education teachers in Brazil to use technologies in the teaching-learning process and the digital skills and abilities that need to be developed so that they can implement educational proposals in the classroom. It is necessary that the curricula of the Pedagogy and Licentiate Degree courses expand the workload of the subjects focused on the use of technological resources, deepening their approach in order to train teachers on the use of different resources even in their initial teacher training, as in general, in Brazil there is little emphasis on this aspect, and this is reflected in teaching practices. In general, the use of technological resources in the teaching-learning process has been emphasized in continuing education courses or refresher courses, which are often opportunities for many teachers to learn how to handle the resources, as many teachers were unable to develop handling skills when they were attending graduation (due to the short time that the courses devoted to practices with these resources) or they graduated at a time when these resources

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did not exist or were not yet used in the teaching-learning process of public Basic Education schools, therefore, there was no in his initial formation a discipline that addressed technologies in Education.

BNCC (Brasil, 2018) has ten general competencies as pillars to ensure the learning and development of Brazilian students in Basic Education. Among these ten general competences is general competence 5, which concerns digital culture, which is structured around three basic elements: digital literacy, digital literacy and digital fluency. This competency must be developed so that Brazilian students can understand and use digital information and communication technologies in a critical, reflective and ethical way in various social practices to communicate, access and disseminate information, produce knowledge, solve problems and exercise protagonism. However, the insertion of digital culture in the Brazilian school context is not only aimed at students, it also encompasses teachers. The BNCC (Brasil, 2018, p. 17) states that Brazilian teachers should be encouraged to "select, produce, apply and evaluate didactic and technological resources to support the teaching and learning process", integrating technology in their classes, renewing their pedagogical practices, and, in this way, bringing them closer to technological contexts that are part of the daily lives of students.

In this sense, Mishra and Koehler (2006) proposed a theoretical framework called Technology, Pedagogy and Content Knowledge (TPCK) stating that teachers need an integrated knowledge of technology, pedagogy and content to develop professional skills that allow the adoption of activities oriented towards the use of technology in the teaching and learning process of specific content in classes. The authors subdivide the TPCK into three subdomains: knowledge of technology (TK), which concerns knowledge about how to use hardware, software and associated peripherals, knowledge of technology content (TCK) which refers to knowledge about how to use the technology to represent and create content in diverse ways and the knowledge of pedagogy and technology (TPK) which concerns the choice of a technological tool based on the aptitude for the learning activity.

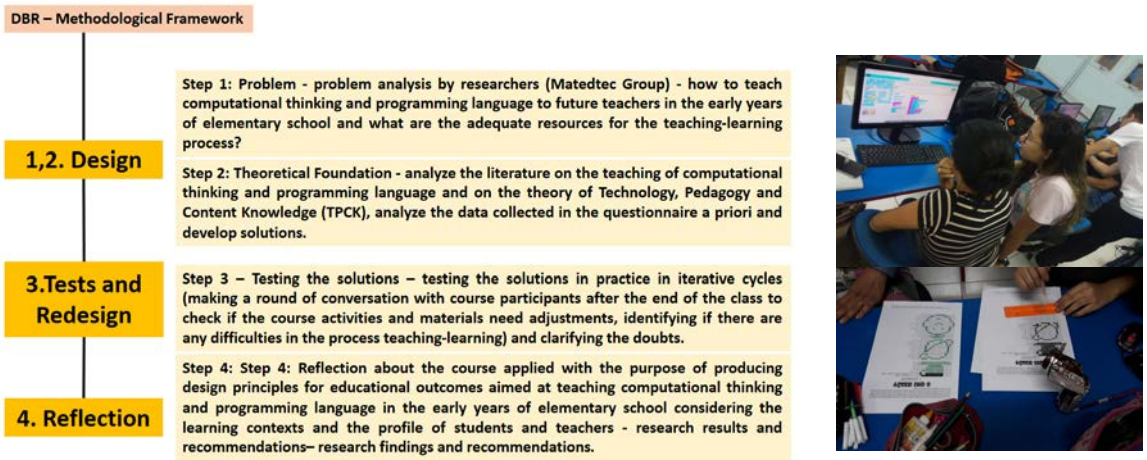
To improve the acquisition of integrated knowledge, Mishra and Koehler (2006) state that teachers must work collaboratively to redesign the curriculum for the TPCK approach, likewise breaking down beliefs and resistances regarding the use of technology in the classroom. Bennison and Goos (2010) also defend this integration with technology for teaching specific content through courses that enable the professional development of teachers, as they improve knowledge, understanding of the use of technological resources in classes and enhance skills. Drijvers (2015) emphasizes the importance of integrating the use of digital tools with activities that use pencil and paper (unplugged) in the teaching-learning process, demonstrating that these resources are complementary and not exclusive, and that neither one overlaps the other. Thus, considering the importance of computational thinking and programming language and its insertion in the early years of Basic Education in Brazil, we held an extension course with the purpose of improving professional learning and promoting the development of Technology, Pedagogy and Content Knowledge (TPCK) and its subdomains (with emphasis on TCK and TPK), enabling teachers in relation to computational thinking and programming language, and for that, we used Design Based Research to configure and redesign the extension course.

Design Based Research (DBR) is still little known and used in Brazil, being an approach that enables educational innovation from collaborative practices considering the needs and problems that teachers point out in their classrooms. There is disagreement regarding how to name the DBR, as there are authors such as Easterday, Lewis and Gerber (2014) who call it a process, Herrington *et al* (2007) claim that the DBR consists of a research approach and Barab and Squire (2004) argues that DBR consists of several approaches. Wang and Hannafin (2005) define Design Based Research as a systematic methodology and flexible aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings. We conclude that the DBR is an approach that implies a process of analysis, design (redesign), development and implementation, which is collaboratively built to trigger a pedagogical solution more suited to the characteristics of subjects and their contexts, contributing to the emergence of theories and design principles for the learning environments of schools, with the classroom being the most common and most used, which may extend to laboratories and maker spaces.

The themes of computational thinking and programming language in Brazilian public schools have always been addressed in a timely manner or through isolated projects, usually with few resources (lack of teaching material such as robotics kits, software, laboratories), but which promote a lot of engagement of the students in the proposed activities, stimulating their interest in participating in the classes. These themes are usually addressed in Mathematics classes because teachers are able to establish a direct relationship with the notions of logic. The computational thinking and programming language gained prominence after the publication of the BNCC (Brasil, 2018) when these themes were recommended to be developed in Basic Education. But, when placing computational thinking in the school context, it is necessary to remind teachers that they will design, apply the activities and select the didactic resources that will be used in pedagogical practices, and for that, teachers must develop skills to deal with the technological resources and also with the concepts that involve computational thinking. This contact with computational thinking should still occur in initial training, but if it

doesn't, continuing education is also a space for it to be developed along with the programming language. In this sense, considering the theoretical bases briefly exposed, we carried out a qualitative research with the purpose of contributing to the initial teacher education in relation to computational thinking and programming language, and for that, we raised the following research question: Which subdomains of TPCK the Will future teachers from the early years working in schools in Maceió (Brazil) be able to develop a course on programming language and computational thinking considering the contributions of DBR as an approach for setting up and redesigning the course based on the needs of the participants? To identify these TPCK subdomains that future teachers could develop, we designed and applied an extension course based on a cycle of DBR that we developed. This research qualitative was carried out during the month of August 2019 through an extension course that was a partnership between the Federal University of Alagoas and the Pedagogy course of a Private University in the city of Maceió, Alagoas, located in the Northeast region of Brazil. Below, we bring our cycle of DBR - Methodological Framework - developed for the extension course on computational thinking and programming language:

Figure 1 – Methodological Framework DBR Cycle (Lozada, 2019) and Extension Course classes on computational thinking and programming language



The DBR cycle that we developed allowed us to visualize the learning route for the development of the TPCK for future teachers and the movement of redesign and reflection on the activities developed for the course. In this cycle of DBR, we highlight the importance of the iterative process in which it was possible to make changes in course activities based on the needs of the participants.

The a priori questionnaire identified the profile of the course participants and the knowledge they had so that we could design the course adapting to their profile, and for that, we used Design Based Research (DBR), making previous tests of the activities that would be applied in the course and changes that were made throughout the application of the course with the collaboration of the participants. After critical and reflective analysis of the a priori questionnaire and cross-referencing with educational data, we designed the DBR cycle that we would go through to elaborate the activities that would be applied in the course, considering the technological infrastructure that public schools in Maceió had at the time the research was carried out, since most schools did not have technological resources and this aspect was essential for us to find an alternative so that future teachers (Pedagogy students) could develop computational thinking and programming language in their classes. The DBR cycle that we developed brings research into the problems and needs of teachers in Maceió, offering tools for improving teaching and for decisions in Education, especially those related to public policies for the implementation of technological resources in the teaching-learning process considering the real contexts of Maceió and its schools where teaching is offered. The course was taught in the computer lab and consisted of a theoretical and a practical part. The theoretical part addressed the fundamentals of computational thinking (decomposition, pattern recognition, abstraction and algorithm) and programming language (language by blocks and by script) for Basic Education and the practical part consisted of unplugged activities (with activities of pencil and paper) and plugged in (with programming activities using Scratch, Code and Kodable). Of the 30 enrolled in the course, 23 completed it.

III. Findings and Discussion

The survey data collection instruments were questionnaires (three questionnaires: a priori, intermediate and a posteriori) and activities (unplugged and plugged in). The a priori questionnaire indicated that 57.1% had already heard and read about the programming language and 33.3% had never heard the programming language. We

highlight some answers from the intermediate questionnaire: Regarding having had some difficulty with unplugged activities, 11.1% said they had no difficulty, but one of The activities in which they presented difficulties were in the pizza ordering algorithm activity, which involved mathematical calculations about the value of the pizza, and in the pizza delivery activity, which involved the calculation of the time spent in moving from one place to another. About understanding the notion of algorithm, 57.1% said they understood the notion of algorithm; about understanding the notion of programming logic, 66.7% said they could understand and 33.3% said they understood more or less. About understanding programming language types (by syntax and by blocks), 66.7% said that they understood the programming language by syntax and by blocks. About the game "Paper computer programming with the human robot" that was played in the University courtyard: 28.6% said they had difficulty understanding the commands, 14.3% said they had difficulty organizing the programming sequence, 23, 8% said they had difficulty understanding how it is performed (how the human being moves in the space given from the commands). Regarding learning objects, 52.4% considered the Kodable to be an easy level, about the Bee Code, 33.3% had no difficulties with the commands, 42.9% more or less understood the commands. Regarding Code Angry Birds, only 9.5% had difficulties in understanding the block commands and the sequence. About the a posteriori questionnaire, we highlight some questions and their answers: about the Scratch level, 78.3% considered it to be of average level and 56.5% managed to learn the commands, with 43.5% learned more or less the commands, what we had already seen during classes and conversation circles when they talked about the difficulties. About the commands with which they had the most difficulties, they pointed out the following: 30.4% with the sensor command, 26.1% with the variable command and 17.4% with the operator command.

From the results of the course, we were able to identify some aspects that are essential to reflect on teacher education in the Pedagogy course: the responses to the intermediate questionnaire, to the a posteriori questionnaire and the dialogue in the conversation circle during the iterative process of the DBR demonstrated that that group of students in the Pedagogy course had little ability to program and this is due to the lack of contact with the language of programming and computational thinking and basic notions of logic, in addition to not being able to associate the composition of an algorithm in a situation of the day daily life with a typical language of writing an algorithm with sequences and commands (formalization of the programming language); it was easy to identify errors in the execution of commands by the course participants, but they had some difficulty in correcting them, as the writing of the algorithm demands a logical sequence with specific commands that were often not fully understood by the participants. The lack of contact with digital learning objects for learning the programming language triggered the beginning of the development of knowledge of technology content (TCK) which refers to knowledge about how to use technology to represent and create content in different ways and the knowledge of pedagogy and technology (TPK) which concerns the choice of an aptitude-based technological tool for the learning activity. The evidence of these subdomains in the questionnaires and in the activities was evident when they showed improvement in the understanding of most of the commands and in the performance of the activities. This advance stems from the DBR cycle, with the iterative process that allowed Pedagogy students to present suggestions for changes and adjustments in activities and clarification of doubts, in a collaborative redesign movement, without harming the level of activities. Finally, we consider this work as a starting point for other actions that promote teacher training on computational thinking and programming language, recommending that this work is also carried out by the education departments in training processes that expand to schools during their working hours. collective pedagogical work (HTPC), as the development of the TPCK is an ongoing process.

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An Exploration on the Individualistic and Collective Moves in Relation to Equitable Participation in Collaborative Game-Design Processes

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Abstract: Collaborative learning environments are not inherently equitable. Learning opportunities might favor some group members over others and an inequitable collaborative learning environment would emerge. To promote equity in participation structure, we explore the relationship between individualistic/collective patterns and (in)equitable participation of one group of three girls. We analyzed a 75-minute session of game design using Bloxels and revealed the complexity in the nested relationships between individualistic and collective moves and (in)equitable participation structure for learning groups. We further discuss the implications for supporting an equitable learning environment.

Designers often work in collaborative teams to solve design problems (Brown & Wyatt, 2010). Integrating design into learning environments could provide plenty of opportunities for children to develop collaborative competence. The current study takes place in such collaborative design learning environments for children where student groups were engaged in a game-design activity. Collaborative learning is a complex phenomenon that involves cognitive, socio-emotional, metacognitive, socio-cultural, and historical aspects where individual and social processes play critical roles. For this reason, collaborative learning processes are often inequitable, with some group members having less access to learning opportunities than others. The understanding of collaboration as a complex phenomenon calls for a research method that looks at the collaborative process from iterative relationships between individualistic and collective moves (Gillespie & Cornish, 2009). Thus, there is a need to move beyond individuals or groups as units of analysis toward identifying individualistic and collective learner moves and their effects on collaborative learning processes and outcomes more generally (Borge & Mercier, 2019). Each individualistic or collective move can contribute to the overall social process to amplify or attenuate the learning opportunities for individuals or the group. As such, we answer the following research question: what is the relationship between individualistic/collective patterns and (in)equitable participation in small group collaborative learning? To answer this question, we conduct interaction analysis to first explore the different individualistic and collective moves, and then analyze how those moves help or hinder the equitable participation from all members.

Methods

In the afterschool program, small groups of 3rd to 6th graders were tasked with solving design challenges. One activity was to use Bloxels to design, play, and share their games using various tools, such as paper and pencils, iPads, and Bloxels kits. Student designers began by using grid paper or the Bloxels kit to create game elements such as characters, backgrounds, and bonuses. Then, designers needed to use the iPad Bloxels application to scan sketches or the Bloxels board to import, edit, and store designs, and further link game elements together. In this paper, we analyzed Group 4 (G4) of three 4th-grade girls– Sadie, Serena, and Evelyn (pseudonyms), as they were sketching, importing, and editing designs in the Bloxels application during Session 3. We conducted multimodal interaction analysis, drawing upon Jordan and Henderson's (1995) and Jewitt et al.'s (2016) works. We identified "hotspots" of individualistic and collective moves as G4 interacted with each other and with tools and artifacts. We analyzed discursive practice (Stahl, 2006), spatial practice (Xia & Borge, 2020), and mediational tools/artifacts (Wertsch et al., 1993). Two types of spatial practices were examined: 1) the participation structure of the group members (i.e., the bodily posture that group members assume, how they position themselves) and 2) the spatial organization of tools and artifacts (i.e., how and where the tools and artifacts were placed in relation to the participants), as who was using the tools and producing the artifacts for how long and where these tools were placed and by whom are key to understanding the inequity issues.

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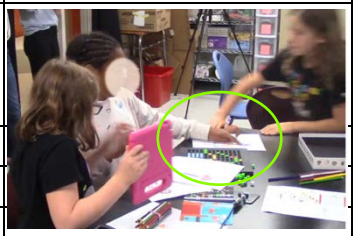
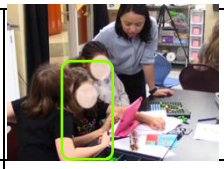
Findings

We found six discursive and tool-based actions and practices associated with individualistic moves. Discursive actions included 1) seeking teacher/facilitator support before asking or problem-solving with groupmates, 2) refusing collaborative work invitations and insisting on individual design, and 3) not take responsibility to communicate ideas clearly to the group. In relation to tool-based practices, 4) tools and artifacts are physically placed in ways that offer partial or zero access from other group members, 5) individuals dominate the use of tools or artifacts, or 6) members fight over the use of tools and artifacts. Overall, individualistic actions did not contribute to the group design process nor create opportunities for group members to learn and grow. For example, seeking out facilitator support without first seeking group support did not create prevented opportunities for collaborative problem-solving. Also, dominance over iPad use, created inequitable participation. However, it is possible to transform these individualistic actions into collective moves. In the case of seeking help from facilitators, if the facilitator or other group members address the problem in front of the whole group, it can create opportunities for collective reflection and problem solving. Also, if the group member who insists on doing individual design can find ways to incorporate their designs into the collective design, they can still contribute to the group design process. However, individualistic actions need early intervention or else risk developing into more problematic patterns detrimental to collaboration.

We found ten discursive and tool-based actions and practices associated with collective moves. Discursive actions included, 1) actively engaging each member in social interactions; 2) actively bringing members to the group design process by explaining what they have done, or propose/accept joint working; 3) actively self-disclosing: group members speaking out loud about what they work on; 4) actively seeking feedback or patiently waiting for input from each member, integrating all members' ideas into the group design artifacts; 5) proposing rules or social scenarios that are inclusive to all ideas; 6) actively volunteering expertise in technology or design; and 7) actively volunteering perspective or information, positioning oneself as a valuable group member and her knowledge as resources. Tool-based practices included, 8) placing tools and artifacts in ways that offer access from other group members, 9) respecting other member's access to the tools, and 10) positioning themselves in ways that grant easy participation. These collective moves favored collective sense-making processes and indicated inclusive intentions. Nonetheless, some collective moves could inadvertently lead to inequitable participation. For example, if one member's active discursive moves did not get uptake from others, they might retreat into individual work. Also, we recognize that volunteering expertise is important for the volunteer in developing identity as a capable collaborator and designer, but in one example, one group member volunteered her expertise multiple times, and the other member responded, "yeah, and you just want to use my TURN," which showed how this move barred the other from engaging.

In this session, we describe an instance from the data to further explain different types of actions and their relations to inequitable participation in the small group. Session 3 began with a brief introduction between the three girls. Sadie and Serena had worked together in previous sessions, but Evelyn had not. Sadie took Evelyn's feelings into account when introducing the existing designs to her, saying "you're gonna be mad at us [herself and Serena], but we kind of have a lot of designs." Presenting shared ideas with Evelyn created an opportunity for her to become an equal contributor, leading to continued reasoning within the group throughout the activity (Mercer, 1996). Collective moves such as this provided a foundation for team equity and effective collaboration. However, around 9 minutes into the session when Evelyn introduced the story block that she had designed, Serena, who did not understand the story block process, quickly asked for the facilitator without consulting teammates first. This was one of the many times that Serena used this individualistic move; she often sought facilitators and did not rely on her teammates as reliable resources. Evelyn nevertheless responded to Serena's question after the facilitator responded, which was a collective move to help ensure the team understood her meaning of the term "story block." Even though groups might encounter problems that may eventually require external help, problems are learning opportunities where members can turn to each other as valuable resources (Simpson et al., 2017) and allow for more creative problem-solving to occur. Seeking early facilitator support eliminates this potential learning opportunity. Furthermore, this individualistic move could potentially lead to trust issues as other members do not feel valued as intellectual equals (Edmondson, 1999). Halfway through the session, the group showed a drastic change from distanced interactions with individualistic moves to closer interactions with the three working together, displaying the complex relationship between individualistic and collective moves and the participation structure, shown in the episode.

<table>
<tr><th>Transcript</th><th>Screenshots</th><th>Note</th></tr>
<tr><td>[35:00] Sadie: “What do you mean?”
Evelyn: “Like... like we control ourselves?”
[Evelyn did not continue explaining herself and leaves the table. Sadie watched her as she walked away]</td><td rowspan="3">  </td><td>Individualistic: Evelyn quit asking questions and seeking an explanation as she left the table and walked around the room.</td></tr>
<tr><td>SD takes back the iPad.</td><td rowspan="2">Sadie and Serena continued making.</td></tr>
<tr><td>Serena: “wait, what...let's create another character”</td></tr>
<tr><td>Sadie: ok, now you do this [pointing to the paper]
Serena: okay, give me. [very excited] (do these need to be in quotes as well?)</td><td></td><td>Sadie took up a leadership role.</td></tr>
<tr><td colspan="3">[37:00–39:00] Tension between Sadie and Serena over iPad.</td></tr>
<tr><td>[Sadie reached for the iPad and turned it to the side to show what she means]
Serena: Wait! [showing a bit frustration at Sadie's move to take the iPad]
Sadie: just turn the thing like this [backing off gesture]</td><td> </td><td>The tension over using the iPad culminated at this point, but Sadie showed back off gesture to recognize Serena’s turn at iPad.</td></tr>
<tr><td colspan="3">[40:00 – 45:00] Evelyn walked off and back frequently. There was tension between Sadie and Serena over iPad.</td></tr>
<tr><td>[45:00] Serena: “Next is Evelyn. Next is Evelyn…She’s not going to make a uni kitty, she’s going to make something else.” [Serena takes the iPad and hands over to Evelyn, showing she is keeping the rule]</td><td>  </td><td>Collective: Serena was actively voicing the inclusive social rule by which Evelyn was supposed to take the turn on making a character with the iPad.</td></tr>
<tr><td>Evelyn took the iPad and knelt in the middle so that both Sadie and Serena could easily see the screen.</td><td colspan="2">Collective: At this time, Evelyn knelt in-between the girls and access to the iPad was transferred from Sadie to Evelyn without anyone getting upset.</td></tr>
<tr><td colspan="3">[46:00 – 50:00] Evelyn kept making character in the iPad with the same participation structure.</td></tr>
<tr><td colspan="2">Serena: “Is the background gonna be black when it's flying?”</td><td>Evelyn went to work on papers to design the background.</td></tr>
<tr><td>[Sadie took the iPad] Sadie: “I know what to do.”</td><td colspan="2">Collective: Sadie offered her expertise to help problem solve.</td></tr>
<tr><td colspan="3">[52:00] Group members worked on different tasks with Evelyn working on papers and Sadie started to dominate the use of the iPad (Individualistic). Serena kept closely watching the iPad. Evelyn later joined after she finished the paper design. They all contributed ideas (Collective).</td></tr>
<tr><td colspan="2">[56:00] As they all centered around the iPad and worked on their design, Sadie reached out the iPad so that everyone could see better and have easy access to the screen. This closely knit participation structure continued through the end of the session.</td><td> </td></tr>
</table>

This episode started with a domination of resources, mainly the iPad, by Sadie. Failure to communicate from Evelyn led to continued fighting over resources between Sadie and Serena. Additionally, this failed communication led to her lack of involvement and accessibility to resources. However, this shifted as the activity continued as Sadie began acting more equitably with resource availability within the group. While the iPad remained in her hands for the first part of this episode, it slowly became the centerpiece within the group as each group member crowded around and had equal access to the device. This positionality continued to play an important role in participation and equity within the activity, as Sadie took note of where to pull up a chair for her group member as she was cognizant of the positioning of the design materials and her partners in maintaining an equal structure. Sadie’s awareness of the positioning of the iPad in relation to the availability of material equity marked a significant collaborative move within the activity. While her actions remained dominant within the group, her awareness of her teammates’ lack of access to the device and her shift in position showed that she trusted and respected their contributions to the project (Edmondson, 1999). Sadie’s proactive actions led to effective synchronous groupwork.

Discussion and conclusion

This study examined the specific interaction moves while focusing on the equity issues in participation structures. Our group of three girls showed less individualistic types of moves than collective ones. In general, collective moves are encouraged since these moves are oriented towards achieving group level learning processes. However, our findings show that not all collective moves equate to equity. For example, while we encourage help offering and seeking to foster peer learning and group solidarity, if this type of learning behavior is not coordinated well and one group member constantly offers expertise by taking away the critical tool, i.e., the iPad application in this case, and directly working on the tool, this takes away other members' opportunities to learn. One suggestion in this case is to go beyond encouraging students to help each other, but also sensitizing them in terms of how to offer help such that all can learn from the experience.

We also want to highlight that in the illustrative episode, one student dominated the use of the iPad but then transformed the individualistic pattern into a collective one by consciously adjusting the tool and artifacts while incorporating every member's idea. Though the commonly used digital technologies, such as personal computers or mobile tablets, are easier for individual users given that it is designed for single users, our group of three girls showed their transformational agency in using tools that helped them break free from the given limits of tools. As such, we believe that in collaborative learning, student agency needs to be considered at the group level, which requires the members to be aware that the way they and the tools are positioned could be inclusive or exclusive and thus they need to be cognizant of each other and their group work.

All these findings are important to facilitators in such learning environments. For example, while facilitators might naturally identify the help seeking from group members to be desirable and showing their willingness to learn, our findings indicate that this might compromise the group's problem-solving opportunities. As such, facilitators are encouraged to be more cognizant of when and how to offer their own expertise. In future work, it would be interesting to factor into gender and conduct analysis on all male groups or mixed gender groups to see if there are other individualistic or collective moves that are not captured in the current study. Also, conducting a longitudinal study such as following the same group over one semester and even longer would yield insights into how children learn to balance their individual and group efforts to achieve equitable participation and, more importantly, how facilitators can help ensure the goal of achieving equity.

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Middle School Students' Learning in Energy flow and Matter Cycling in the Ecosystem

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Abstract: An ecosystem is a complex system, including multiple layers of organization, complex interconnections among components, and invisible dynamic processes. Research shows that learners' often see energy and matter in ecosystems as mostly a linear, not cyclic, pattern. This study examined 35 students' energy and matter models at three points (pre, mid, and post) and interviews from 7 students during a Compost unit focused on ecosystems. We coded the models to examine students' understanding of energy and matter over time and included excerpts to show students' ability to identify system components and understand energy flow and matter cycling. We found that more students explained energy flow by including observable and non-observable organisms and process. Even though more students explained matter cycling as cyclic by including invisible process (decomposition), this was mostly at a superficial level. Students also conflated the terms "matter" and "energy", often using them interchangeably. This indicates a need to better assist students explicitly understand the two processes and how they are connected.

Key words: complex system, energy flow, matter cycling

Introduction

Complex systems consist of interactions between multiple components at different levels of organization as well numerous patterns that emerge from these interactions (Ladyman et al., 2011; Yoon et al., 2018). Although complex systems commonly occur in the physical and natural world, students find it difficult to comprehend their non-linear, dynamic, and sometimes invisible nature (Wilensky & Resnick, 1999). Being able to recognize and reason how these patterns emerge and behave is critical to understanding ecosystems (Hmelo-Silver et al., 2017). Instead, students tend to recognize visible, linear relationships among components of an ecosystem (such as a predator-prey relationship), as opposed to understanding invisible and cyclic relationships (Hayes et al., 2017). Making sense of the more complex, non-linear, invisible, relationships are fundamental for understanding the dynamic nature of ecosystems.

Liu & Hmelo-Silver (2019) found that virtual models can help students focus on the interdependencies among the different components in a complex system. Instructional supports, such as a combination of virtual and physical models, could assist students in focusing on the important aspects while the learning content is complex (Puntambekar et al., 2020). For our study, we developed a 14-week, design-based "Compost" unit combining virtual and physical models, aimed at helping students understand energy transfer (manifest in the macroscopic process) and matter cycling (a microscopic process) in an ecosystem. We investigated students' understanding of the relationships between the different ecosystem components. Our research questions were: 1) How did students' understanding of energy flow and matter cycling change over time? and 2) How did students illustrate their understanding of the ecosystem components?

Methods

Context of the research

Thirty-five eighth-grade students in one science teacher's classes from a midwestern middle school in the United States participated in this study. Students participated in cycles of inquiry to iteratively learn about the science of decomposition and ecosystems to solve a design challenge to create a compost that broke down quickly and contained a lot of nutrients. Students built a physical compost bioreactor, where they input materials (such as food scraps) and observed how their compost broke down (or not), based on what they added to the bioreactor. They also used a compost simulation to isolate, investigate, and visualize how specific abiotic factors (such as water, particle size, and carbon to nitrogen ratio) impacted the microorganisms in compost ecosystems, thereby affecting decomposition.

Data sources and analysis

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Energy and matter models

Students drew models to show how matter and energy flow at three points: before, at a midpoint, and at the end of the unit. Students included concepts such as sun (S), producers (P) (i.e., different plants), consumers (C) (i.e., different animals), dead organic matter (M), decomposers (D), and other abiotic factors. We created a coding scheme to assess students' models, with five levels of connections. A higher-level connection indicated an understanding of more complex connections between observable and non-observable elements. For example, the PMDP connection in level 3, PCMDP and SPMDP connections in level 4, and SPCMDP connection in level 5 showed that students understood the cyclical nature of how matter *cycles* through an ecosystem, i.e., decomposers break down dead organic matter down to its constituents, which is then available as nutrients in the soil for plants to uptake. Lower-level connections showed students' understanding of the linear relationships in the complex system, such as SP or PC.

Two researchers independently coded 23% of the data and achieved a 91.07% interrater reliability. The first author coded the remaining data. We used the non-parametric Friedman test to evaluate the overall differences from pre, mid, to post models. We then used the Wilcoxon Signed-Rank test to compare the connections that students made over time in each level, separately. We also examined the connections representing the cyclic nature of matter cycling.

Student interviews

Of the 35 students in this study, we conducted semi-structured interviews (about 30 minutes on average) with 7 students and asked them to interpret and explain their models. Excerpts from the transcribed interviews were grouped by three main topics: identifying system components, understanding energy flow, and understanding matter cycling.

Results

Changes in students' understanding of energy flow and matter cycling over time

We calculated the frequency of the number of correct connections between ecosystem components (e.g., SP, PCM, CMDP, etc.) in each level for all 35 students' pre, mid, and post models to examine learning over time. Using a Friedman test, we found that students included significantly higher-level connections in their models over time ($\chi^2_{(14,\ N=35)} = 362.97$, $p < .001$). Our follow-up pairwise comparisons using Wilcoxon signed rank tests, with a Bonferroni correction to control Type I error, showed students included significantly more level 5 connections from their pre to post, and mid to post models.

Students' connections of energy flow and matter cycling

As mentioned earlier, students often struggle to understand non-observable and cyclic aspects of complex systems. To understand how the Compost unit may have supported students' ability to recognize these relationships, we examined students' understanding of non-observable organisms and their interactions with other organisms in the ecosystem. The connections we examined are displayed in Table 1.

Table 1

Number of students who made connections at higher levels

Connections	Prior to curriculum	End of curriculum	Decomposition included or not	Linear or cyclic
SPCM (level 3)	10	19	No	Linear
PMDP (level 3)	0	10	Yes	Cyclic
SPCMD (level 4)	7	15	Yes	Linear
PCMDP (level 4)	3	13	Yes	Cyclic
SPCMDP (level 5)	2	12	Yes	Cyclic

When looking at students' connections related to energy flow at a visible and non-visible scale, we compared the number of SPMC (level 3) and SPCMD (level 4) connections students included in their models over time. Students made fewer SPCMD (level 4) connections than SPMC (level 3) connections both prior to and at the end of the unit. This indicates that understanding the direction of energy flow from matter to decomposers, which is unobservable in most cases, was challenging for students. However, when we compared the number of students who identified a SPCMD (level 4) connection prior to and at the end of curriculum, eight more students were able to incorporate these ideas into their model, showing that some students were able to build this understanding over time.

Next, we examined students' understanding of matter cycling as cyclic. We compared the number of students who made higher-level connections that incorporated the cyclic aspects of the complex system, PMDP (level 3), PCMDP (level 4), and SPCMDP (level 5) prior to and at the end of unit. We found that 10 more students included connections in each of these levels at the end of curriculum, showing that they made growth in understanding that matter cycling is a cyclic, rather than linear process.

Even though some students did make progress in understanding the cyclic aspects of the compost ecosystem, we found that the number of students who made linear connections was higher than students who were able to identify cyclic connections. Specifically, at the end of the curriculum, 19 students identified the SPCM (level 3) linear connection versus the 10 students identifying cyclical PMDP (level 3) connection; and 15 students identified the SPCMD (level 4) linear connection in comparison to 13 students with cyclical connection of PCMDP (level 4).

Students' explanations of their energy models

Students were generally able to identify system components within the ecosystem. However, we found that students had difficulty explicitly articulating what "matter" was. Further, some students conflated energy flow and matter cycling, using "matter" and "energy" interchangeably. For example, one student defined matter as "things that could be eaten, and the energy is compacted into food".

Energy flow in the ecosystem

We found that all 7 students were able to explain both the microscopic and macroscopic scales of organisms in the ecosystem (i.e., SPCMD) when discussing energy flow in their models, such as:

> "I started with the sun...our main source of energy for the producers sun goes to the producer ... grass gives energy to the cow...the consumers eat the producers and it's in chemical energy form, ... and then it goes as the consumers transfer energy ... I have some bacteria up here that ... could get energy from a decaying apple, and it eats part of it, and that's how it gets its energy"

In this example, the student explicated the process of energy being transferred from producers to consumers and further transferred to decomposers by breaking down (dead) plants/animals or leftovers from humans. While this student did not discuss breakdown of matter and uptake of these nutrients by plants, other students (incorrectly) discussed that energy is directly reused by plants at the end of the decomposition process.

Matter cycling in the ecosystem

Unlike in their descriptions of energy flow, where all students included information about the macro and microscopic scales, students' discussions about matter cycling as a cyclical process varied (see Table 2 for examples). In general, in more successful examples, students were able to articulate how matter was broken down by decomposers so that it could be used again by plants to start another cycle; Whereas, in less successful examples, students did not explain this. Further, even if students discussed matter cycling, their explanations were often vague and inaccurate.

Table 2

Examples of students' discussion of cyclic nature of matter cycling during interview

More Successful	Less Successful
"the matter is what humans, they eat it, and then what's left over that goes into the compost and then, earth worms and mold...eat that matter and then whatever is left that others things can't really eat is, um, is good for the soil and then producers can use it."	"when things die…the mold eats the matter, the dead matter, and the matter is mostly like it eats these because it's not like from the sun to the plants…[matter] is an actual thing, and it's not like just an energy flow. It's like the dead things...it's really hard to explain"

Discussion

We found significant gains in the complexity of students' understanding of these dynamic processes by including more components from mid to post models, demonstrating that some students could understand their interconnections. The students' increasing ability to see relationships between the ecosystem components revealed that their understanding of energy flow and matter cycling changed from simple to complicated over time. These findings are in line with prior studies which have suggested that students find it challenging to understand interconnections between components of complex systems (Grotzer & Basca, 2003; Hmelo-Silver et al., 2007)

We also observed that students could explain energy flow through both the observable and unobservable organisms in the ecosystem in their interviews. As other researchers have noted, students in this study found it less challenging to make connections between observable organisms and their interactions with the biotic and abiotic factors, as was evidenced by the frequency of level 1 and 2 connections made in their models. However, in line with Hayes et al., (2017), we found that a deeper understanding of the invisible processes such as the decomposition was less prevalent in students' written models. This highlights the importance of scaffolding students to see both the structures and dynamic changes in the systems (Opitz et al., 2017) to help them link the components to the processes.

Even though we made the unobservable processes of decomposition more observable via the compost simulation, many students did not include explanations about how matter is recycled and conserved (Grotzer et al., 2017). Similar to Lee & Liu's (2010) findings, few students included the highest-level connection (SPCMDP), between multiple levels of organisms in the ecosystem in their models and most were also unable to discuss connections at this level during their interview. Understanding decomposition at the microscopic scale is important for explaining the cyclical nature of matter cycling in the ecosystem.

Conclusion and Future Work

The combination of a physical bioreactor and a compost simulation in this unit may have helped students notice and learn about the unobservable processes (i.e., decomposition) occurring in ecosystems, since they showed a better understanding of decomposers' role in the ecosystem as well as the interrelationships among multiple organisms over time. Although some student's explanations showed growth in understanding energy flow, this was only a part of understanding the complex and interrelated nature of ecosystems. This indicates a need to better assist students in developing a more sophisticated understanding of the macro and microprocesses underlying the complex relationships between energy flow and matter cycling in ecosystems, specifically about decomposers' role in breaking down matter during decomposition. To help all students achieve a deeper level of understanding, more supports that enable students to explore and understand the role of decomposers and matter are needed. In future work, our aim is to understand how the compost simulation could better support students' understanding of the unobservable phenomena in an ecosystem, and how the simulation can be better integrated with the physical experiments.

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Playful Learning Following Deviations: A Mixture of Tinkering, Causal Explanations, and Revision Rationales

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Abstract: This work expands on process-based accounts of the intersection between play, learning, and failure. We examine middle school and college players navigating *Baba Is You*, a puzzle-based video game, based on prior scholarship in debugging and problem-solving. We document how players notice deviations, generate causal explanations, and revise their approach when problem-solving. Using qualitative interaction analyses and quantitative sequential analyses, this work shows how players approach the puzzle through persistent tinkering guided by generating causal explanations of game mechanics and providing revision rationales. In addition to nuancing the field's understanding of the relationship between failure and learning, the study has implications for theorizing about and designing for learning through play and problem-solving.

Introduction and literature

Play is a perennial childhood activity and an enduring quality of adult life, considered by many to rise above the status of a privilege and toward recognition as a human right (Souto-Manning, 2017). In the learning sciences, play is recognized as a common and generative context for learning (Gee, 2005). Numerous mechanisms have been proposed to describe how play supports learning. In the context of a puzzle-based video game named *Baba Is You*, we examine one of these mechanisms in this paper: how play-based learning productively facilitates responses to impasses, breakdowns, incompatibilities, or failures. These terms are heterogeneously defined in the literature, but are primarily concerned with moments (however brief) in which actions lead to outcomes that are out of sync with a player's goals (Clifford, 1984). Scholars have developed many arguments to account for how failure during play supports learning, including collaborative discourse about the game mechanics (Anderson et al., 2018; DeLiema et al., 2019), just-in-time feedback (Gee, 2005; Williams-Pierce, 2019), play-based framings of failure that curb the otherwise aversive experience of struggling (Juul, 2013), and flow during the play activity (Kiili et al., 2012). A central challenge for the field is to build on these accounts to document process-based views of what players are doing following moments of failure during play to generate learning. Building on DeLiema, Bye, & Marupudi (2021), the backbone of our approach is scholarship that has over decades consistently recognized three components of debugging (Katz & Anderson, 1987): (a) noticing a deviation between the programmer's preference/goal and the outcome when running their code; (b) forming a causal explanation of why that deviation arose; and (c) formulating and implementing a plan to revise the code and resolve the discrepancy.

Deviations are not neutral, objective characteristics of goal-oriented play. Particular situations stand out to players as deviations from intention/expectation based on the player's goals and their awareness of some form of misalignment between those goals and their approach. In the problem-solving literature, this type of problem finding is non-trivial (Hayes, 1989). Following moments of deviation, there is a robust human tendency to search for a *causal explanation* (Weiner, 2018). In the debugging literature, causal explanations for why a program is failing drive how the programmer fixes their code (Ko & Myers, 2005). Lastly, when moving through a goal-directed play activity, players *revise* their approach to resolve deviations. Without having a ready-at-hand fix, players engage with problem-solving, in that players do not have "a prescribed set of actions to reach the goal," and have to consider multiple parts and possible solution paths (Salehi et al., 2020, p. 157).

Study goals and context

We center the following exploratory research question: How do players (middle school and college students) of a puzzle-based video game notice and respond to deviations during play in ways that foster their learning of game mechanics? The play context for this study is an independent video game, *Baba Is You* (see a screenshot in Transcript 1). Players use a keyboard to move Baba, a small sheep-like creature. The game's core conceit is that players see the game's rules within the playable game field (e.g., the phrase WALL IS STOP is out in the open), enabling the player to interact with particular words in the rule phrase. Moving a word, and thus breaking (or creating) a rule, changes the physics on that level (e.g., a previously impenetrable wall is now permeable) as the

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player tries to find a winnable arrangement. The player must add the WIN attribute to an object (e.g., FLAG IS WIN) and then touch it, but the player does not know at the outset what object will allow them to win. We selected *Baba Is You* because the player's interactions with explicit rules makes their problem-solving process particularly visible. Furthermore, the game requires no previous content knowledge, while having a unique structure with a consistent rhythm of new rules, which make it accessible but challenging for a diverse body of players, and hence calls upon authentic problem-solving practices previously identified in the literature (Salehi et al., 2020).

Method

Middle school students (n=13) and college students (n=12) with no *Baba Is You* experience participated in the study. Participants played the game on recorded Zoom sessions with a researcher for an hour once a week for three weeks. We used a think aloud protocol for the sessions and the researcher did not intervene unless the participant needed help. For data selection, we examined data across all players, focused on *Baba Is You* levels in which players were (a) progressing after learning core game mechanics; (b) grappling with new mechanics; and (c) solving the level typically in under 5 minutes. We chose two levels – Float and Changeless – that met these criteria. We transcribed the video data from these two play sessions for all participants following conversation analysis conventions and including multimodal detail. Our research team worked over several months on interaction analyses (Jordan & Henderson, 1995) of other transcribed *Baba Is You* levels. Over time, we iteratively refined our problem-solving framework and codebook. Our 5-member researcher team then broke into (rotating) teams of 2, each team member coded a transcript while watching the primary data, team members met to compare their interpretations, and then worked toward a consensus. Each team kept a record of interrater discrepancies. Discrepancies were then discussed with the full team and used to update and formalize our coding scheme, before we re-coded the data and reached a new consensus. Below, we present interaction analyses (Jordan & Henderson, 1995), and sequential analyses (Faraone & Dorfman, 1987) to investigate players' problem-solving processes.

Study outcomes

Our analysis amounted to a refined problem-solving framework (see Fig. 1 below) and coding scheme. Higher levels in each category refer to a greater level of detail provided by the player (e.g., ND-1 refers to noticing the deviation; ND-2 refers to partially describing the deviation; ND-3 refers to fully describing the deviation).

Figure 1

Our framework for describing the Baba Is You puzzle environment and player's puzzle approach

Goal-oriented action (revisions) - AR. Goal: What proximal and distal goals are players pursuing? Strategy: What manipulation rules and meta manipulation rules are they using/changing/linking together?

> ***Noticing deviation - ND***. Does the player notice anything deviating from their approach (e.g., misalignment; obstruction; unknowns; unexpected/unplanned) that they judge needs addressing? How do they describe the deviation, including descriptions of actions and inputs that preceded it?
> ***Causal explanation - CE***. What from the game's manipulation rules (implicit or explicit) or meta manipulation rules does the player position as responsible for causing the observed deviation?

(Revise goal-oriented action above)

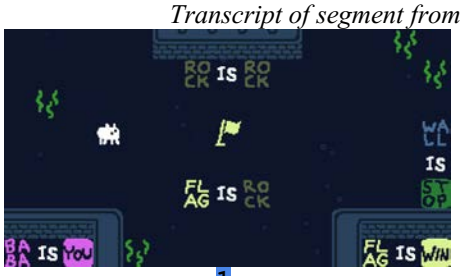
Interaction analysis applying the framework

We apply this framework in an interaction analysis to demonstrate how the framework operates. The transcript is from a college student playing Changeless. The player, Aya (a pseudonym), has read aloud the rules on the screen, including re-reading the WIN statement. Transcript 1 begins when Aya moves Baba and reacts when the flag changes into a rock. Aya doubles back with Baba toward the now-rock, followed by a pronounced "oh:::" and a raised eyebrow (Lines 4-5), but does not explain what they find surprising. Aya then articulates the deviation from expectation: "okay (.) flag turned into rock" (Line 6). Immediately after, Aya intervenes, breaking off ROCK from FLAG IS ROCK, and saying "we're gonna change that" (Lines 9-10); these words do not include an account of why this revision might work. This action leads Aya to notice a new deviation, indicated by the pause in action and the surprised reaction (Lines 11-12). Aya then articulates an explanation for why their most recent revision did not work as expected: "cuz its gone" (Line 6). In this stretch of play, Aya notices a deviation (ND-1), describes in detail what deviated from expectation (ND-2), attempts to resolve the deviation without providing a rationale (AR-1), notices a new deviation (ND-1), and proposes a causal explanation (CE-2). Interaction analyses like this

one drew our attention to how participants were tinkering by noticing deviations and then deepening their inquiries by providing explanations about the game's core mechanics and accordingly revising their approach.

Transcript 1

Transcript of segment from Aya's Changeless game play



1

2

Line	Time	Transcript	Code
1 2 3	0:19	AYA: **((1 Baba moves right as flag turns into rock 2))** **((Baba moves down twice))** **((Baba moves up twice))**	
4 5	0:21	AYA: [↑oh::: (1.5) [**((raises eyebrows markedly))**	ND-1
6 7 8	0:24	AYA: [o:kay (0.8) >flag turned into rock<= [((**moves Baba down and to the right, stopping under FLAG-IS-ROCK))**	ND-2
9 10	0:26	={so } >we're gonna change< tha::t. **{FLAG-IS/ROCK}**	AR-1
11 12	0:28	AYA: (1.5) **((eyes widen))**	ND-1
13 14	0:30	AYA: I can't [ch(hhh)ange that cuz its gone (1.0) [**((smiling and laughing lightly))**	CE-2

Sequential analysis of problem-solving moves

We combined ND-2/3s, CE-2/3s, and AR-2/3s for the sequential analysis to focus on any moments players described the game mechanics. The clearest pattern in the sequential analysis (see Fig. 2) is that the moments of deviation noticing (both ND-1 and ND-2/3) were most commonly followed in the adjacent problem-solving action by players revising (but not justifying via causal explanations or rationales for their revisions) their approach to the puzzle (AR-1), and vice versa. However, players also investigated the game mechanics by generating causal explanations of deviations (19/21 players of Float; 11/17 players of Changeless) and/or explanations for why their revisions might work (9/21 players of Float; 8/17 players of Changeless). When did these inquiries into the game mechanics take place? Though ND-1s and ND-2/3s were mostly followed by AR-1s (as noted above), ND-1s and ND-2/3s also almost exclusively preceded causal explanations (13/16 times in Changeless, and 23/27 times in Float). Similarly, in Changeless, ND-1s and ND-2/3s primarily preceded high level ARs (9/12 times), while in Float, both NDs and CE2/3s preceded high level ARs (6/11 and 4/11 respectively).

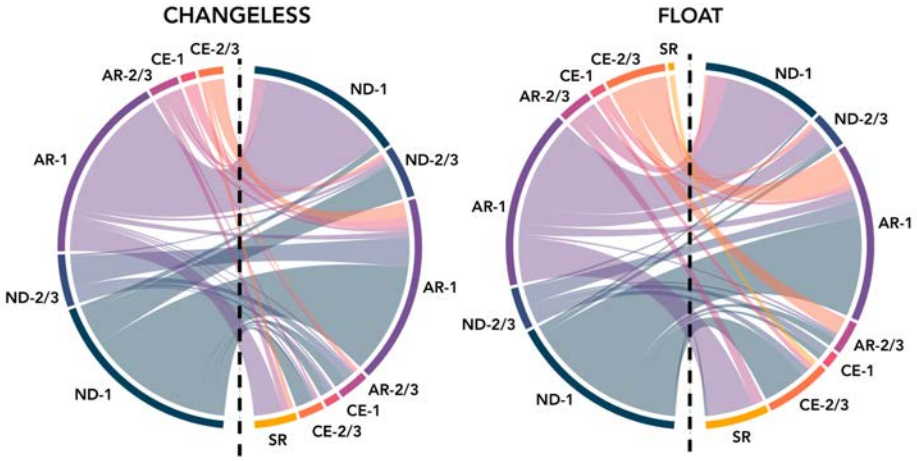
Discussion

We aim in this work to extend a long-running inquiry in the learning sciences into how players respond to deviations during play in ways that deepen their exploration of the game world. First, we note that it is somewhat misleading to say that players only respond to deviations; they first have to notice them. This process of noticing deviations is active work in its own right, and ignites the player's exploration of new game mechanics. Second, and in alignment with prior scholarship on the productivity of tinkering (e.g., Berland et al., 2013), we found that players tended to operate within a baseline pattern of alternation between noticing a deviation and revising their approach without outwardly stating what had gone wrong and how their revision might work; they were seemingly 'playing with' the game mechanics to understand the puzzle at hand. Third, the vast majority of players eventually branched out to generate causal explanations of their deviations and/or provide rationales for why their revisions might work, clear indicators of their sense-making about the rules of the game world. Fourth, we found that efforts to explain the game's mechanics by generating causal conjectures and revision rationales primarily trailed moments of noticing deviations. These findings introduce a nuanced description of problem solving in a puzzle-

based video game: players primarily respond to noticed deviations by tinkering with revisions, and secondarily respond by conjecturing about the game mechanics in the form of causal explanations and revision rationales.

Figure 2

Problem solving moves (left of each dotted line) that precede other problem-solving moves (right of dotted line) in Changeless and Float. The width of each arc corresponds to the number of times the transition occurred.



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How Different Types of Teacher Dashboards Impact Teachers' Problem Detection Accuracy

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Abstract: Little is known about how design choices in teacher dashboards (i.e, digital tools that summarize and visualize information to support the teacher in the teaching process) impact teachers' monitoring and interpretation of critical events. Therefore, this study examined how designs that offer different levels of support impact pre-service teachers' monitoring. Three dashboard designs (from least to most supported: mirroring, alerting, and advising) were compared. In three conditions teachers (n = 50) processed nine teacher dashboards of a particular design. Teachers were required to detect the critical situations in each dashboard. Results demonstrated that the alerting dashboards resulted in more successful problem detection than the mirroring dashboards. Though advising dashboards, in theory, offer more support, no additional benefit over alerting dashboards was found.

Introduction

Teacher noticing refers to teachers' successful monitoring and management of students. It is imperative for effective education and encompasses teachers' cognitive processes about *attending* to noteworthy events, *making sense* of such events, and *responding* to these events to make informed decision in a teaching context. In short, teacher noticing includes three main aspects: (a) identifying what is important in a teaching situation, (b) making connections between specific events and broader principles of teaching and learning, and (c) using what one knows about the context to reason about a situation (van Es & Sherin, 2002). The introduction of computer-based learning impacts teacher noticing, but also presents opportunities to enhance it with for instance, teacher dashboards.

Teacher dashboards are accumulations of learning analytics that aid teachers' monitoring and management of students' progress (Verbert et al., 2013). They often contain visualizations (e.g., social interaction, time spent, and test results) that enable teachers to get insight into processes that would otherwise go unnoticed (Verbert et al., 2013). Research shows that teacher dashboards can facilitate teacher noticing (Vrikki et al., 2021) but also that their effectiveness to do so depends on specific design features that offer guidance (Leeuwen and Rummel, 2019; Soller et al., 2005). For example, dashboard that contain features that make relevant information more noticeable, can foster *attending* (Mottus et. al., 2015). Dashboards that support teachers to interpret and give meaning to the data to decide what is relevant or useful for their teaching can foster *sense making*, (Verbert et al., 2013). Dashboards that, for example, help teachers to assess the urgency and gravity of a detected situation and decide on how to follow up can foster *responding* (Molenaar et. al., 2019; van Leeuwen et. al., 2019).

Based on the presence or absence of guiding features, teacher dashboards can be grouped differently. Soller et al. (2005) categorized them as *mirroring* and *guiding* tools. A similar categorization was created by van Leeuwen and Rummel (2019) who distinct between *mirroring*, *alerting* and *advising* dashboards. Both agree that *mirroring dashboards* provide the least support and leave the interpretation mainly to teachers. In these dashboards, teachers decide what information should be paid attention to and how to respond without any alert (Soller et al., 2015). When guidance is added, this is usually in the form of alerts and/or advices. In *alerting dashboards*, possibly relevant information is pointed out to teachers (Schwarz et al., 2018) while in *advising dashboards* teachers receive guidance in the process of interpretation of the given information and the actions they could take (Martinez-Maldonado, 2019). Van Leeuwen and Rummel (2020) showed that guiding tools benefit effectiveness. They found that advising dashboards, compared to mirroring dashboards, lead to an increased amount of detection of problematic situations, decrease in effort, and an increase in confidence about decisions.

Though a general conception might be that all steps of teacher noticing are ideally supported in teacher dashboards, presenting too much information can be burdening instead of facilitating them (Van Leeuwen, 2015). Research demonstrates that there is a risk of increased orchestration overload when the information provided to teachers increases (Martinez-Maldonado, 2019). Redundant or confusing information can result in increased cognitive load which will negatively impact effectiveness (Mayer & Moreno, 2010). Moreover, over structuring can create an ambiance of overreliance and reduce effortful processing and critical thinking and narrow teachers' focus. For example, when the designed support intentionally highlights something, teachers could become over reliant on what is highlighted and might neglect other potentially important things (Brunvand & Fishman, 2006).

To conclude, teacher dashboards have unique affordances, but their effectiveness depends on how they are used. They should be carefully tailored to achieve their full potential. Teachers should be supported but not

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overwhelmed (Mottus et.al. 2015) or limited in their noticing (Brunvand & Fishman, 2006). Understanding how support features in teacher dashboards impact teacher noticing can advance dashboard design, theory, and praxis. This study explores the impact of three levels of support: 1) *mirroring*, 2) *alerting*, and 3) *advising* dashboards.

Method

The study followed a quasi-experimental design with three conditions. Conditions only differed in the type of teacher dashboard: mirroring, alerting, and advising. Data was collected through virtual meetings where teachers processed nine simulated dashboards. After the teachers were introduced to the study, they went through the dashboard simulations one by one, at their own pace. Teachers were required to detect critical cases in each dashboard and report this on a questionnaire. For each reported case they were asked to clarify why this case was critical by answering a selection list (indicating problem) and open question (asking for rationale).

Participants were preservice science teachers enrolled in a four-year science teacher education program of a public university in Turkey. To ensure that they had sufficient pedagogical knowledge, the sample was drawn from teachers in the 3rd and 4th year of their education. In terms of gender distribution (male/female) the sample was representative of the population of preservice science teachers in the university. Conditions were similar in terms of size and demographics (Table 1).

Table 1

Demographics and Means for Each Condition and One-way ANOVA Results

	Mirroring	Alerting	Advising	F	*p*
N (male/female)	17 (2/15)	16 (2/14)	17 (2/15)	-	-
Age in years	22.06	21.13	21.82	2.13	.130
Teaching experience (in months)	0.59	0.94	0.41	0.48	.634
Experience with collaborative learning*	3.00	2.88	1.06	1.73	.188
Experience with instructional technology**	2.47	2.56	1.76	2.62	.083
Experience with teacher dashboards**	0.94	1.50	1.12	1.38	.262

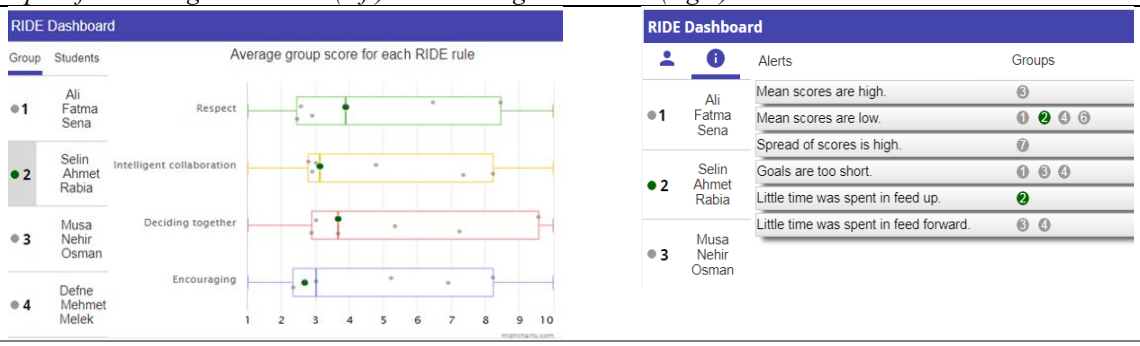
* measured in 'class periods' (i.e., class periods in institutions are 40 to 50 minutes in general)
** range 0-5 (i.e., never used to always used)

Teacher dashboards types

The *teacher dashboards* presented data gathered from a collaboration reflection tool, called RIDE Assessment Tool designed by Eshuis et al. (2019). RIDE is an abbreviation of essential characteristics of successful collaboration (i.e., Respect, Intelligent collaboration, Deciding together, Encouraging). This tool required students to collaboratively reflect on their collaboration and logs data on student's self and peer assessment for each RIDE rule (in a 10-point Likert scale), student's written reflections, and their time on task in the tool.

Figure 1

Example of Mirroring Dashboard (left) and Alerting Dashboard (right)



In total nine simulated dashboards were created, each dashboard presented 'fictitious' data of a class that had collaborated and reflected on their collaboration using the RIDE tool. Each dashboard presented data of 21 students (a common class size) who collaborated in triads (a common collaboration set-up used in education). Data in each dashboard would include one or more groups with common collaboration problems. For each of the nine dashboards, three versions were created: *mirroring dashboards* only provided visualizations of the data, while in *alerting dashboards*, alerts were added to highlight groups that might have specific issues (see Figure 1). In *advising dashboard*, the alerts were complemented with advice for teachers on how to follow up on the provided

alerts (e.g., for the alert 'mean scores are low' teachers would receive the advice that students might not understand that RIDE rule and additional instruction could help them)

Measurements

The amount of participants' *identification of 'intended' problems* in each dashboard was coded. If all intended problems in a dashboard were identified correctly, they received the score of 1, if only part of the problems was identified the score would be a derivate (i.e, 1 out of 2 scored as 0.5). The total score was the sum of the score of all dashboards, ranging from 0 to 9. A high score meant that the participant identified all urgent problems.

Participants were not restricted to detect only one problem in dashboard simulations. Participants might think some situations as a problem, although they were not intentionally illustrated. Participants' rationale for stating a specific problem were inspected in detail. The number of agreed problems were decided after checking whether they had a clear rationale for those problems by referring to the related data. The percentage of agreed problems among all detected problems in a specific dashboard was calculated. Mean score for *detection of unintended problems* refers to the mean of these percentages for each dashboard.

Results

A one-way between-groups ANOVA was conducted with *condition* as independent variable (i.e., mirroring, alerting, and advising), and the number of detected *intended problems* as dependent variable. The results revealed a significant difference, F (2, 47) = 5.04, p = 0.010, eta squared 0.18. Post-hoc comparisons using the Tukey HSD test indicated that teachers in the mirroring condition (M = 1.51, SD = 1.20) performed significantly poorer than the teachers in the alerting condition (M = 3.00, SD = 2.04, p = 0.023) and advising condition (M = 2.98, SD = 1.33, p = 0.023). There was no significant difference between advising and alerting condition (p = 0.999).

In addition, a one-way between-groups ANOVA was conducted with *condition* as independent variable (i.e., mirroring, alerting and advising) and *detected unintended problems* as dependent variable. The results revealed a significant difference, F (2, 47) = 4.01, p = 0.025, eta squared 0.15. Post-hoc comparisons using the Tukey HSD test indicated that, on average, teachers in the mirroring condition (M = 51.06, SD = 23.10) performed significantly poorer than the teachers in the alerting condition (M = 70.76, SD = 23.50, p = 0.032), but did not differ from the teachers in advising condition (M = 67.65, SD = 18.04, p = 0.076). There was no significant difference between advising and alerting conditions (p = 0.910).

Discussion

In this study, the impact of different levels of support provided in teacher dashboards on teachers' noticing was investigated. In line with our hypothesis, teachers' noticing improved when they worked with dashboard types that included some form of support (i.e., alerts or advices). Teachers using alerting and advising dashboards detected the critical cases that were indicated via the support more often than teachers who worked with a dashboard that merely 'mirrored' the data. In general this aligns with findings in literature where researchers found that providing support increased teachers' detection accuracy of critical situations (Casamayor et al., 2009; Schwarz et al., 2018). But the results seemingly contradict with findings by van Leeuwen et al. (2019). In their study, dashboard type did not affect successful problem detection, but they did notice that teachers using advising dashboards demonstrated more in-depth interpretation of the provided information.

Though the previous finding indicates that providing support might be the ideal option, it should be noted that over-structuring or providing too much support can cause less effortful processing. Meaning that note-worthy information might go unnoted. Teachers in the current study were encouraged to interpret all the data, instead of just looking at the summary page. Therefore, their detection of problems that were not addressed in the alerts or advices was also evaluated. The results revealed that the participants using alerting dashboards detected unintended problems better than the participants using mirroring and advising dashboards. Unexpectedly, the participants using advising dashboards (with the highest level of support) performed similar to participants who worked with the mirroring dashboards (no support). This showed that although the advising dashboard supported teachers in the detection of 'intended problems', the high level of support might have limited teacher's noticing. This finding corroborates the idea that a high level of support for pre-service teachers might cause a "mimicking" effect (Gaudin & Chalies, 2015). That is, when highly structured support is provided, pre-service teachers might over rely on the support and might simply express what they perceive as "right" based on support, instead of evaluating the data critically (Brunvand & Fishman, 2006; Gaudin & Chalies, 2015). Based on this, we carefully conjecture that more support does not always equal more effective use. This supports the general consensus that the level of support in dashboards should be tailored to the needs of the users (Brouwer & Robijns, 2014).

Overall the findings support the conclusion that teacher dashboards with support (like alerts or advises) are likely to be more effective than dashboard that only mirror the data. However, designers should be wary that

more detail (like advices for further pedagogical actions) might not necessarily benefit teacher's interpretation of the provided data. There is a risk of mimicking and suboptimal processing. With these findings, it should be noted that the sample size was relatively small and that the participants were pre-service teachers who were relatively inexperienced on teaching collaborative learning and using teacher dashboards. Therefore, they are more likely to demonstrate a tendency to over rely on support. Based on the insights of this study, it can be said that, further design attempts for this kind of dashboards should be careful with providing too much support, but different target groups might respond differently. The findings emphasize that dashboards should be carefully tailored to the experiences and needs of the users.

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International Society of the Learning Sciences

“Can Molecules Change their Color?” Exploring Students' Non-Canonical Ideas while Programming a Model of Diffusion

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Abstract: This study investigates students' non-canonical ideas while creating computational models. Four 5th-grade students individually observed a diffusion experiment and created a model to explain the experiment using domain-specific programming blocks. Results illustrate that translating ideas into code reveals various non-canonical ideas. We argue that a limited number of blocks does not interfere with students expressing their ideas. However, creating domain-specific blocks for modeling needs to be a thoughtful and carefully designed process.

Introduction

Designing computer models is a promising approach to science learning. It combines the advantages of traditional modeling with computational literacy, opening new possibilities for inquiry-based learning (Weintrop et al., 2017; Wilkerson, 2015). In the past decade, many new environments have been designed to allow kids to create their own models using block-based (as opposed to script-based) programming languages and other innovative user interfaces such as NetTango (Horn et al., 2014), Deltatick (Wilkerson et al. 2015), StarLogo Nova (Klopfer et al., 2009), ViMap (Sengupta et al., 2015), or the phenomenological Gas Particle Sandbox (Aslan et al., 2020). Domain-specific block-based programming environments often use a small library of blocks based on canonical scientific ideas, thereby allowing students to focus on a particular aspect of a phenomenon. In science classes, these modeling environments are often used to confirm a theory rather than as an inquiry tool, so students don't have the opportunity to use models to test and explore their own hypotheses. Students are given a final, canonical model that scientists have developed over numerous years, and little time is spent showing them the evidence for the model or allowing them to construct models by themselves (Krajcik et al. 2012). In some cases, students are asked to use or manipulate a model from existing blocks/elements that present a “canonical" scientific explanation of a phenomenon. In doing that, students may not understand that scientific inquiry is necessary to design models and that model building is an iterative process that builds on the results of inquiries verified by data. With this context in mind, we designed domain-specific blocks of the scientific phenomenon of diffusion as an extension to the visual programming environment Scratch (Fernandez et al., 2021).

Diffusion is a fundamental concept in many fields, including chemistry, biology, and physics (Friedler, Amir & Tamir 1987). However, during the last 30 years, several studies have shown that it is extremely difficult for students to master the concept of diffusion (Odom, 1995). In this paper, the term "idea" is used to refer to the understanding that students have developed about the phenomena of diffusion of ink in hot and cold water. For the purposes of this paper, we define "canonical ideas" as science ideas that are typically found in textbooks, and "non-canonical ideas" as explanations for scientific phenomena that are not commonly used in textbooks or in traditional lab activities; this includes students’ initial ideas that are different from normative scientific concepts. In this sense, designing a model with domain-specific blocks can be a valuable way to disclose students' non-canonical ideas about diffusion while students are still in the midst of an inquiry activity. In this paper we present students' non-canonical ideas on the topic of diffusion while they design a model using a block-based computer modeling environment. These alternative ideas can be a starting point for teachers, curriculum designers and designers of educational environments to design activities and environments that allow students to test and develop their ideas. Our paper asks: What non-canonical ideas do students have about diffusion? How do they express these ideas while designing models using a computerized modeling environment?

Methods

The Scratch scientific diffusion model using domain-specific blocks

We created nine domain-specific blocks related to diffusion as a Scratch extension for younger audiences who lack programming knowledge (Fernandez et al., 2021). Each block was designed to embed a set of commands that perform a specific key procedure related to diffusion. The idea was that, rather than spending time dealing

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with the complexity of the code, students could focus on testing and refining their ideas about the mechanics of diffusion while designing a model. While we felt it was important to have specific blocks that allowed learners to engage easily with the big ideas related to diffusion we defined, we also wanted learners to be able to represent and test their own ideas about the phenomenon rather than being restricted to only the scientific ideas we had previously considered.

Participants, settings, and instructional sequence

The first two authors recruited seven US 5th-grade students (10-11 years old), four boys and three girls, to participate in this study. Five out of seven students (71%) were familiar with Scratch before the study. Each student participated individually in a one-hour Zoom call with the authors, wherein the authors instructed the diffusion session for the present study. We analyzed data from the four students (two boys and two girls) who had the richest sessions in terms of detailing their thoughts. The hour-long online session was based on the Bifocal Modeling approach (Blikstein, 2014; Fuhrmann et al., 2018) and was split into four "mini activities" followed by a short reflection interview. In the activities, students: (1) watched two diffusion videos with food coloring in water at different temperatures, described what they observed, and created a hypothesis to explain the phenomenon observed; (2) were presented with several examples of models and were asked to define and explain the function of a scientific model; (3) were introduced to the Scratch extension and the domain-specific blocks and explored the environment in an open-ended way; (4) were asked to work on three models (of cold water particles, of ink spreading in water, and of ink spreading in cold and hot water) that scaffolded them to design their final model of diffusion.

Data sources and analysis

Data included four hours of video recording. Students and parents signed consent forms for the Zoom sessions to be recorded. Videos were transcribed and analyzed with a focus on students' ideas regarding the process of diffusion that were expressed and captured during their programming session. We scanned the transcripts and selected the non-canonical explanations regarding diffusion.

Results and Discussion

We illustrate five different non-canonical ideas expressed by students while designing a model for diffusion using the Scratch Scientific Modeling Extension. For each idea, we present examples of how students stated it and how (if at all) they expressed it with blocks from the environment. All names are pseudonyms.

1. Water particles change their color when touching ink particles

Another non-canonical idea expressed by one student was that the phenomenon of diffusion can be explained by the propensity of water particles to change their color when touching an ink particle. Alice was designing her model of diffusion in hot water when she was looking for a new block that would make the color of a particle change, explaining "*I am trying to change the color of the particles. I think that since the color is dispersed...this will be the change in hot water.*" Her hypothesis was that when an ink particle touches a water particle, it "infects" it with its color, so the water changes color to become the same color as the ink. However, she could not translate her idea into a working code, and thus she couldn't test her hypothesis (Figure 1).

Figure 1
Blocks used to represent particles changing their color when touching

2. Ink and water particles move at different speeds

One student, Alice, expressed the idea that ink and water particles do not move at the same speed when mixed in one receptacle, saying "*I think that water will be a little slower than the food coloring.*" To represent this idea in the model, she used the "set speed" block to set different speeds for the two particles (ink particles with high speed, and water particles at medium speed). When she ran the model and watched the results, she changed her mind regarding this explanation, saying that "*Actually, they will be the same speed because I think that they [food coloring particles] are mixing with the water [particles].*" She then adapted her model, setting the speed

of all the particles to high and concluding "*yes...they are all the same speed and mixing together.*" In this case, the existence of a block to change the particles' speed enabled Alice to test her ideas using the model. Thus, she shifted from a non-canonical idea about ink and water particles moving at different speeds to the canonical idea that both particles move at the same speed, even without explicit instruction from an external source.

3. Temperature is related to the "weight" of the particles

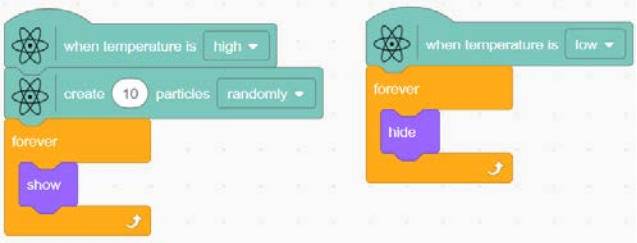
Introducing the variable of weight to the system, Tonia thought that the particles in hot water were lighter than those in cold water and floated on the surface: "*I guess the hot water particles are maybe lighter and they float to the surface faster.*" She mentioned that the behavior observed and the density of the particles is related to the bubbles in the hot water: "*I don't know, but this relates in my mind to the bubbles... I don't know why.* " Tonia expressed these ideas verbally without translating them into a model.

4. Temperature is related to a particle's appearance and disappearance

This non-canonical idea was that in high temperatures more particles are appearing, and that they disappear as the temperature gets lower. When designing his model of cold and hot water, Owen related the behavior of particles at different temperatures to their appearance or disappearance. When researchers asked him to further explain his idea, he only said, "*What I want to do is this: when the temperature is high my costume shows and when the temperature is low my costume does not show*." However, he faced challenges while coding his model and could not test his ideas since he was not able to create a working code (Figure 2).

Figure 2

Blocks used to represent particles appearing and disappearing



5. Temperature is related to the number of particles

Three students expressed the non-canonical idea that hot water and cold water contain different numbers of particles, and that that explains why ink behaves differently in the two temperatures.

Alice was designing the diffusion of ink in cold water when she suggested that "cold water particles move slower and there are less of them." When asked to explain her idea, she stated that "in cold water, they are all bunched up. In hot water, they are all mixing and stuff. In the hot water there are more particles because they disperse more." To adapt her model to express this idea, she said: "For the cold water, I will change the speed and make less amounts of particles." and changed the number of particles in her model from 30 to 20.

Mark expressed this same idea, relating it to a "chaotic movement". While designing his model, he reasoned about ways to make it more similar to the experiment and said, "I would change the water molecules to be really, really chaotic. And I would change the food coloring molecules to be about as chaotic as the water molecules." To make the particles more "chaotic," he started by changing the number of particles: "To make it more hectic I can make this one [ink] 20 and this one [water] 35." After changing the number of particles in the code and observing its effects, he confirmed his idea that more particles make the water movement more chaotic: "Yes, that's way more hectic. (...) If I wanted it to be less hectic, this [ink] would be 10 and this [water] would be 15." In this case, his non-canonical idea resulted in a model that behaved similarly to the experiment.

Tonia's initial thought was also that hot water had more particles than cold water. While designing her model for hot water, she stated that "In cold water I guess I will make less particles. My hypothesis is that cold water has less particles than hot water." When creating the hot water model, she said: "[In hot water] I guess there are more particles because it is hotter, but I don't know... The cold water does not have so many particles." So, she started by creating 100 water molecules and then changed it to 500 to represent hot water.

Conclusions

This study presents examples of non-canonical ideas expressed by 5th-grade students while designing a model of diffusion using a block-based programming tool. These non-canonical ideas were not imagined by the

designers of the original tool. These ideas are related to phenomenological primitives, or p-prims (diSessa, 1993; Hammer, 1996) defined as relatively minimal abstractions of simple common phenomena, often hard to access and not easily put into words. Often, the p-prims, these self-contained explanations based on students' intuitive background knowledge, are non-canonical ideas. In science learning, it is important to offer students opportunities to explore these ideas, using them as epistemological resources to get to the accepted explanations (Hammer & Elby, 2003). However, designers are reluctant to present them in their environment, and teachers are concerned about using them to guide instruction. We argue that in order to incorporate these non-canonical ideas into science instruction and environments, it is essential to identify them for different reasons. Being aware of students' prior knowledge and identifying possible sources of confusion allow science educators to mediate the scientific knowledge-building process for learners; help them make sense of how scientific models are generated and validated; and scaffold learners' conceptual understandings rather than merely giving them the "correct answer." While learning how students' reason about a phenomenon, designers and researchers can create more domain-specific blocks that acknowledge students' initial ideas and sensemaking processes. As in Alice's reasoning about particles' speed, equipping students to model their non-canonical ideas can lead to their independent development toward disciplinary norms. Also, for designers, these ideas can guide the development of tools that acknowledge students' non-canonical ideas as a way to scaffold their sensemaking process based on their own hypotheses about the phenomenon. Although this study included only four students, future work could determine the degree to which these non-canonical ideas are shared among learners, helping prioritize their inclusion in block-based modeling environments.

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Addressing challenges in changing science teaching in the Global South: an integrative model for science education reform in Brazil

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Abstract: Development of sustainable science education reforms requires transformation, and therefore involves integrative approaches that result from collaboration between researchers, teachers and policymakers. Using a DBIR approach, we developed a model for design and implementation of new science standards that addresses three main challenges identified throughout the research: fostering teachers' agency and deep conceptual knowledge; translating principles into lesson plans; and creating resources and expertise.

Introduction, background and context

In recent years, there have been significant efforts to develop new science standards and frameworks that emphasize not only conceptual knowledge but also the practices of science and engineering (e.g. ACARA, 2016; British Columbia Ministry of Education, 2017; National Research Council, 2012). However, implementation remains an important challenge. If the goal is to sustainably develop innovative standards, the "document" itself is not sufficient, and the process of implementation must also be prioritized (Levin, 2010). Moreover, to allow for transformation, teacher buy-in is perhaps the most important factor for successful implementation of curricular reform (Burt & Boesdorfer, 2021). This is even more critical in developing countries like those in which our research takes place.

In this paper, we describe a science education reform project that was developed over four years in a city in the northeast region of Brazil (Fernandez et al., 2020). The project was initiated in 2017 by the city government in collaboration with a US-based research team to redesign science education for the city's 49 K-9 public schools. Members of the research team designing the program and working with teachers were Brazilian and the work was conducted in Portuguese.

In Brazil, science teaching is often based on lectures, using the textbook as the main reference for lesson planning and students' activities (Andrade & Massabni, 2011; Bassoli, 2014). Most teachers do not have the necessary infrastructure and human support to conduct science activities in their schools, because of classroom size (usually more than 35 students/classroom) and lack of space and materials (Andrade & Massabni, 2011). Official reports in Brazil show that only 8.6% of public schools have adequate science labs, and 11.5% have access to science kits (BRASIL, 2020).

Methods and Design-Based Development of the Integrative Model

Educational systems in developing countries are very different from those of the US. In Brazil, expenditure per student is one order of magnitude smaller, infrastructure for professional development is lacking, and there is much less funding for research and implementation. As such, reform guidelines developed elsewhere might not work in the Brazilian context, and therefore we had to create a new implementation model to account for those specificities. The work described in this paper comprises three cycles of implementation and data collection, in which different components of the project were evaluated and refined using a design-based implementation research approach (Fishman et al., 2013). We worked with a group of elementary and middle-school science teachers invited by the secretariat to be part of the curriculum committee, as well as with teacher educators from the city's provider for in-service teachers' PD (School of Teacher Professional Development) and municipal coordinators for elementary and middle school levels at the Secretariat of Education. A total of eight teachers actively participated throughout the project (1 elementary and 7 middle school teachers). Three other teachers started the process but, due to individual constraints (such as not having enough time, being reassigned to other schools, or not showing interest in trying new approaches to teaching), only participated in the initial meetings and then left the project. New teachers joined the project during the process, and as such the number of participating teachers varied from one implementation cycle to another. Our data sources include extensive field notes, evaluation meetings, interviews, questionnaires and documented interactions with teachers and administrators. Based on the data and on our assessment of local educational policies, we identified challenges that informed our initial design, as well as further redesigns.

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Findings and discussion

At the beginning of the project, we set out to develop a collaborative approach in which the new curricular standards would be designed together with elementary and middle school science teachers. In preparation for this work, we conducted a pre-survey among the teachers participating in the working group, and found that science teaching in the city was often very traditional: Teachers usually started a lesson by reading the textbook or presenting a lecture, followed by exercises from the textbook (Fuhrmann et al., 2018). Experiments were rare, and when used, followed very strict, step-by-step procedures, serving as a way to illustrate theoretical content previously presented by the teachers.

After gaining this understanding of the context of science learning in the city, we developed an integrative approach to reform science education with four elements: (1) development of new city-wide science standards co-designed with teachers; (2) professional development for elementary and middle-school science teachers, (3) implementation of infrastructure (low-cost makerspaces with science lab resources), and (4) hiring a dedicated pedagogical redesign teacher who co-designs curricular units with other teachers, develops toolkits for the units, and conducts research on student learning, and who we called the "pedagogical redesign teacher". Below, we describe the main strategies deployed to achieve each of these elements.

Table 1
Overview of the process

Cycle	Description
Pre-Cycle 1 May 2017	**Workshop with Stakeholders** (city's Secretary of Education, Teacher Educator from School of Teacher Professional Development, local university Professor involved in the implementation of educational technology in schools)
Cycle 1 Aug 2017	**Workshop** for science teachers: teachers participated in an introductory two-day workshop (work in small groups on science activities and lectures about science education from researchers). **Online meetings:** periodical small group co-design sessions between teachers and researchers; whole group instructional meetings on central themes of science teaching and student learning. **In person meetings**: classroom observation and reflection interview
Cycle 2 Apr 2018	**Online meetings:** periodic small group co-design sessions between teachers and researchers; whole group instructional meetings on central themes of science teaching and student learning **Implementation of makerspaces** at two schools and **reassignment of two science teachers as pedagogical redesign teachers**
Cycle 3 Oct 2018	**Online meetings** between researchers and pedagogical redesign teachers focused on co-design and on reflections about their daily practices

Strategies

1. Development of new city-wide science standards co-designed with teachers

This was the initial primary interest of the city's administration. They had previous experience with setting up groups of teachers led by specialists developing their math and language (Portuguese) curricular documents and envisioned a similar process.

1.1 Fostering teacher agency and deep conceptual knowledge

Our goal was to develop novel science standards in a participative way, considering teachers' perspectives in order to provide the conditions to enable sustainable implementation in an agentive manner within the local reality. Teachers were presented with findings from the learning sciences and their implications in science education (e.g., selection of central ideas, spiral progressions, science and engineering practices), and analyzed how science standards worldwide (such as NGSS, British Columbia, Australia) implemented these innovations. The group analyzed and explored the science component of the Brazilian National Standards (BNCC), and did extensive work to integrate new pedagogies aligned with BNCC's requirements. Doing this work together with teachers was fundamental to building agency, deep knowledge about the theory behind standards, and a sense of ownership.

1.2 Translating principles into lesson plans:

To connect teachers' practice with the science education principles we intended to incorporate into the curricular document, teachers had the opportunity to co-design curricular units with the research team in three cycles, and to progressively incorporate into their practice the main principles guiding the development of the standards. This allowed teachers to experiment and better understand what these strategies could mean in real contexts.

Subsequently, these learnings helped guide the choices made in the design of the document and provided teachers with a greater sense of how these principles can be translated into classroom activities and their potential for students' learning.

2. Professional development in science teaching for teachers

Our initial survey indicated that it would be necessary to build a common vision of science education within the teachers' group, and most importantly, that teachers should be given opportunities to implement and test in their classrooms the concepts and principles of science education that were being proposed for the new standards, rather than just learning about them through theoretical discussion.

In the professional development program, teachers redesigned curricular units that they would implement in their classroom(s) in the near future, with a focus on the connection with their teaching practice. Participating teachers in this working group were middle school science teachers and elementary teachers, as well as teacher educators from the School of Teacher Professional Development. Through periodic small group co-design sessions with researchers, intercalated with whole group instructional meetings where central themes of science teaching and student learning were reflected upon, teachers were encouraged and supported to adopt new concepts and strategies in their lesson planning as well as in their teaching. After implementation in the classroom, teachers and researchers reflected upon the outcomes and teachers' personal perceptions. These learnings were then incorporated into the next cycle of redesign. This process was repeated in three cycles of redesign throughout a period of 16 months.

At each new cycle, new increased levels of sophistication/complexity were expected in the planning and/or implementation. To define these requirements, researchers were informed by the experiences and outcomes of the previous PD cycle.

In all cycles, teachers received continuous support and mentorship from researchers, in the form of periodic meetings and 1:1 encounters in more specific moments (such as when individual teachers were refining their learning goals, researching and designing classroom activities aligned with these goals, or refining and planning their teaching strategies for upcoming implementation in the classroom). Teachers in the group were encouraged to collaborate and share experiences during the course of the PD. They planned in groups, and also reused and built upon curricular units that their colleagues had designed.

3. Implementation of infrastructure

It was important that teachers were given access to rich resources and materials, thus in our strategy we designed new spaces for learning (low-cost hybrid makerspace/science lab). Two pilot labs were implemented in one full-time and one part-time school (the two models of service in the city). We worked with architects that designed a laboratory blueprint for modular areas that include woodwork, electronics/electricity, digital fabrication, crafts, sewing machines, and science. These laboratories were the site for teacher training as well as for the pilot implementation of curricular units by teachers. Currently, the municipality is working on expanding these laboratories to another eight schools, and has a goal of ultimately expanding them to serve all schools.

4. Creating local expertise

An important takeaway from this project is the importance of the co-design partnerships between researchers and teachers as a strategy to support teachers in redesigning and implementing their lesson plans. Researchers held periodical meetings to discuss the big ideas and learning goals, helped to research resources and design activities that could support students' engagement with science practices and promote learning aligned with the established goals, and gave feedback and support for implementation. From this experience, we established a new school position of a "pedagogical redesign teacher" centered on the co-design of curricular units with other teachers, development of resources for teaching and learning, and on researching student learning (rather than on teaching technology classes).

In the second cycle of co-design, the two middle school science teachers designated as pedagogical redesign teachers started participating in co-design meetings with researchers and teacher(s), as well as additional reflection meetings with the researchers as part of their professional development. In the third cycle, the pedagogical redesign teacher took the lead in the partnership with the classroom teachers, with the support of researchers. This strategy contributed to the sustainability of the program, by creating local resources and expertise.

A new cohort of pedagogical redesign teachers is currently being formed to oversee the upcoming new labs. Moreover, one of the pedagogical redesign teachers has taken a manager role within the Secretariat of Education that involves collaborating, supporting and training new pedagogical redesign teachers, and overseeing the implementation of the new labs.

Outcomes

We are currently working on the implementation of the new science standards. The core team of teachers involved in the development of the document is now leading the implementation workshops with support from the researchers. New labs will be implemented in the city and the core team is involved in providing the professional development for the new pedagogical redesign teachers – through technical workshops and by partnering with them in the redesign of curricular units. In the group of teachers that participated in the professional development, some presented their work as research papers at conferences. Two teachers entered a masters' program based on their science teaching practice during the development of the project.

Insights from the study have been integrated into the permanent program of the center of in-service teacher PD, thus reaching all middle-school teachers in the system.

Sustainability is a major concern in this project. Working closely and collaboratively with teachers, teacher educators from the school of teachers' PD, and administrators has been critical to establishing an integrated system that is also reflected in policy.

Conclusion

To integrate modern science pedagogies to the Brazilian reality, considering the lack of resources and teacher professional development, our model identified challenges related to teacher agency, translation to lesson plans, the creation of materials, and the development of expertise. Taking into account the local context and school culture, working with teachers and policymakers, we co-designed ongoing solutions for those challenges, and created a culture of design-based iteration. Further research is in progress, and our data so far – in the form of classroom observations and analysis of lesson plans delivered by participant teachers – indicate that classroom practices and pedagogy are significantly different than at the onset of the project.

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International Society of the Learning Sciences

Cognitive Apprenticeship: A New Lens for Better Understanding Online Doctoral Provision

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Abstract: By and large, the specific characteristics of online doctoral education is unknown. This qualitative study is the first attempt to unpack what it means to be an online doctoral student. I employ the concept of cognitive apprenticeship to help us better understand the individual trajectories of students in online programs. The data show that when the technological affordances are coupled with the structural design, doctoral students in online programmes seem to encounter further challenges that hinder their development as scholars. This research provides both theoretical and practical accounts for further discussion and debate on online doctoral provision in general and doctoral students' experience in these programmes in specific. It concludes that rethinking the theory and practice of online doctoral provision in relation to the concept of cognitive apprenticeship can provide more nuanced means for understanding the specific characteristics of online doctoral provision.

Research Background

Doctoral experience is a "journey from apprentice or novice to master (Bastalich, 2017, p. 1146), during which "the successful student will typically develop from a state of relative dependency to competent autonomy over the period of candidature" (Gurr, 2001, p. 85). Here, I want to understand one fundamental component necessary for this transition: apprenticeship. In specific, I want to understand the individual trajectories of online PhD students through the lens of cognitive apprenticeship. Whilst apprenticeship is hardly a new concept for doctoral education (Jones, 2013), research on this topic limited its scope with explaining supervisory relationships. I propose to utilise the concept of apprenticeship to understand doctoral experience, particularly the process of enculturation of online doctoral students.

As a natural way to learn, "apprenticeship was the vehicle for transmitting the knowledge required for expert practice" (Collins, Brown, & Holum, 1991, p. 6). It is possible to extend this definition to doctoral education: students acquire sophisticated research skills or practical tacit knowledge (e.g., interview skills, research ethics) through their interactions with their supervisors and other experienced researchers, as well as their peers. It is through this relationship that discipline-specific knowledge is communicated, utilised, and cultivated. This type of apprenticeship, however, often operates at the cognitive level. I employ the concept of cognitive apprenticeship to explore both the implicit and explicit processes by which online doctoral students can acquire the knowledge and skills necessary for scholarship. Research I report in this manuscript is concerned with one of the four dimensions of the cognitive apprenticeship framework: sociology.

Theoretical Framework: Doctoral Education as Cognitive Apprenticeship

Research has long shown that apprenticeship is one powerful framework for conceptualising learning implicit knowledge and skills (Lave & Wenger, 1991). According to this framework, learning occurs through various apprenticeship arrangements through a relational process of legitimate peripheral participation, suggesting that "activities, tasks, functions, and understandings do not exist in isolation; they are part of broader systems of relations in which they have meaning. These systems of relations arise out of and are reproduced and developed within social communities" (Lave & Wenger, 1991, p. 53). In this model, learning is about acquiring domain-specific methods through a combination of observation, coaching, and practice (Lave, 1991).

The concept of cognitive apprenticeship is built on these principles, but it goes beyond practical skills and focuses on cognitive skills. Cognitive apprenticeship is concerned with knowledge required for expertise: not only learning subject matter specific concepts, facts, and procedures but also acquiring nuanced knowledge about how to learn and when to apply, new concepts, facts, and procedures. Two major differences between cognitive apprenticeship and traditional apprenticeship should be noted here. First, in traditional apprenticeship, the demands of the workplace define the nature of the relationship between the apprentice and the master, not the concerns with pedagogical scaffolding; whereas, in cognitive apprenticeship, problems are designed with increasing complexity to demonstrate the skills or techniques required for the task. Second, traditional apprenticeship is context specific whilst cognitive apprenticeship prioritises generalizing knowledge. These two major differences operate to produce different relationships; that is, "individual learners and groups of learners navigate complex matrices of intersecting

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sociomaterial and epistemic practices" differently (Simmons, Parchoma, & Koole, 2018, p. 1).

Research Question

How and what are the ways in which the patterns of relations performed and recursively emergent within the socio-material environment of online doctoral courses?

Research Design

This phenomenological study was conducted in five different online doctoral programmes in two different research-intensive public universities based in the UK and Canada. I only focused on the students who were close to the completion of their thesis project or recent graduates of the programmes within the past five years per discussed above in the introduction.

I employed the descriptive and critical discourse analysis in order to construct meanings across participants (Fairclough, 2003). Several meanings emerged through this process and I combined, compared, and contrasted them in order to create more comprehensive yet more distinct meanings.

Findings

There are four characteristics affecting the sociology of cognitive apprenticeship: situated learning, community of practice, intrinsic motivation, and exploiting cooperation (Collins et al., 1991). Here, I present the findings with respect to these four categories.

Situated Learning

The data suggest that sense of support and being able to personalise the tasks were deemed essential for situated learning in online doctoral programmes. For example, Judith, a fourth year PhD student, stated that she felt that the instructor and the members of the cohort did a great job of supporting each other and she felt especially "really got a lot out of the [synchronous] collaborative sessions". Till found it easy to use the synchronous and asynchronous communication. For him, the text and multimedia-based broadcast resources were "essential for completing assignments". Bruce stated that he appreciated the ability to "chat about the assignments using the audio [synchronous] feature" with both peers and the instructor. Maggy particularly valued opportunities to "talk in real time via ongoing [asynchronous] text and periodic [synchronous] audio" with both her peers and the instructor provided within the course website. Sherry stated that she wanted to "talk with the instructor and the scheduled synchronous sessions provided those opportunities". Elaine echoed this sentiment and went on to say, that "2-way communications… during the live [synchronous] session(s) was easy". These accounts are important: if students are to understand the purposes or uses of the knowledge they are learning, they should be able to "learn by actively using knowledge rather than passively receiving it" (Collins et al., 1991, p. 45). I was, however, not able to find evidence that students acquire knowledge in a dual form, both tied to the contexts of its uses and independent of any particular context. The abstraction of knowledge is an important goal for situated learning: the unbinding of knowledge from a specific context fosters its transfer to new problems and new domains. It is this fluidity of the patterns of relations that allows movement of knowledge depending on the emergent characteristics/membership of the assemblage.

Community of Practice

The sense of community of practice was strong; however, the sense of isolation caused by the impersonal nature of online spaces seems to dissolve relatively strong social ties that may have developed earlier in the programme. For example, Josh, a fourth year Ph.D. student explained how he failed to continue these relationships:

> we had the residential [meeting] in the first year, we had the residential [meeting] in the second year … Because we felt that we really wanted to maintain that sense of community and it was actually really important to us. So, we tried to extend it as long as we could, and then we all went off after the residential [meeting]…. we were really motivated. And then it all sort of started to [fade] unfortunately.

For Josh, sense of community was important but despite their best efforts, they failed to maintain these relationships:

> I think the community aspect just sort of dissipated really, and having spoken to a few people in previous cohorts, I think they felt the same thing. How do you maintain a sense of community? I don't know, I … would have managed to sustain it, it would have been nice because we had a really strong sense of community, but we couldn't find a way [to maintain it].

When the patterns of relations within the assemblage are not maintained, students can struggle with developing a sense of personal investment and mutual dependency. Along with time, geographical proximity emerged as an important factor for online doctoral students' socialisation. For Russell, a fifth year Ph.D. student, physical distance

was played a role in his attempts to keep the social ties and connections:

> there's one of my cohort who's here in [my country], and the beginning of [thesis work] we still help each other out and chat. I think like it's good if you have someone geographically sort of close, which is really, really helpful.

However, whether it is due to time constrains or geographical proximity, individual attempts to promote a sense of community of practice seemed to have a short life span.

Unfortunately, students seemed to internalise and normalise the sense of isolation for their development as a researcher or scholar. In fact, the personal nature of the doctoral thesis was the main theme in their explanation of the thesis process.

Intrinsic Motivation

The data show that students were able to comprehend their position shifted within the pattern of relations. Participants in this research unanimously acknowledged learning academic writing as the catalyser for the transition from student-like mindset to developing their own identity as a scholar.

I was able to find traces of intrinsic motivation in our data, albeit scarce and weak. Angela, a recent graduate, for example, explained that:

> Learning to write academically and learning to [give] feedback was very important to me. The process of doing it; looking at other people's work was very interesting. I learned my peers have very different perspective. The most important thing I learned is that you can you can argue anything; you just have to explain why.

When Angela was asked to articulate as to why she identified learning academic writing skills was an important process for her, she continued:

> Learning how to write helped me so much into becoming an independent researcher and also someone who can … um, who is able to defend her position. My self-confidence was just, yeah, that has changed completely. Now I see PhD as something sensible to achieve. I managed to get something published last year and there was a great sense of achievement in it.

Angela's accounts can explain how doctoral students internalise their role expectations through the integration of the self and the professional role. "Individual and social roles, personalities and social structures become fused" and students "form a professional identity" (Weidman, Twale, & Stein, 2001, p. 14). Students, then, can identify themselves as full members of academic or professional community. In terms of sociology of cognitive apprenticeship, this means that a new identification emerges out of a new pattern of relationships.

Exploiting cooperation

Whilst the asynchronous text-based group discussions were intended to support triads of students in peer review processes, these fora were not strictly private. Anyone in the class could read and even respond to posted draft work. This design within the course was intended to be an optional way for individual learners to engage with variety of their peers in order to gain insights into what additional peers in the course were doing and discussing. Maggy noted that the group discussion provided opportunities to "get feedback" on draft work and "offer feedback on others'" draft work, which resulted in her "using the [assessment] rubrics several times" and this process provided opportunities to also check on "other people's feedback". Till commented that he was "able to understand and learn some new principles for supporting others' learning". These accounts indicate that the online space provide flexible patterns of relations that can support group work. Scarcity of opportunities for cooperation, however, suggest that these opportunities are not inherent in online doctoral provision.

Peer and instructor feedback both in the asynchronous threads and during synchronous sessions provided opportunities for students to review their peers' sets of expertise. For example, Maggy noted that she "learned a lot from others". Jenny noted that engaging in the course tasks "introduced us to a variety of skills that could be applied to support learners in many different settings". Sherry remarked that she became a proficient multimedia developer: "not only did I learn how to create using different programs I feel I learned how to learn new programs/techniques". Sherry's articulation is important to note because it shows that the online component of the assemblage played a role in her identity formation.

Discussion and Conclusion

Doctoral experience can be understood as "networks of learning relationships", whereby students are positioned "at the centre of a constellation of others" (Cullen et al. (1994) as cited in Boud & Lee, 2005, p. 502). Precisely because the contextual and situated nature of this experience, doctoral education, particularly in online programmes, requires different level of understanding and commitment depending on individual needs, goals, profession, and the nature of

the discipline. Cognitive apprenticeship, I believe, is the most productive theoretical framework to understand and appreciate these nuances: it is a useful paradigm to explicate and instil the notion of scholarship to doctoral students rather than a packaged formula for teaching. The level of expert support doctoral students receive should gradually reduce as they move from peripheral participants to central members; and, completely fade when doctoral students slowly become independent scholars. Data I reported in this manuscript explains this process.

I can provide some key observations for this process in online doctoral programmes: 1) the choice of tools (and other elements of the assemblage) permits a variety of patterns of relations; and, 2) as learners engage with the assemblage, their needs, desires, and activities co-structure the assemblage, and as such, the development of broad and/or sub-groups emerge. This process, nevertheless, as the data show, does not naturally occur in online doctoral programmes. In fact, it is evident in the data that the lack of scaffolding for apprenticeship appears to be disconcerting: as the nature of the assemblage shift, the identity of doctoral students shifts; however, this transference is not enough for students to identify themselves as a scholar. Doctoral students need a sense of community of practice; in specific, they need a cognitive scaffolding for this metamorphosis to occur. Our challenge, then, is to inscribe potentialities into programme designs to allow for multiple assemblage formations that can help with situating different learners in the complex virtual continuum.

Data of this research show that structural elements inherent in online doctoral programmes occasionally support the characteristics affecting the sociology of cognitive apprenticeship. Participants in this research confirmed that some opportunities exist for situated learning to occur and community of practice to be formed; however, these are not pedagogically designed elements of teaching/learning but serendipitous experiences. Opportunities for intrinsic motivation and exploiting collaboration, on the other hand, are poor and short. Taken altogether, the findings convincingly show that students lack enculturation in the principles of cognitive apprenticeship. This lack of enculturation is manifest in how they internalised their isolation as a natural process inherent in the thesis work. The result is that they are inaccurately equating the unstructured and personal nature of the thesis work with the experience of working alone which has resulted from the lack of program structure at this phase of the doctoral journey.

Overall, there is a lack of knowledge and frameworks for understanding online doctoral provision. I suggest a shift in the research agenda concerning this issue. Perhaps, the first step towards a more effective direction is to focus less on quantitative measures for success, like enrolment statistics or graduation rate but rather to employ qualitative judgements for the evolution of the doctoral experience. What might be the guidelines for such qualitative approaches? Here, I explored one option: cognitive apprenticeship. According to this perspective, doctoral education is not just about completing a series of coursework followed by a thesis work; rather, it is a transformation from that of a knowledge consumer to a knowledge producer. I believe cognitive apprenticeship can be utilised as a framework for studying this metamorphosis.

The infancy of research agenda for understanding doctoral experience as cognitive apprenticeship warrants that I should be cautious with the conclusions. However, it is evident that we have to rethink the theory and practice of online doctoral provision. It can be argued that when the technological affordances are coupled with the structural design, doctoral students in online programmes seem to encounter further challenges that hinder their development as scholars.

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International Society of the Learning Sciences

LEARNING LAB METHODOLOGY FOR EXPANSIVE LEARNING AND INCLUSIVE EDUCATION DURING THE COVID-19 PANDEMIC IN BRAZIL

Abstract: The global policies of inclusive education often ignored local knowledge and cultural-historical ecologies. As a result, the top-down policies become either irrelevant or oppressive. This study presents a formative intervention study, Learning Lab, conducted in Brazil to design a new system at specialized school for blind and visually impaired students. Fourteen practitioners engaged in nine meetings with the final goal of producing a new system of inclusive education for students with multiple disabilities during the COVID-19 Pandemic. We will present the expansive learning actions, which educators took as a conduit for critical dialogue, collective agency and expansive learning for designing the future of their school.

Objectives

The global movement of inclusive education "as a global travelling policy and practice" (Singal, 2016, p. 7) has often ignored local social-historical-spatial contexts that leads to practices that do not hold or have unintended results. A seemingly unifying set of international recommendations to ensure inclusive education for children with disabilities will take different flavors mediated by culture in specific contexts in Global South (Artiles & Dyson, 2005). In Brazil, for instance, cultural and historical aspects of education (e.g., quality of public school system and political hegemony of specialized school organizations) shaped an initial full inclusive education agenda to a different direction (Mendes, 2019). Though inclusive education legislation asserted students with disabilities the right to access age-appropriate regular education classrooms, it also established a continuum of provisions for those students whose intense and continuous support as well as significant curricular adaptations was beyond what other schools can provide.

Specialized schools for the blind and visually impaired in Brazil

Following a national inclusive education policy, the number of blind students with additional disabilities gradually increased in Brazilian specialized schools for the blind and visually impaired (Mendes, 2019). Internally, the specialized schools for the blind and visually impaired discontinued a self-contained program for blind students with additional disabilities (e.g., autism, intellectual disabilities, and cerebral palsy) to place them in the regular classroom having access to general curriculum content alongside peers with visual impairments. On the other hand, re-structuring of the public regular school system also meant the placement of students with disabilities in the regular classrooms with specialized educational services support. However, in the hierarchy of disabilities, inclusion of students with significant support needs is met with resistance.

Though schooling of students with significant disabilities, historically segregated within segregation, is an uncharted terrain for both specialized and regular schools, they are typically sent to specialized schools taking for granted their collective self-efficacy for addressing the emotional, social, and academic needs of students with significant disabilities (Mendes, 2019). The re-structuring of both specialized schools and the general schools prompted by an inclusive education agenda, placed the specialized schools in a double bind. On one hand, specialized schools historically were envisioned to develop the academic potential of students with visual impairments. On the other hand, the entrance of students with significant disabilities as residues of an inclusive education agenda. These "competing alternatives" take teachers into a need state in which practitioners are "unable to determine the direction of their efforts" (Engeström, 2015, p.133). The need state "manifested in threats and conflict situations" (Engeström, p.154) within spaces struggling to redefine their practices, represent opportunities for potential expansive learning.

Learning Lab: A formative intervention

Informed Cultural Historical Activity Theory (CHAT), Learning Lab, a formative intervention model, aims to empower local practitioners facing daily contradictions in their practice and facilitate expansive learning. Expansive learning stems from the articulation, identification., and resolution of challenges or contradictions in an activity system (e.g., the specialized school). For instance, educating blind students with additional disabilities means adaptations that go beyond Braille, tactile graphics, contrast, or large print books to encompass modifications in content or assessment which disrupt the normative center and trigger contradictions between a previous historical activity and an emerging new form of activity and practice.

To our knowledge this is the first formative intervention for collective systemic design in a specialized school. Furthermore, though using the first generation of Vygotskian CHAT is more prevalent in Brazil, only a

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few studies has ventured into the third or the fourth generation of CHAT which takes activity systems and social movement as the unit of analysis (Cenci et al., 2020).

Theoretical framework

CHAT provides analytical tools to examine and intervene in activity systems (e.g., hospitals, schools, factories, and social movements) facing historically accumulated contradictions (Bal, 2017)). In a formative intervention, participants actively follow a cycle of change ascending from the abstract to the concrete. When accomplished, this movement supports an understanding of challenges not as a mystical form but as a conceptual one articulated in both social relations of the here and now as well as in the larger cultural-historical context (Ilyenkov, 2009). Daily disturbances, dilemmas, or conflicts experienced by practitioners in the local specialized institutions should be analyzed in relation to the evolving activity system of the school which in turn is examined across the larger national and international discourses of special education and inclusion. As individuals progressively understand how the elements of a phenomenon are constituted by the whole, consciousness about reality expands embodied into expansive learning actions towards a transformation process that has the potential to re-mediate practice through innovative pedagogical solutions (Bal, 2017).

Activity systems

Expansive learning stems from the articulation, identification, and resolution of contradictions in an activity system. Across cycles, the subjects within a community of practice and, according to their expertise and related tools, simultaneously shape and are shaped by the object – the element that gives meaning and direction to the activity. Multivoicedness the source of conflict of motives around the object, give rise to the internal contradictions, "the driving force of change and development in activity systems" (Engeström, 2015).

Contradictions

Contradictions are part of every component of object-oriented activity system evolving historically in the context of global capitalism. In the current neoliberal era, the primary contradiction in the activity system of a school, for instance, is the competing motives between accountability (exchange value) and meaningful pedagogy (use value). In this case, contradictions harnessed by dialogue and collective work become a driver for innovation. Contradictions are only visible through their discursive manifestations. Engeström and Sannino (2011) identified four types of discursive manifestations of contradictions: Dilemmas, conflicts, moral conflicts, and double binds. Double binds, the highest level of consciousness and, thus the most aggravated contradiction, demands a collective call for change. Usually, the result is a "third way" in which practitioners generate "novel mediating models, concepts and patterns of activity that go beyond and transcend the available opposing forces or options, pushing the system into a new phase of development" (Engeström & Sannino, 2011, p. 371). This third way depends on multivoicedness embodied in the manifestations of contradictions or level of consciousness.

Learning Lab: A formative intervention model for education systems

Learning Lab is a formative intervention that takes expansive learning theory and respective methodological cycle of expansive learning with a commitment to give voice to historically underrepresented groups in schools' knowledge-production and decision-making activities such as Black, Indigenous, People of Color (BIPOC) and low-income families. Expansive learning is defined as the formation of a new, expanded object and an expanded activity system organized around the new object (Engeström, 2015). Learning Lab differs from other activity theoretical formative intervention approaches) for its commitment to participatory social justice (Bal, 2017). Contributing to the newly emerging fourth generation CHAT, Learning Lab builds heterogenous coalitions and deals with complex societal problems or runaway objects such as racial disparities in educational opportunities and outcomes or inclusion. Drawing from critical education and radical pedagogies, Learning Lab engages school stakeholders in collective decision-making that address disparities in educational outcomes and opportunities experienced by BIPOC students and families. A full cycle of change in Learning Labs encompasses the following expansive learning actions: (1) Forming Learning, (2) Questioning "Here and Now", (3) Analyzing, (4) Modeling, (5) Examining, (6) Planning for Implementation, (7) Reflecting on the Leaning Lab Process and Outcomes, and (8) Actual Implementation.

Methods

The goal of this case study is to examine how practitioners design a model of inclusive practice through expansive learning actions to respond to their local challenges. Learning Lab took place during the COVID-19 outbreak which made a Virtual Learning Lab as a natural choice.

Setting

The setting of the study is a specialized school for the blind and visually impaired students facing organizational changes (e.g., student profile, teaching methods). Regarded as a landmark in the history of special education in Brazil, the specialized school was influenced by the different trends in the field: segregation, integration, and inclusion (Jannuzzi, 2017). After studying for six years at the Institut des Jeunes Aveugles a Paris, Álvares de Azevedo pursuit the idea of building in Rio de Janeiro an institute like its Parisian counterpart. The institute for students with visual impairment was developed under the influence of the Jesuit model of education in which the objective was to separate students from the world. In a pedagogical universe, students under constant surveillance had access to an elementary school with religion, music, and crafts for manual work (Januzzi, 2017).

In the late 80's, the identification of some blind students with additional disabilities, initiated the activities of an Alternative Educational Program (AEP), opened in 1991. This separate self-contained program catered for the need of blind students with additional disabilities with activities based on a functional perspective. In 2016, following the national inclusive education policy guidelines (Brasil, 2008) the new administration closed the self-contained program and the blind students with additional disabilities entered the regular classrooms with access to grade-level general curriculum. The school took the role of an 'inclusive' specialized school and following the inclusive education initiative (Brasil, 2008) in which special education was no longer a place but a service for blind students with additional disabilities within the age-appropriate regular classes.

Participants

Learning Lab consisted of 14 practitioners: eight teachers from the different school levels (e.g., early childhood, elementary school, and middle school), three special educators, two administrators and a former staff from the early intervention department.

Data collection

Data was generated through video recordings of nine monthly meetings, two agenda meetings and one subcommittee meeting. Artifact analysis included historical and institutional documents from the specialized school (e.g., audio-recorded past community meetings and institutional videos), field notes and collective map of the activity system. All transcribed data was transferred into Nvivo 12™, a qualitative data analysis software.

Data analysis

To understand how Learning Lab facilitated practitioners' expansive learning, the study utilized two complementary methods of analysis. The first method offers a method for the identification and analysis of discursive manifestations of contradictions (Engeström & Sannino, 2011). The second method included analysis of expansive learning actions (Engeström, 2015).

Findings

Participants completed the cycle of change and designed a new model of inclusive practice. The following expansive learning actions were identified: The action Forming Learning Lab occurred nine times in the first two meetings, questioning actions occurred 21 times so far, and analyzing twelve times. Questioning school's existing inclusion support system and questioning school's practices emerged as subcategories of questioning action. The analysis of the discursive manifestations of contradictions indicated dilemmas are the most frequent discursive manifestation with 33 occurrences, followed by conflicts that emerged 20 times, nine critical conflicts and two double binds. In the initial sessions dilemmas were linked to discussion topics related to the pandemic outbreak. On the one hand participants were excited about the collaborative project and possible outcome, on the other hand they expressed concerns with the current events and explained they would participate "as much as possible."

Other dilemmas were tightly related to the inclusive practices in the school and in the classroom. Learning Lab members acknowledged the importance of access to the curriculum for students with additional disabilities. They also communicated uncertainties about the feasibility of an individualized instruction in the collective environment of the classroom. Margarida, former head of the early intervention department, highlighted the challenges of instruction in the classroom contrasting with her experience in the early intervention department. She compared early intervention as a one- on- one "craft work," while described learning and teaching in the classroom as challenge for the teacher that needs to involve everyone the process.

Conflicts were related to diverging views between the access of a functional or academic curriculum. Disagreement with the position of the institution in relation to blind students with multiple disabilities. Pedro, the history teacher, was very straightforward and criticized the laissez-faire position of the institution which led to some teachers going above and beyond to include students with additional disabilities while others did nothing.

According to Pedro, families with students with additional disabilities demand very little from the school because the institution itself allows teachers to be less accountable for students with additional disabilities than students with visual disabilities: "There is a tacit hierarchy and that is accepted by the school."

Critical conflicts were highly emotional and related to the current pandemic. Practitioners felt guilty or had inner doubts about the best ways to support students with additional disabilities in the online mode of instruction. Isabor, Language Arts teacher, admitted that because of the pandemic she did not know most of the students with additional disabilities; some came to the first class and then disappeared: "I punish myself for not trying to learn what happened to those students. I thought to myself 'Oh, they gave up.' This was my mistake; I should not have done this." Finally, double binds as unequally unacceptable alternatives in the activity system emerged in the tension about the need of new staff such as paraprofessionals supposedly prepared to mediate appropriate services for students with multiple disabilities.

Discussion

Through Learning Lab, participants designed a new model of inclusive practice as they articulated contradictions and collectively found the means to resolve them. Initial analysis of discursive manifestations of contradictions and expansive learning actions reinforce the non-linearity of the cycle of change. The cycle of change offers a blueprint to guide facilitators and members towards expansive learning actions. However, it does not entail linearity in the process. For instance, analyzing the historical-genetic occurred in the second meeting during the questioning of the 'here and now.' This shows the importance of the historical development of the activity to understand the challenges of the present moment. The personal sense that gives meaning and direction to the activity seems to be paramount for the involvement of practitioners in the collaborative process. Though many were uncertain about the future and had many other additional responsibilities, they participated actively and engaged in serious reflective conversations. Learning Lab formative intervention accomplished its promise bringing practitioners together in a virtual space where they were able to discuss the new identity of the school, the inclusion of a new group of students in the specialized school and concrete ways to respond to the changes and challenges in their practice.

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Infect, Attach or Bounce off?: Linking Real Data and Computational Models to Make Sense of the Mechanisms of Diffusion

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Abstract: This study explores how the interplay between data and model design shifts 6th graders' students' ideas about diffusion as they build a range of models ("paper and pencil" and computational models). We present a new web-based environment and approach that integrates model-based and data-based features in the same display which facilitates the comparison of models and real-world data. Further, we illustrate how this environment and approach lead students to converge on one canonical scientific model.

Introduction and Background

Modeling has become a core element in scientific practice (Harrison & Treagust, 2000, Pluta et al., 2011; Halloun, 2011). Data plays a fundamental role in the development and evaluation of scientific models, anchoring the modeling process (Fuhrmann et al., 2018; Schwarz et al., 2009). However, model-based practices remain largely separated from data-based ones in science classes. Recent work shows that linking experimental data and scientific models in science activities has strong potential to improve student learning. For example, activities designed using Bifocal Modeling (Blikstein et al., 2016), which enables real-time model and experimental data comparisons, can support conceptual understanding, modeling, and meta-modeling competencies (Blikstein et al., 2016; Fuhrmann et al., 2018). Other researchers suggested that interlocking models with one another to draw attention to microscopic entities and their behaviors supports meaningful practice (Georgen & Manz, 2021). Gouvea & Wagh (2018) showed that coupling experiments and modeling in learning activities helps students learn how to engage in scientific practice by focusing on the goals of their investigations, allowing for comparison and triangulation. Much of the existing research on integrating modeling and data practices has involved students using pre-designed models. Little work has focused on students designing their own computer models using data to validate their models. This research is needed to understand the learning opportunities that arise from comparing real-world data and computational models, and, per the conference theme, how innovative technologies can support more effective science learning experiences.

In this paper, we ask how the interplay between data and model design shifts 6th-graders' ideas about diffusion as they build a range of models and refine their explanations based on data. We present a web-based environment and approach that integrates model-based and data-based features in the same display, facilitating the comparison of models and real-world data. Further, we illustrate how the environment and approach lead students to explore the interplay between observed data and the designed model during a unit on diffusion.

Methods

Design, settings, participants & instructional sequence

This study seeks to investigate ways to make computational modeling a sustained practice in middle school classrooms. We developed a domain-specific block-based online modeling environment based on scientific modeling research and previous studies on linking model-based and data-based practices (Blikstein et al. 2016; Fuhrmann et al., 2018; Gouvea & Wagh, 2018). The domain-specific blocks make the computational modeling accessible for students to focus on testing and refining their ideas about mechanisms underlying phenomena (Kahn, 2007; Wagh & Wilensky, 2017; Wilkerson, Wagh & Wilensky, 2017). Figure 1 shows the modeling platform, with the model and the display of the experiment side-by-side. This paper uses data from a pilot study with 43 students from two 6th-grade classes taught by the same science teacher in a middle school in California.

We designed the diffusion unit based on the Bifocal Modeling framework (Blikstein, et al. 2016). Students worked in pairs over five class periods. First, they conducted an experiment in which they compared the rate of spread of ink in hot and cold water. They ran two iterations and documented their measurements before

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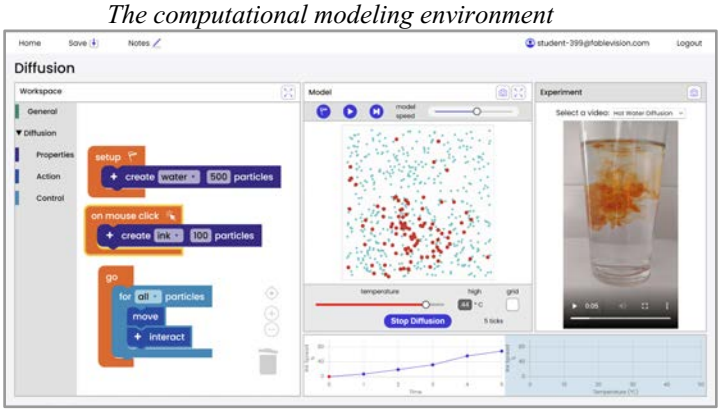
plotting the data. Next, they designed a paper model to explain how dye spread in hot and cold water. Students then used a computational modeling environment to implement and revise their paper models. Finally, they tested their various models by comparing models' behavior with the experiment to select the model that best explained diffusion. Through class discussions, students eventually converged on a single model.

Figure 1

The computational modeling environment

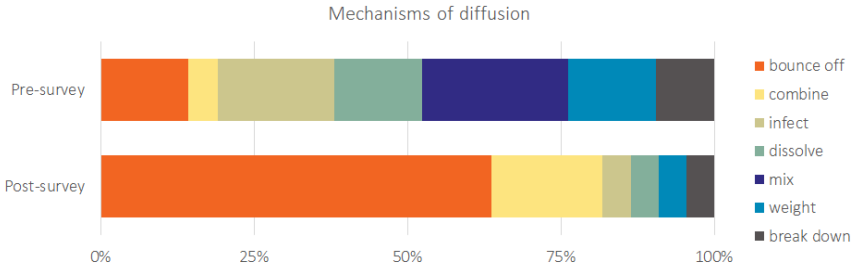


Data sources and analysis

Data included observation notes, student artifacts, and pre/post-tests. We analyzed whole-class and student-pair data. In the observation notes, we identified critical junctures when students were, (1) constructing conjectures or explanations for the phenomenon, and (2) comparing the experiment and model. We analyzed open-ended responses to see how they shifted from pre to post. We focused on the action words students attributed to the process of diffusion (e.g., spread out, bounce off, infect), indicative of mechanistic reasoning about the phenomenon (Russ et al., 2008). These terms also align with the programming blocks in the environment. Our initial rubric was developed through open coding and further refined through reference to 10 example responses. Initially, our agreement was 60%, but we reached 89.12% agreement after several cycles of refinement.

Figure 2

The mechanisms of diffusion as reflected in pre- and post-test open-ended answers

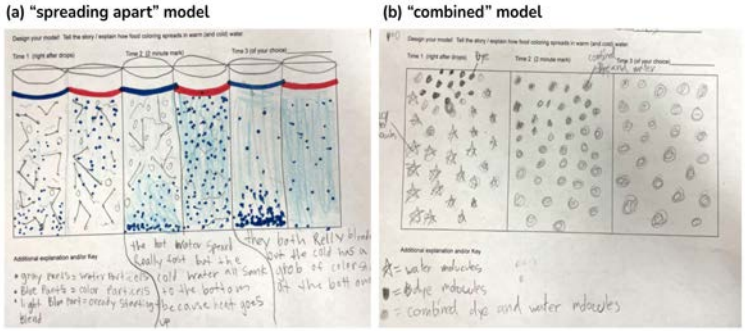


Results

Results from pre- and post-test analysis (Figure 2) showed a shift in the mechanistic language students used to describe ink spread. At the pre-test, student responses varied greatly. By contrast, in the post-test, a majority of students drew on the "bounce off" model, a canonical explanation for diffusion. For example, one student said on the post-test: *"The paint particle will bounce off the water particles, making it spread around. If it was in cold water, it would move slower than in hot water. The paint will sink before it starts spreading."* Below, we examine how this shift in language might have come about through the instructional sequence.

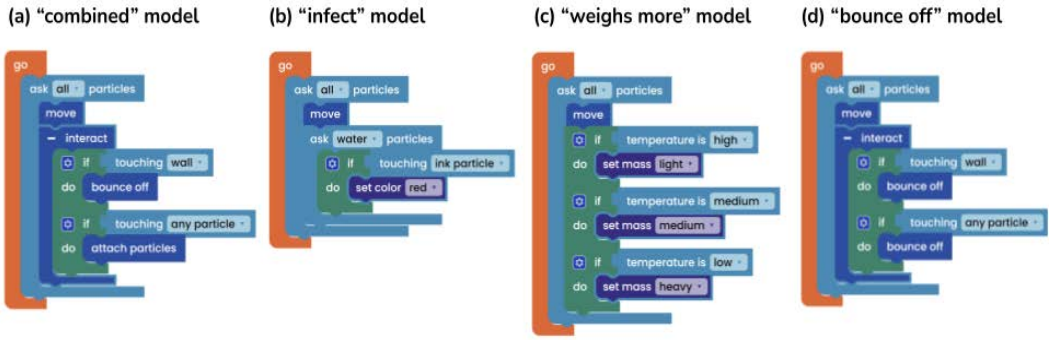
1. *Generating ideas for how ink diffuses in water:* In their paper models, students drew their explanations of experimental results. While students did not talk about particles to describe the phenomenon during the experimentation phase, they included particles in their paper models (e.g., mentioning type and color of particles). After completing this activity and discussing their ideas, students began to converge around two potential models: a "spreading apart" model that did not directly explain how particles interact with each other, and a "combined" model, in which dye particles and water particles combine to create larger particles.

Figure 3
Students' "paper and pencil" models: a. the "spreading apart" model, and b. the "combined" model



2. Translate from paper to computer, discard ideas that cannot be explained based on experiment, create new models (Figure 4). Students who drew the "combined" model used the code to create the same model (Figure 4a). When running their model, they noticed that the particles in their model attached to each other when interacting, resulting in big blobs. After comparing their model with the video data, this student pair realized that these blobs were missing from the real experiment and therefore discarded the "combined" model. These students explored other more ways to explain the dye behavior in the water using the modeling environment.
3. Converged on three candidate models. At a class level, students converged on three candidate models: the "infect" model (color particles infect water particles, which then turn blue; Figure 4b); the "weighs more" model (particles are heavier in cold water than in hot water; Figure 4c) ; and the "bounce off" model (particles spread by bouncing off each other, and they bounce off at different speeds according to temperature; Figure 4d).

Figure 4
Students' design of four models: a. "combined" model, b. "infect" model, c. "weighs more" model and d. the "bounce off" model.



This persistence of three models created noticeable tensions in the classroom. Students are used to being given the correct answer by the teacher at this stage rather than seeking it themselves. Additionally, the teacher was concerned about students using incorrect models and anxious to tell them how diffusion is defined. Nonetheless, the students and the teacher had to figure out how to navigate the situation by running additional experiments.
4. Converging on one model. To resolve the situation, students discussed with their partners potential experiments that could help prove or disprove their models. For example, to disprove the "weighs more" model, students came up with an experiment in which they used a scale to weigh the water when it was hot or cold; they discarded the model when they noticed the weight was the same. To evaluate the "infect" model, they decided to boil the diffusion water to examine the condensation on a cold plate; since the evaporated water was transparent, students agreed that the dye had not infected the water molecules and then discarded this model. Students in this class thereby converged on the "bounce off" model, which is the canonical explanation of diffusion.

Conclusions

Our findings indicate that creating models with real-world data provides students with learning opportunities that would hardly arise if they focused on model-based and data-based practices separately. We observed a shift in the mechanistic language students used to describe diffusion, shifting towards language aligned with a final canonical model. Contributing to existing work on how such convergences occur in classroom settings (see Lombard &

Weiss 2018 for a review), our findings suggest that the juxtaposition of video data of a real experiment and the model facilitated the process of generating multiple models, followed by subsequent comparison, evaluation, revision, and rejection. The scope of this paper did not allow for analyses of how the teacher guided this convergence, though previous research suggests significant influence (Millar, 2010). In future work, we intend to continue to examine the types of learning opportunities that arise from comparing real-world data and computational models, the conditions under which such opportunities arise and what designers and educators need to do to scaffold students' learning while using models authentically as tools of inquiry. Such lines of inquiry could additionally explore the ways that students' model building shapes their perception of science practices and of their agency as scientists.

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The Role of Color in Debugging Lego Structures

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Abstract: This study blended the fields of debugging, spatial thinking, and change detection. We explored 12 K-2 students' debugging skills as they fixed a Lego structure by using multi-color or grayscale manuals. Students in both groups were most likely to debug the bugs on the top and bottom of the structure, while the multi-color group was more successful at debugging bugs in the middle of the structure than the grayscale group, possibly because they were also more likely to trace the steps in the manual and use an understanding the structure strategy. Overall, students used debugging strategies similar to those found in programming, providing initial evidence that young students can successfully engage in debugging during unplugged, non-programming activities such as Lego building.

There has been increasing attention to the importance of computational thinking (CT) across the elementary curriculum in the United States. Two key aspects of CT that are found in unplugged activities are abstraction and debugging. Abstraction involves focusing on important components by ignoring unnecessary details, and debugging is identifying and fixing problems (Caeli & Yadav, 2020; Wing, 2008). In spatial activities such as Lego building, abstraction and debugging might be used in the process of 3-D shape composition and decomposition. In fact, one area where both CT and mathematical practices align (and debugging can play a significant role) is in analyzing and comparing three-dimensional shapes in different sizes and orientations and composing and decomposing three-dimensional shapes (Brennan & Resnick, 2012; Lye & Koh, 2014; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; Kotsopoulos, et al., 2017). To demonstrate that CT is an encompassing framework we also need to understand how children use CT in domains other than programming. Building on the popularity of spatial, block building activities in early childhood, we investigate CT in unplugged, non-programming-based activities by targeting debugging in Lego structures using a visual perception lens with a specific focus on how color plays a role in students' debugging.

Debugging in programming, offline, and visual-change-detection tasks

The greatest difficulty for novice programmers is debugging their code (Fitzgerald et al., 2008; Murphy et al., 2008; Wing, 2006). Students have been successful when debugging familiar code (Katz & Anderson, 1987) and easily found obvious bugs (Fitzgerald et al., 2008). Unplugged spatial activities such as block building and puzzles (e.g., Bell et al., 2012; Bofferding et al., 2021; Dietz et al., 2019) can also involve or support debugging. Bofferding et al. (2021) asked first and third graders to debug a non-standard shape puzzle, where students had to layer tiles on top of each other to create a composite design. More students debugged the puzzle on the posttest by using their spatial thinking skills, such as visualization and rotation of the tiles. Likewise, to complete change detection tasks (i.e., tasks where students must identify what is different between two scenes), students draw on visualization skills (Shore et al., 2006). Thus, spatial activities could support emerging debugging skills.

Finding bugs in spatial tasks requires visualization skills, such as detecting visual differences in change detection tasks. In such tasks, participants must determine what is different between two pictures. In one version, they see the original and changed picture side-by-side, similar to "Hidden Pictures" in the children's *Highlights* magazine (https://www.highlightskids.com/games). Prior studies have shown that visual differences are easier to detect if they are central to a scene (Rensink et al., 1997) and when there are fewer elements in the scene (Shore et al., 2006). Further, changes in object location or orientation were easiest to spot, followed by changes in color, and deleted parts were the most difficult to find (Rensink et al., 1997; Shore et al., 2006). Learning how children debug block structures could influence task design and bring this CT practice into classrooms.

Debugging strategies

Two main debugging strategies include forward reasoning and backward reasoning (Katz & Anderson, 1987). Forward reasoning involves searching for bugs starting from the initial lines of code or while paraphrasing or representing the code; whereas, backward reasoning involves searching for incorrect behavior by mapping output to lines of code (Katz & Anderson, 1987). Novice programmers and those unfamiliar with the code use forward reasoning more than backward reasoning (Fitzgerald et al., 2008, Katz & Anderson, 1987). Murphy et al. (2008) investigated novice programmer's debugging strategies, adding different categories to the classification of

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debugging strategies. These include strategies such as tinkering, tracing, and pattern matching. Tinkering refers to unproductive or random changes, pattern matching is recognizing differences by focusing on looking, and tracing is physical or mental checking of outputs with inputs in a linear fashion. Further, some young students rewrite the entire program instead of fixing buggy lines of the program (Bofferding et al., 2022).

Our Study

Our study blended ideas of debugging, spatial thinking, and change detection. We used a version of a side-by-side change detection task by giving students a complete Lego structure and asking them to fix the Lego structure to match a modified version of the structure. Our task involved students debugging multiple differences in one structure. In addition to exploring the features of size (e.g., a 6 x 2 versus a 4 x 2 block), thickness (e.g., flat versus standard block), and location or orientation, we also explored the extent to which seeing the pictures in color versus grayscale play a role in students' change detection and debugging. Finally, we explored the role of being able to see the larger picture in smaller chunks by providing students with a picture of the Lego structure versus a manual that shows how pieces are put together. Our main research questions were (1) What strategies do students use to debug a Lego structure? and (2) Which bugs (i.e., changes to the structure) do they fix? For each of these questions, we considered the role of seeing the manual in multi-color versus in grayscale.

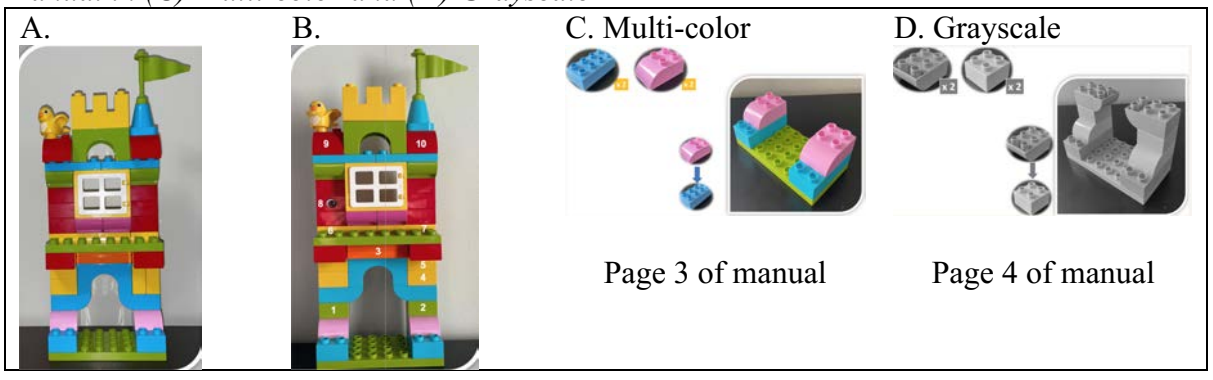
Methods

Participants and study design

We worked with four kindergarten, four first grade, and four second grade students during their afterschool program at a Montessori school in the midwestern United States. We targeted a balance of genders. All names in the paper are pseudonyms. The data in the study comes from the first out of three sessions of a project where we explored students' composing, decomposing, and debugging process through Lego building activities. During this session, students composed a Lego structure using multi-color or grayscale pictures versus step-by-step manuals. The focus of this paper is on the debugging activity that came next. Starting from their completed Lego structure (see Figure 1A), we wanted students to use a new manual to find and fix the differences (see Figure 1B). The new manual had a picture of a modified structure on the first page, followed by the steps needed to correctly make the Lego structure (see Figure 1C and 1D). This version of a change detection task involved 10 bugs or changes (labeled in Figure 1B) including missing pieces (bugs 1 and 2 in Figure 1B), incorrect pieces (bugs 4, 5, 6, and 7 in Figure 1B), incorrect placement (bugs 3, 9, and 10 in Figure 1B), and incorrect orientation (bug 8 in Figure 1B). Because some students saw the modified manual in grayscale, we did not include color differences as bugs. We worked with students individually and video recorded each session with two cameras.

Figure 1

(A) Initial Lego Structure, (B) Modified Structure, and Example Pages from the Building Manual in (C) Multi-color and (D) Grayscale



Analysis

We first identified each bug students fixed (and in what order) for a total of 10 bugs. We also made notes of whether they introduced a new bug while debugging, i.e., changed something that was correct or added in a piece that was not needed. Then, drawing on debugging strategies in programming (Murphy et al., 2008) and strategies used in change detection tasks (Shore et al., 2006), we classified students' debugging strategies (see Table 1).

Table 1

Program Debugging Strategies and Potential Application to Block Debugging Strategies

Debugging strategy	Programming description (Murphy et al., 2008)	Application to finding bugs in block structures or block composition
Tinkering	Students randomly make changes.	Students randomly add or remove pieces.
Tracing (top-to-bottom or bottom-to-top)	Students follow each line of code and match it with the result, reasoning forward or backward.	Students start at the top or bottom of the structure and match it sequentially with the steps in building the structure.
Pattern matching	Students just know what is wrong or recognize the bug based on experience.	Students quickly notice a difference by looking at the overall structure.
Rebuilding	Students reprogram from the beginning. (Bofferding et al., 2022)	Students take apart the structure and rebuild it.
Understanding the Structure	Students reason about how the code works and why there is a problem.	Students turn the physical structure or take apart parts to see how they are composed.

Results

Overall, students debugged 65 bugs out of 120 (M=5.4 out of 10). Interestingly, first graders found the most bugs (33 bugs), followed by kindergarteners (17 bugs) and second graders (15 bugs). Second graders' low performance may have been due to disinterest in fixing a Lego structure they had already put together. Students using multi-color manuals were more likely to debug than those using grayscale manuals (42 bugs versus 23 bugs, respectively). Further, students were most likely to debug the bugs on the top and bottom of the Lego structure. For example, bugs 1 and 2 (see Figure 1B), new pieces in the structure, were fixed by all six of the students in the multi-color group and three students in the grayscale group. Likewise, four students in each group debugged bug 8, which had an incorrect orientation, and bugs 9 and 10, which had an incorrect placement (see Figure 1B). Bugs in the middle of the structure were harder, especially for students using grayscale manuals.

Overall, nine students debugged by keeping the main structure intact as much as possible. However, two students (Carter A., a kindergartener from the grayscale group, and Yellow, a first grader from the multicolor group) used a *rebuilding* strategy and started over using the manual. Further, five students in the multi-color group, compared to two students from the grayscale group, used an *understanding the structure* strategy by turning the whole structure to identify bugs. This strategy might have been particularly useful for helping students notice bug 3 (see Figure 1B) because the pieces were no longer flush on the backside. Seven students relied on *tracing*, starting with the bottom of the structure (i.e., first step in the manual). Most of the bugs occurred symmetrically on left and right sides of the structure, encouraging students to use pattern matching. At one point, a few students started to remove the pieces symmetric to the location of bugs 4 and 5 (see Figure 1B) until they realized that those were already correct. Three students used a combination of *pattern matching* and *tracing*. For example, one first grader, Ashley, alternated between identifying changes in the picture and going through the steps of the manual. First, she noticed the uppermost differences in the structure (bugs 9, 10, and then 8 in Figure 1B), and then she fixed bugs 1 and 2 (see Figure 1B) while starting to go through the manual. After fixing the bugs at the bottom, she went back to the picture of the final structure and identified and fixed most of the middle bugs (bugs 4-7 in Figure 1B). Finally, she found and fixed the final bug (bug 3 in Figure 1B) using the manual.

Discussion and significance

Overall, students' success at identifying the bugs at the top and bottom of the Lego structure is interesting because in the visual change detection tasks, students have the easiest time identifying changes in central features (Rensink et al., 1997). If *central* means "toward the middle," students should notice bugs 4 and 5 (see Figure 1B) most often. However, students may have interpreted the top pieces as central to defining the structure or the base as central because it holds up the structure. Future work could incorporate student interviews about the nature of the structure and their impressions about the structure to better understand what parts they might consider central.

Another possible reason for students' focus on the top and bottom bugs is that they were easier to spot visually, consistent with programming studies (e.g., obvious bugs are easy to find, Fitzgerald et al., 2008). In fact, bugs 9 and 10 were under two visually striking pieces (a bird and a flag). However, based on prior change detection studies (e.g., Rensink et al., 1997; Shore et al., 2006), students should have had a hard time identifying missing pieces (bugs 1 and 2). Having the manuals that highlight pieces to use at each step likely reduced the difficulty of identifying the missing parts. Of particular interest were the differences demonstrated by students in the two groups: multi-color versus grayscale manuals. Students who did not identify the missing pieces were all in the grayscale group. Further, two of these three students did not look at the manual's steps, debugging by looking at

the picture of the final structure. Identifying the bugs in the middle of the Lego structure was more difficult, especially for the grayscale group. One reason may have been because the line designating a break between pieces was black, which may have been more difficult to discern in grayscale pictures.

The results of this study provide initial evidence that young students can engage in productive debugging tasks that are unplugged and that CT skills are broader than programming. Further, students' processes in working with the materials suggests a few implications for promoting debugging skills. First, children should be encouraged to understand Lego structures by rotating them and even investigating how certain pieces are put together. Second, Lego structures could involve both symmetric elements to encourage pattern matching as well as sections that do not lend themselves to pattern matching in order to encourage students to question how pieces are put together. Further research could then investigate to what extent debugging in these Lego environments might correspond to students' debugging in tangible, block-based programming environments.

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Reflective Use v. Rote Use: Engaging Students in Computational Thinking for Science with Computational Tools

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Abstract: As computational tools are becoming increasingly common in scientific practice, developing students' computational thinking for science (CT-S) skills is a priority in science education. To support educators in meeting this need, we present a theoretical construct that distinguishes between science activities that engage students in CT-S through interactions with computational tools and science activities in which students use computational tools but do not engage in CT-S. We discuss how this theoretical construct can support educators in developing or modifying science learning experiences to promote CT-S.

Introduction

Contemporary science is becoming increasingly computational. Scientists employ computational tools to conduct investigations and contribute to the design of new computational tools for their specific research. To learn authentic science practices, students must have opportunities to think deeply about how to leverage the computational nature of tools for scientific purposes (Denning, 2017; Kaczmarczyk & Dopplick, 2014). This necessity is reflected in new science standards in the United States—most notably, the Next Generation Science Standards (NGSS), which mandate that computational thinking be taught as a practice of science (NGSS Lead States, 2013). Although it is becoming more common for science lessons to incorporate digital models, simulations, and other computational tools, the use of these tools alone does not guarantee that students will engage in computational thinking (Li et al., 2020; Yadav et al., 2016). We offer a theoretical construct that specifies whether a student using a computational tool is engaged in Computational Thinking for Science (CT-S).

Methodological and theoretical approaches

The theoretical construct presented in this paper contributes to an ongoing multiyear study investigating the role of computational thinking in middle school science learning. The project aims to create an instrument that can measure middle school students' CT-S abilities. At the commencement of this project, we convened a panel of experts in relevant fields—including educational research, learning design, computer science, and computational thinking—for a two-day retreat at the University of California, Berkeley. Participants reviewed a series of activities involving computational tools in the *Amplify Science Middle School* curriculum. Discussion centered on the potential of each activity to engage students in CT-S—defined as the cognitive processes involved in building or modifying a mental model of a computational tool's functionality within a given science activity. Participants concluded that for CT-S to occur, students would need to attend to the functionality and positionality of the computational tool within the given science activity. This was consistent with ideas about computational tool use in the literature (e.g., Grover & Pea, 2013; Sengupta et al., 2013; Weintrop et al., 2016).

We understand computational thinking as situated in activity and distributed across the actors and tools involved in an activity (Engeström, 1987; Greeno, 1998). These intrapersonal cognitive processes are only a piece of broader goal-directed activities, but are critical to understand nevertheless (Greeno, 2015). With this perspective, our team reexamined a set of science activities, employing Activity Theory as a framework for analyzing students' use of computational tools and cognitive processes in each situation (Vygotsky, 2012; Leont'ev, 1978; Engeström, 1987). This approach builds on an established tradition of using Activity Theory to analyze outcomes of technology-centered learning experiences (e.g., Brine & Franken, 2006; Murphy & Rodríguez-Manzanares, 2008). Activity Theory is a framework that considers an entire activity system that extends beyond the individual, or *subject*, engaged in activity to include the components that contribute to the outcome of the activity—like tools (Engeström, 1987). In an activity system, the subject's efforts are motivated by and directed toward an *object*, or *goal* of the activity (Kuutti, 1996; Engeström, 1987). Through the subject's employment of *tools*, an *outcome* of the activity is reached (Engeström, 1987). Tools in an activity system can be either physical or immaterial. Activity systems are dialectically structured, such that components mutually influence one another. Through using a tool, the subject may come to new understandings about the tool or the activity's goal—informing the subject's subsequent actions.

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For each middle school science lesson analyzed, we devised a series of activity systems—each with the same subject, computational tool, and context, but with a slightly different activity goal. We examined how the shift in goal would impact the students' use of the computational tool, their subsequent cognitive processes, and activity outcomes. Across lessons, we determined that computational thinking was most likely to be an outcome of activity systems in which the goal was to understand the functionality of the computational tool itself. This goal would arise, for instance, when students would tinker with a computational tool that they had never previously used, when students would investigate how to employ a computational tool in a novel way, or when students would encounter a glitch or an unexpected outcome during tool use and would need to reinvestigate an aspect of the tool's functionality accordingly. Aggregating examples resulted in a generalized Reflective Use construct.

We analyzed student interactions with computational tools without explicit attention to the cultural-historical mediators of activity characteristic of modern Activity Theory (Engeström, 1999). With measurement development as the primary motivator of our work, we made this choice in order to focus on the individual contributions of the subject within each activity: what are the cognitive resources brought to bear in tool-mediated, goal-oriented activity, and how might those resources and those mental models, become visible and get revised through activity? However, a complete understanding of CT-S within an activity system must attend to the complex situativity of learning represented in the "bottom row" of the modern Activity Theory triangle: the rules, community, and divisions of labor within activity systems (Engeström, 1999). We will address this in future work.

Reflective use construct

Activity Theory positions intelligence as being distributed throughout an activity system such that knowledge emerges from a subject's interactions with tools (Engeström, 1987; Greeno, 1998; Pea, 1993). It follows that when students use a computational tool, their activity could engender critical thinking about the functionality of the tool itself (Kaptelinin & Nardi, 2006; Kuutti, 1996; Jonassen & Rohrer-Murphy, 1999). However, students do not necessarily engage in CT-S every time they use a computational tool. Our construct distinguishes between science activities in which students engage in CT-S as a result of using computational tools, *Reflective Use*, and science activities in which students use computational tools but do not engage in CT-S, *Rote Use.*

Reflective use

A Reflective Use activity system is one where the subject builds a mental model of a computational tool's functionality by interacting with the tool. Imagine a student is investigating bacterial growth to better understand how bacterial populations change over time. This student has a graphing calculator (the computational tool) and data on a bacterial population's size at different timepoints. However, this student has never used a graphing calculator. Before this student could employ the calculator to investigate population growth, they would need to determine what computations this tool can perform that may support their science investigation. To do this, the student could engage in Reflective Use. The student might begin by manipulating the calculator, selectively pressing certain buttons, and observing the results of those actions. The student could then reflect on the outcomes of these actions and form an initial mental model of the graphing calculator's functionality. As the student continues to interact with this computational tool, their discoveries may reinforce, revise, or supplement their developing mental model. In this way, Reflective Use is bi-directional in terms of information transfer: the student takes actions, the student reflects on what the computational tool does, and the student takes new actions based on their reflection. Through this process of Reflective Use, the student builds a mental model of the graphing calculator's functionality with respect to their goal of graphing population growth: the student has engaged in CT-S. (Figure 1).

Rote use

Reflective Use stands in contrast to Rote Use of a computational tool. When a student is engaged in Rote Use, they do not build or modify a mental model of the computational tool's functionality. Building on the previous example, once the student has formed a mental model of the graphing calculator's functionality through Reflective Use, the student can now employ that mental model alongside the graphing calculator in a new activity system to create a graph of the bacterial growth data. (Figure 2). Since the student already knows what the calculator can do in this context, they do not need to engage in CT-S. As demonstrated, it is possible for Rote Use to immediately follow Reflective Use of a computational tool. However, these do not need to occur at the same point in time. Notably, Rote Use would also take place when a student uses a computational tool by merely following a step-by-step instruction set.

Significance

Attending to the distinction between Reflective Use and Rote Use can support the development and implementation of science learning experiences that effectively engage students in CT-S. Imagine, for instance, a science lesson in which students use a computer-based simulation to investigate the Guiding Question: *how are the Moon's phases related to the Moon's orbit around Earth?* The instructor could choose to begin the lesson by teaching students how to manipulate the simulation. The students might then employ the simulation, in accordance with what they have learned from the instructor, to make observations. Through using the simulation to make observations, students may arrive at an answer to the Guiding Question. In this Rote Use scenario, students would engage in thinking about the moon's phases and orbit; however, students would not need to engage in CT-S because the activity did not require students to construct a mental model of the simulation's functionality in relation to their science goal. To promote CT-S more effectively, the instructor could instead structure the lesson to begin with Reflective Use of the computational tool. For example, the instructor could start the lesson by asking students to consider: *how could this computer-based simulation support us in answering our Guiding Question?* Students would need to investigate the functionality of the simulation in relation to their goal of answering the Guiding Question—in other words, students would *reflectively* use the tool. After this Reflective Use, students could proceed to investigate the relationship between the moon's phases and orbit and formulate a response to the lesson's Guiding Question. When the lesson is structured in this way, using the computational tool could promote students' computational thinking in addition to their thinking about the moon's phases and orbit. Moreover, we posit that designing lessons to engage students in Reflective Use could motivate additional science learning opportunities. For instance, perhaps during their Reflective Use, the student observes that the moon sometimes enters into an eclipse but does not do so every month; this observation could inspire students to manipulate the simulation further to figure out how a 2-D model of the sun-earth-moon system is insufficient for understanding the 3-D interactions between the three objects. Overall, attending to the distinction between Reflective and Rote Use of computational tools could enable educators to design learning experiences that more effectively meet expectations for contemporary science education and that may lead students to engage with scientific phenomena more deeply.

Figures

Figure 1

Reflective Use Activity System

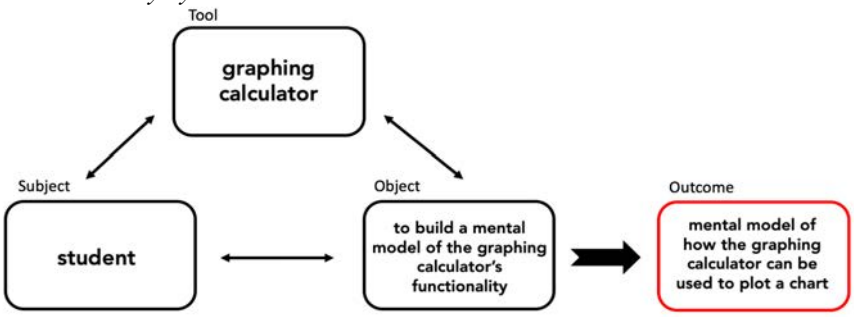
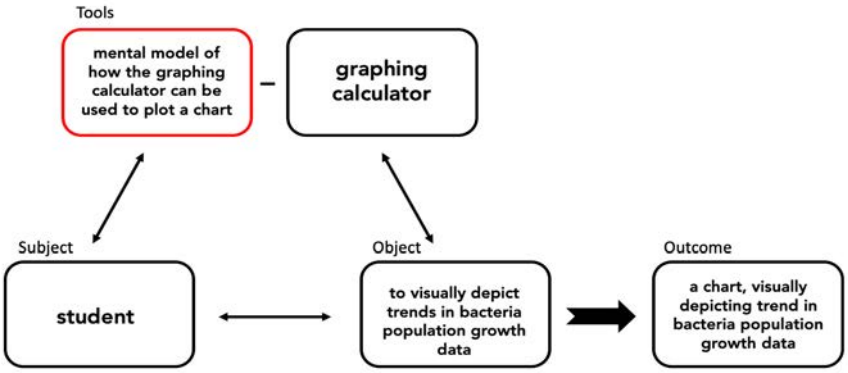


Figure 2

Rote Use Activity System



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Case-based Scenarios for Supporting Equitable Mathematics and Science Instruction: Articulating Design Conjectures and Emerging Tensions

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Abstract: Cases have been used in teacher education to engage pre-service teachers (PSTs) with realistic situations that they might encounter in the classroom. While research suggests affordances of using cases for PST learning, little research has systematically explored productive features of cases or principles for case design. We use design-based research to develop design conjectures about the use of cases to support equitable mathematics and science instruction among PSTs. We describe a project in which we engaged in-service teachers in the development of cases grounded in their own teaching experiences and then implemented those cases as pedagogical tools in elementary mathematics and science teaching methods courses for PSTs. We share two design conjectures emerging from this work and discuss paths forward.

Introduction

Case-based scenarios, or cases, have been used to engage pre-service teachers (PSTs) with challenging classroom situations they might encounter. A case is typically presented with questions, asking PSTs to analyze the scenario and discuss potential responses. Cases have been shown to represent the complexities of teaching (Baier, Maurer, Dignath, & Kunter, 2021; Shulman, 1992), create opportunities for reflection (Abell et al., 1998), elicit PSTs' beliefs (Katsh-Singer et al., 2016), and enable PSTs to build connections between theory, practice, and teaching contexts (Shin, Brush, & Saye, 2019). Yet, little research has systematically explored productive features of cases and principles for their design. Here we see the potential for the learning sciences and, in particular, design-based research (Cobb et al, 2003; diSessa & Cobb, 2004; Sandoval, 2004). In this work, we focus on cases as a pedagogical tool to engage PSTs in exploring issues at the intersection of equity and elementary mathematics and science instruction, given persistent historical inequities in these domains.

Case-Based Scenarios in Teacher Education

Cases, or narratives depicting specific teaching situations, critically engage and challenge learners (Shulman, 1992). Scholars have employed cases for many purposes, from promoting growth of teachers who design cases (Arellano et al., 2001) to collecting data on teachers' beliefs (Katsh-Singer et al., 2016) to illustrating exemplary practices (Carter, 1999). We argue that cases could foster learning environments for PSTs that allow for links between theory and authentic practice. Yet, the development of cases is rarely discussed or problematized in existing research, leaving questions about how to produce cases that could support such an environment. While some aspects of case development have been identified, such as authenticity (e.g., Shin et al., 2019), these have not emerged from systematic investigations into design principles. Further, few studies have examined cases that forefront equity, yet developing equitable teaching practices is a key priority of teacher education.

Design-Based Research Approach

We use design-based research (DBR) to iteratively generate cases that foster PST learning. Aligning with the goal of DBR to build theory (diSessa & Cobb, 2004), in this paper we present design conjectures (Sandoval, 2004) that contribute to knowledge about how to design cases that forefront issues of equity in STEM education. We conceptualize equity in line with Aguirre et al. (2013) who describe the need for responsive instruction that centers learners' identities, competencies, and varied knowledge resources, while providing opportunities for all learners to engage deeply with mathematics.

Case Development, Implementation, and Data Collection

A team of teacher educator-researchers worked with in-service elementary teachers (ISTs) to design cases in three virtual workshops. ISTs first explored ideas about equitable instruction from Aguirre et al. (2013) and discussed their relevant experiences. ISTs then used their experiences to design cases for use with PSTs.

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Here we draw on data from two cases designed by two pairs of ISTs during the workshops. In the *Daily Schedule* case, a new teacher in a Title 1 elementary school with a large multilingual population is given their schedule and notices that they have been allotted only 1 hour for science each week and 45 minutes a day for math, compared to 3 hours per day for literacy. When the teacher inquires about the lack of science and math time, a coach replies, "That's not what these kids need." Discussion prompts explore the coach's perspectives and actions the teacher might take moving forward. In the *Group Dynamics* case, three students work together on a science activity about plants' water and nutrient needs. A dialogue is presented in which two students, Ramon and Roman, start working with materials rather than first doing the required computations stated in the instructions. Meanwhile, the third student, Keza, quietly works on the computations until the boys realize what she has done and take her work. Discussion prompts ask PSTs to analyze group dynamics and potential contributing factors and to discuss pathways to equitable group engagement.

The *Daily Schedule* case was administered in an elementary math methods course in two consecutive semesters. The *Group Dynamics* case was administered during two consecutive semesters in an elementary science methods course. PSTs first responded individually to prompts in writing and then engaged in discussion in small groups, followed by the whole class. Discussions were audio recorded, and written responses were gathered virtually. After each implementation, our team reviewed the data, noted key themes, discussed themes as a group, connected with prior research, and finally made changes to each case. To support our conjectures, we draw on artifacts, notes, and video recordings from our workshops with ISTs; documentation from research group meetings; written responses and audio recordings from implementation with PSTs; and prior research.

Design Conjectures and Lingering Tensions

Here we articulate two conjectures for case design at the intersection of equity and STEM instruction, providing supporting evidence and articulating tensions related to each. We also describe ways in which the conjecture can support deep engagement with cases at the intersection of equity and mathematics and science education. Our ultimate goal in this research is to share formalized design principles to be used by others; this work is a first step in that direction, proposing in-progress conjectures and describing initial evidence to support them.

Design Conjecture 1: To engage PSTs in deeper critical thinking and offer a framing of teaching as a complex activity involving continual learning, case prompts should ask PSTs to unpack and analyze situations, not come up with solutions.

While cases often ask participants to develop a solution to the presented challenge, we have observed that moving towards a solution limited PST thinking and encouraged simplification of the situation. For example, in the *Daily Schedule* case, the original third prompt asked PSTs how they might provide students with rich math and science learning opportunities despite stated constraints. All students who submitted written responses to that question mentioned integration as a/the solution – several excitedly so (e.g., "Integrating with other subjects!" and "Integrate!!! We can do reading comprehension with science and math with phonics!") These responses seemed to diminish the richness of responses to the first two questions, conveying a sense that the challenge is easy to solve. Here, we do not blame the PSTs; rather, we felt that asking for a solution to such a complex situation was unfair, as even the ISTs who designed the case based on their experiences were at a loss for what to do. In fact, they had previously discussed the possibility of integration but felt that the situation was more complicated than that. Given PSTs' tendency to turn to this solution, in part reducing the complexity and thinking brought forth by the first two questions, we revised our initial prompts (Figure A). In particular, we removed the final question and expanded the prior questions to draw out more deep thinking. We concluded with a prompt for PSTs to think about how they might work to advocate for students' math and science learning moving forward. This question conveys a sense of action as a process, rather than a simple solution, and encourages PSTs to brainstorm various types of information they would want to gather to engage in advocacy.

Figure A

Daily Schedule Case Prompts

Initial case prompts:	Revised case prompts:
1. What's the value in your coach's perspective? What are the drawbacks of that perspective? 2. What would you want to learn more about in order to have conversations with your	1. What do you notice happening in this scenario? What initial reactions and feelings come up for you? 2. What's the value in your coach's perspective in terms of supporting student learning and

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coach, administrators, or other stakeholders moving forward? a) What kind of research might be helpful to know about as you work to advocate for your students' math and science learning? (e.g. It would be helpful to know if researchers have studied… It would be helpful to know what research has found about…) 3. Knowing the constraints that currently exist, what are some things you might do in order to still provide your students with rich math and science learning opportunities?	engagement? What are the drawbacks of that perspective for student learning and engagement? 3. What is your own personal perspective, and what experiences have you had or ideas have you encountered to support that perspective? 4. Given the circumstances, how do you think you can best advocate for your students' math and science learning moving forward? a) What information would you want to gather and what research might be helpful to know about to inform your advocacy? (e.g. I would want to learn more about… It would be helpful to know if researchers have studied…)

We recently implemented the revised case and are analyzing the data; preliminary observations reveal some new emergent themes. In response to question three, many PSTs cited their own experiences as evidence for the drawbacks of emphasizing literacy at the expense of STEM subjects (e.g., "I have had a lot of language arts and English experiences...Mathematics was not a focus...I would argue that I feel more comfortable with writing and reading than with mathematics for this reason."). Additionally, question four elicited many responses about the value of data gathering and finding research to support your arguments with stakeholders (e.g., "I think that if I could present research and data that shows that there are not only studies outside of this school that support the idea of teaching math and science as a way to assist in reading, but that this concept has been applied and is working with my own classroom as well, it would be pretty helpful in making my point that we can use math and science as a way to help teach reading."). While some students did still write about integration, a wider variety of approaches were mentioned, and many PSTs focused on areas for teacher learning and strategies for arguing against the current schedule, rather than simple solutions to fix the problem.

Design Conjecture 2: Provide comparable demographic details about all students depicted in the case.

While we know specificity in cases is important (Nemirovsky & Galvis, 2004), prior research lacks theory around what kinds of details to include and how to include those details. One aspect we have investigated is the comparability of detail provided about each student. This conjecture emerged as our research team discussed the following paragraph that teachers wrote about the three students depicted in the *Group Dynamics* case:

> Keza, Roman and Ramon were put in a group together. Keza, a refugee from Rwanda, is good at math, has been in the U.S for a year and is part of the ELL class. She is the only student from an African country in a class mixed with other students of color. The two boys in the group are rowdy on the playground and good at math in the classroom.

One key challenge we noted is that details provided about the students in this description are not equivalent. Keza's refugee status, country of origin, and language are highlighted; while the boys' rowdy disposition and math competency are highlighted. In our prior work, we have seen PSTs perceive demographic details as cuing the solution pathway; such assumptions seem even more likely given the unevenness of the descriptions. This concern is supported by research about the tendency to name minoritized identities but not white students' identities (e.g., Gilliam et al., 2016), as well as how such naming can cue implicit biases and perpetuate stereotypes (e.g., Godsil et al., 2014). Subsequently, we rewrote the paragraph as follows:

> Keza, Roman, and Ramon were put in a group together. Keza tends to perform well and seems comfortable in math. She is a refugee from Rwanda, has been in the U.S for a year, and is multilingual while still learning English. Roman and Ramon are good friends, and they both perceive themselves as good at math. Roman is white and grew up on the Wasatch front. Ramon is Chicano and grew up in the Salt Lake area. Both boys are monolingual English speakers.

Here we attempted to provide comparable details about all students, including language spoken, ethnicity, where they grew up, and comfort level with math.

While our group agreed that presenting comparable details supports more equitable discussion, we continue to grapple with many tensions related to student demographic details. For example, we wonder which demographic details to include and how much detail to include overall such that those details are not perceived as the only – or even primary – keys to the solution, thus removing agency and critical thinking from PSTs. We

are currently exploring these questions by examining PSTs' responses to prompts in which we ask them to consider what factors might be playing a role in the situation. We will explore whether factors emerge that are not included in the case description, and how such answers differ in cases with few versus many details. Also, we have included prompts asking PSTs to discuss what else they would want to know to better understand the situation; we will analyze those responses to see if inquiries arise regarding additional demographic details.

Conclusion

In this work, we offer preliminary design conjectures for systematically designing case-based scenarios at the intersection of equity and STEM instruction. While the context for which we are designing is university methods courses for PSTs, we aim for these conjectures to be applicable to cases designed for a variety of purposes – for example, for both PSTs and ISTs. These conjectures can also be applied to cases designed by a range of stakeholders, from researchers and teacher educators to practicing teachers. Additionally, as we work to solidify these conjectures, we believe they might prove useful for designing activities beyond the types of case-based scenarios we describe, such as video cases and sample anecdotes provided in teacher education textbooks.

Moving forward, we hope that these conjectures will serve as a springboard for other scholars to systematically explore the design of case-based scenarios and prompts. While these conjectures certainly are not sufficient to cover all issues related to case design, we hope they offer a fruitful first attempt at moving the research field towards a rigorous, robust process for developing cases.

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Designing for More Than Just Product: Student Co-design of Digital Badge Systems

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Abstract: Student co-design – the process in which students participate as an integral part of designing learning programs and curriculum – is one avenue for including student perspectives and experiences into the creation of curriculum and learning environments. Historically, the goal of co-design has been to finalize a product (video game, curriculum, badge system, etc.) and/or to validate the usability of a product. Examining data from student co-design of badge systems of three university courses, this paper provides a framework that expands the goals of co-design, specifically the co-design of digital badges, to focus on 1) impacting designers (youth and adult) and 2) impacting educational systems and processes. Findings indicate the value of the co-design of digital badges as a metacognitive process for learners, an assessment tool of learning for instructors, and an evaluation tool for programs.

Major issues addressed

With the goals of equitable and consequential learning, educational curriculum and programs often face the challenges of how to make learning meaningful, engaging, and authentic to students' lives. Student co-design – the process in which students participate as an integral part of designing learning programs and curriculum – is one avenue for including student perspectives and experiences into the creation of curriculum and learning environments (Pitt, et al., 2019; Tierney, Horstman, & Tzou, 2021). Co-design bridges learners' experiences, perspectives and expertise to that of the expectations designed into the educational program (Pitt, et al., 2019; Tierney, Horstman, & Tzou, 2021; Yip et al., 2017). However, when enacting co-design, it is valuable to address what the goals or outcomes of the co-design are. Broadly speaking the goal of co-design has historically been to finalize a product (video game, curriculum, etc.) and/or validate the usability of a product. Typically, with this goal, student and youth co-designers are involved as end-users. Yet, co-design, and specifically co-design of digital badges, creates a unique opportunity to accurately reflect the needs of the learners and at the same time enable the group to challenge implicit hierarchical structures embedded in curriculum design. To understand this further, we have identified three additional goals for co-design: 1) For the learners, it reveals their own thinking and perceptions of the content, prompting reflection and redirection when necessary, and is responsive to collaborators and experts. 2) For the teachers and educators, it brings to light the different perspectives of the learners, captures the unique dynamics of the community, making visible a scaffolding trajectories of learning content, and providing an opportunity for teachers and educators to observe their own learning and teaching. 3) Lastly, the structure of the badge system creates a vantage point from which both the learners and teachers can reflect how they view the hierarchy and relationships of the content itself. However, it is important to understand what the outcomes are when involving students. How does co-design of digital badges impact… a) The learning and development of students involved? b) The learning and development of teachers and educators involved? c) The educational structures and content in which the co-design is situated?

Potential significance

This paper describes a research project that used the co-design of digital badges as a design tool for student co-designers to map out their development and learning. This work is distinct from other research on the creation or co-design of digital badge systems, in that we used digital badges to design, without intention to create badges as an end product for future students to use. In this way the badge systems that were created act more as a conceptual map of learning and development. The badges describe activities and markers of successful completion but within the larger context of a learning trajectory. The close integration of co-design strategy with the structure of a badge system as an organizational mechanic, allows for highly tailored or customized learning experience for the group that creates it. The potential significance is developing a practice in which this model is scalable across different content types and communities.

Theoretical perspectives

Co-design can be a powerful approach for designing a curriculum that reflects the needs and priorities of its participants. In student co-design, students are asked to be an integral part of designing learning programs,

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curriculum, and assessments (Pitt, et al., 2019; Tierney, Horstman, & Tzou, 2021). In this model, students are treated as *design partners* in which they are "part of the research and design process throughout the experience." and "…considered to be equal stakeholders in the design of new technologies." (Druin, 2002). For educational equity, it matters who is involved in design. Student co-design as a process centers students in the design of the learning environments in which they participate. We argue that without utilizing a co-design approach, products such as digital badges may represent only hierarchical concerns while overlooking important but subtle aspects of learning and program experiences that are highly valued by learners. Further, through co-design, students can identify learning trajectories that are of importance to them and reflect the contexts and cultural practices of their communities in combination with the content and pedagogy taught in school courses.

Our approach to designing digital badge systems focuses on leveraging badge systems as a mechanism to involve students in the design process as collaborators (Pitt et al., 2019; Tierney, Horstman, & Tzou, 2021). Digital badges are part of what can be described as an achievement system (Hickey & Chartrand, 2020; Horstman, Tierney, & Tzou, 2020). One promise of digital badge systems is how they mark the combined social, emotional, and academic achievements that learners accomplish (Horstman, Tierney, & Tzou, 2020) and create visible trajectories for learners to follow (Pinkard, Barron, & Martin, 2008). Taken together, individual badges can create a pathway that, when followed, indicate what participants have learned, but also indicating membership of a learning community, having achieved valued practices and rites of passage. When badge systems are not used for motivational purposes but for educational program design, it serves as a mechanism for tracking a design framework in addition to highlighting the shifts in perspective around power, participants, and what is valued. Co-design of badge systems shifts the focus of the badge system as a design tool instead of an end product; its value is in its development. Combined, co-design of badge systems creates a unique opportunity that reflects values associated with socio-cultural models of program design. It makes visible and prioritizes the needs of the community, it is responsive to the uniqueness of the community it serves, it redistributes power and equity, and enables the agency of learners (Lave & Wenger, 1991; National Research Council, 2000; Rogoff, 2003). We believe this unique combination creates the right amount of space and structure to capture and reflect the unique needs of different learning communities.

Methodological approaches & data sources

In the spring, summer, and fall of 2021, students in the co-design of digital badge systems for three courses connected to a single-subject credential program in a teacher education program in the United States. The first course, Adolescent Development, is a prerequisite for entry into the Single-Subject Credential Program and is often one of the first courses students take in the College of Education. The students co-design for the Adolescent Development course focused on first creating a digital badge system that represented the course as it existed and then revising the badge system to focus centrally on equity and inclusion. Adjacent to this work, separate students and author one co-designed a digital badge system for two courses in the Single-Subject Credential Program: a General Pedagogy course and the Science Subject Methods Course. These two courses both occur in the first semester of the Credential Program and include fieldwork components, as candidates begin their student teaching. For all three courses, student co-designers had recently completed the course. Together, the three courses were chosen to understand developmental trajectories in and across courses at various points in the program.

Data for this project includes video recordings of virtual design sessions for three separate courses (19 sessions total). In addition, student co-design participants were interviewed following their participation in the design process. Analysis for this presentation focused on, first, an examination of digital badge systems as a design tool for mapping developmental trajectories and, second, the co-design of the digital badge systems with students in the credential program in order to identify learning and engagement in and across courses. More specifically, we analyzed video and documents from co-design sessions using grounded theory (Corbin & Strauss, 2008) to understand how students were making sense of the co-design process. The videos were reanalyzed and coded for using a previously developed coding scheme (Tierney, Horstman, & Tzou, 2021) that focused on negotiation of design content, as well as identified learning and development. We then analyzed interviews for perspectives on the design process and individual learning that occurred through co-design. Memos and associated vignettes of data were generated around emerging themes.

Major findings

While badges have traditionally been used to track and mark achievements in learning programs, this study demonstrates that the co-design process, in conjunction with badge structure, enables learning through program design. Though the final badge structure is important, it is evidence of how the participants interpret and prioritize learning content and activities as discovered through a badge co-design process.

Impact for learners

Co-design of digital badges reveals designers' thinking and perceptions of the content, prompting reflection and redirection when necessary. Across all three badge design processes, students were asked to identify aspects of their learning and development from the course of focus. Then, as a group, designers organized the content into a system of badges, each badge representing significant learning that had been identified. Across all three design processes, designers identified the personal value they gained from the process.

One student designer discussed how the co-design process had helped her transition into her role as a student teacher, helping to solidify what she had learned, while also pushing her learning through collaboration.

> I think it helped me realize how much I did learn so that I prepped me for the next semester. Like okay, these are all the things that I know and tools, I have in my back pocket now let's take them into the classroom and develop them, so I thought it was a cool way to like reflect but also move forward at the same time. And that the fact that over the summer I didn't just let it fall through the cracks I got to like discuss it and collaborate, I feel, stronger like in the classroom doing it.

The student then went on to discuss the collaborative nature of the reflection, how it highlighted new aspects of the course and sequence of the badges that she would not have gained on her own.

> And so, I had like my linear point of view of what I had learned and then I looked over at others. And they had totally different branches and we're making connections that once I looked at it, I was like that totally makes sense and it's like an aha moment. And then, when we combine them, all together was like I was saying, like the most well rounded version of that class. And I think if I was to do that, alone, it would have just been that like linear view um without, like the other things that they took away that made it unique for them, so I think the co-design made it like a learning experience but also made the badges like more than just like a one point of view, it was just everyone's once you put it together.

Similar statements were echoed by other student designers. One designer, who was involved in two of the badge design teams, reflected on her participation in general:

> I think it was fun, on a personal level for me just to review what I learned and kind of synthesize the class, especially since I'm becoming a teacher. That seeing the back end of design and being involved in it in a class I had just experienced was a really cool experience and I also felt like voices would be heard, without it being like in the class itself, so I think it's a great method to hear student voices.

Other students discussed how the conversations in the co-design sessions had transformed how they thought about education. One student who was an aspiring teacher noted how a discussion on whether or not teachers should accept late work changed how she thought about how she would approach and work with adolescents. In this way, the digital badge co-design sessions created a space of collaboration, reflection, and socializing that was distinct from other educational contexts that designers experienced.

Impact for teachers and educators

For the teachers and educators involved in co-design, the process can bring to light the different perspectives of the learners and learners' experiences. In this way, co-design of digital badges can act as an assessment tool for teachers on what learners took away from their course. To demonstrate one aspect of teacher/educator learning in the project, we highlight how the digital badge system captured concepts and pedagogy focused on equity and inclusion (a central tenet of the teacher education program in which the courses reside).

The first course, a science methods course, focuses on the epistemic practices for science teaching. This course focus was clearly represented in the digital badge system that student designers created. However, despite conversations around equity and inclusion in the program, these ideas did not initially emerge in the badge system for the course and, when they did, equity existed in a separate node of badges, removed from the primary interlocking system. The results indicate that equity concepts and practices were an add-on to students' learning about science pedagogy, which mirrored the actual design process of the science methods course.

In a second badge co-design process, a general pedagogy course, the course had recently undergone a revision during which equity was built in as one of the major pillars of the course. In the badge system, student designers both created equity-focused badges, but also discussed the ways in which equity pedagogy intersected with other badge nodes, such as building classroom community. While the course centered equity and inclusivity as central ideas, the badge design process introduced new connections and extensions that could be made.

The third badge co-design process focused on an undergraduate adolescent development course, which is a prerequisite for entering into the teacher education program. This course was already identified as needing to be more centrally focused on equity and inclusion. For this co-design process, student designers first created a badge system of their learning and development in the course. Then they redesigned the badge system to center

ideas focused on equity. This process required a reconceptualization of many of the course topics and ideas, a process that both co-design and badge design afforded.

Impact on educational structures and content

By involving students to be an integral part of designing the digital badge systems, they introduced concepts more directly linked to their experiences and development in and across the university courses. One key element of this process was how student participants drew links between existing course content and issues of race, equity, and inclusivity. This suggests the value of combining co-design and digital badges as a design tool to integrate development and engagement more deeply into learning environments. For example, after an initial brainstorming session where the participants captured main content ideas they felt should be included in the course, the participants began to organize and sort these topics by using funds of knowledge (Gonzalez, Moll, & Amanti, 2005) as the primary filter or lens. The following topics represent the highest priorities of the learners and the educators of what should be covered in their program: Student Wellness; Educator Role; Identity & Autonomy; and Puberty/Development. It should be noted that Puberty/Development is the only content category that is broken up into three sub-categories: biological, social and cognitive development. The sequence of topics identified by the group represents not only the agreed-upon priorities of the community, but also shows how the group views and interprets the relationship between topics. For these participants, the artifact of the badge system created a vantage point from which both the learners and educators can reflect on how they've represented the hierarchy and relationships of the content itself.

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When failing generates math anxiety instead of productivity

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Abstract: Experiences of failure and confusion can be intentionally purposed for learning tasks. In the Productive Failure instructional design, students attempt to solve problems before they are formally instructed on the relevant content. However, confusion and the perception of failing can elicit negative emotions in learners, even more so in students who already feel anxious about failure. Although research has demonstrated that failure can lead to math anxiety, and vice versa, the role of math anxiety in instructional designs that leverage moments of failure has not been investigated. This negative emotional cycle may negatively impact some students' learning and interest. We argue that future research would benefit from considering potential tradeoffs between enhanced learning and increased anxiety. We ground our arguments in an exploratory mixed-methods design that combines behavioral data with a task-based interview.

Affect and Math Anxiety in Math Education

The various elements of affect, attitudes, and student beliefs—such as those concerning one's understanding of math, or beliefs concerning success and failure—are increasingly acknowledged to play an important, yet poorly understood, role in math learning. For example, students' affective disposition can be a more critical predictor of entry into STEM subjects than enrollment and grades (Maltese & Tai, 2011).

When experiencing a negative emotion, we may focus on our negative sensations. Psychologically, this is done to find the means of eliminating the negative feeling. Thus, it is not surprising that there is an effect of emotions on learning, and studies have shown that learning is negatively influenced by unpleasant emotions, unless the tasks are simple (attention allocation elsewhere; see Hascher, 2010). Regardless of their valence, emotions can also be beneficial for learning, such as happiness (Kim & Pekrun, 2014), confusion (D'Mello et al., 2014), and even frustration (Liu et al., 2013). On the other hand, boredom and anxiety are associated with reduced learning (Pekrun, Elliot & Maier, 2009), while frustration can be destructive (Kort, Reilly & Picard, 2001).

While uncertainty has been shown to be beneficial for learning, it may also be detrimental (Lamnina & Chase 2019). In short, instructional designs that intentionally generate uncertainty could contribute to either:

(1) negative emotions about knowledge (Sinha 2021): a focus on the uncertainty of the problem, or

(2) negative achievement emotions (Pekrun & Linnenbrink-Garcia, 2014): a focus on personal failure.

Thus, fostering uncertainty could lead to (1) curiosity to learn what the student is (now aware to be) lacking—but may also lead to (2) self-preoccupying thoughts that interfere with learning. The latter may even feed into vicious cycles of anxiety and failure (Pekrun, Elliot & Maier, 2009). Some affective aspects in math learning appear to be rooted so deeply that they are difficult to diminish by instruction (Gomez-Chacon, 2000).

Because there is more to a learning situation than the *local* affect, we also must attend to the *global* affect—the lingering presence of experiences that made the learner the person they are (Gomez-Chacon, 2000). We argue that it is important to also attend to the more global affects, such as *math anxiety*, when designing for uncertainty. Math anxiety, which develops through various educational and non-educational experiences throughout the learner's life, has been described as a feeling of panic, helplessness, paralysis, and mental disorganization that arises when one is solving a mathematical problem or managing numbers (Ashcraft, Kirk & Hopko, 2000). In interviews with math anxious individuals (Sloan, 2010), the most reported causes of math anxiety were: negative experiences with math classes, teaching practices in school, memorization of procedural knowledge, math avoidance—low math achievement, test anxiety—failure, lack of confidence. Thus, pre-existing math difficulties cause or aggravate math anxiety (Núñez-Peña & Suárez-Pelliconi, 2014), and poor math performance can lead to math anxiety. Taken together, math anxiety is not merely a local affect but is better understood as a global affect that influences learners' behavior and cognition. This global affect ought to be considered when designing instruction that generates instances of failure and uncertainty, because this approach could generate or reinforce a student's already existing negative attitudes, beliefs, and feelings towards math.

Productive Failure and Affect

Productive failure (PF; Kapur, 2016; Kapur & Bielaczyc, 2012) is a subset of Problem Solving followed by Instruction designs (PS-I; Loibl, Roll, & Rummel, 2017), that broadly follow the paradigm of preparation for

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future learning (Schwartz & Bransford, 1998). In PF, the problem-solving phase is intentionally designed as an initial generation and exploration phase, which offers students the opportunity to activate existing and intuitive knowledge. Since the problems are based on concepts that have not been formally taught to the students, the problem-solving phase typically generates feelings of uncertainty and moments of failure (e.g., incorrect solutions). In a subsequent instruction phase, the desired concepts are conveyed to the students.

PF designs, like impasse driven learning (Van Lehn, 1988), lead students to an impasse in their learning that forces a transition into "repair" strategies, such as seeking help, to overcome the impasse. Piaget (1964) formulated in his theory of cognitive development that we experience a state of imbalance when encountering information that requires us to develop new schema or modify existing schema. This uncomfortable state of imbalance drives us to the assimilation of new schema or the adaptation of old schema. Without accommodation, we are left with old schemas. For some, this might be "I am not good in math; I don't know how to do it".

Present Study

Only a few studies investigated the role of affect in PF (e.g., Lamnina & Chase, 2019; Sinha, 2021). To our knowledge, we are the first to investigate math anxiety specifically in a PF design. Math anxiety affects all stages of cognitive math processing (e.g., Ashcraft, Kirk, & Hopko, 1998). Therefore, we hypothesize that students with higher levels of math anxiety will benefit comparatively less from the PF design on learning outcomes.

Method

Participants

Sixty-two students (age range = 18-24) were randomly assigned to one of the conditions (PS-I or "Direct Instruction followed by Problem solving - I-PS"). Two students dropped out due to their high level of math anxiety. Those two students took longest on the task and vocalized their perceived difficulties and feelings towards the situation. The first author took notes of these comments and conversations and translated them to English. All participants were naïve to the goals of the experiment and provided written informed consent. The study has been approved by the local Ethics Committee following the Declaration of Helsinki.

Procedure and Materials

A classical PF design (Kapur, 2014) was used along with questionnaires about different cognitive and affective mechanisms such as knowledge gap awareness, state curiosity, cognitive load, learning goal orientation, and attitudes towards mistakes (Sinha & Kapur, 2021). In addition to that and relevant to the present study, math anxiety was measured with the Abbreviated Math Anxiety Scale (AMAS; Hopko et al., 2003). The participants responded using a 5-point Likert-scale, ranging from 1 (low anxiety) to 5 (high anxiety).

Results and discussion

Quantitative results

An ANCOVA was performed to investigate whether the conditions would differ in the posttest scores. The results are shown in Table 1. Contrary to expectations from previous research, the students in the PS-I condition (M = 19.37) did not significantly outperform those in the I-PS condition (M = 19.03). Moreover, there were no differences on any other cognitive and affective measurements. However, the impact of math anxiety—as a covariate in the analysis—was highly significant and could explain why the students in the PS-I condition did not perform better on the posttest. This supports our hypothesis that math anxious students—who were more prominent in the PS-I condition—do not benefit as much as non-math anxious students from the PF design.

Table 1
ANCOVA for Achievement by Instruction Type, Attitudes and Feelings

		Achievement		
Type of Instruction		**Mean**	**SD**	**N**
I-PS		19.03	4.00	30
PS-I		19.37	3.45	32
Source	**SS**	**MS**	**F**	**η^2_p**
Condition	12.59	12.59	1.17	0.02
Math Anxiety	121.30	121.30	11.31*	0.16
Learning Goal Orientation	4.12	4.12	0.38	0.01

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Attitude Towards Mistakes	1.76	1.76	0.16	0.00
Knowledge Gap Awareness	36.97	36.97	3.45	0.05
State Curiosity	3.95	3.95	0.4	0.01
Germane Cognitive Load	0.76	0.76	0.07	0.00
Residuals	589.35	10.73		

Note. Levene's Test for Equality of Variances $F(1, 60) = 0.031, p = .9$; *p < .001

Qualitative results and discussion

The quantitative results do not capture the experience of the excluded participant Belinda (name changed; highest AMAS score in the sample: 43). The inclusion of interview notes illustrates the challenges faced by math-anxious individuals when dealing with designs that intentionally introduce feelings of uncertainty and failure.

> Belinda: [looking at first author after reading the problem] "Oh, I don't know how to do this!"
> First author: "It's okay, it's about learning something new, the solution doesn't have to be right."
> Belinda: "Okay, but this is math, and I am *not* good in math." […]
> [solving the task shows motor restlessness, changes sitting position, fidgets, sighs heavily]
> Belinda: "Can you please give me clues? I don't even know what to do. […] If I don't get an example of how to solve [a math problem] or an explanation I don't know how to solve it."
> First author: "[…] It's not about doing it correctly, just about trying. […]"
> Belinda: "Okay, I'll try. If I do this [shows notes] is it going in the right direction?"
> First author: "See, you're coming up with something without being instructed."
> The problem-solving phase ends, and first author explains the next step of the instruction phase.
> Belinda: "Oh no, now I will see how wrong I was."
> First author: "You'll see a standard way to solve the problem. You're not wrong but creative."
> Belinda: "Erm… So… my nervousness has increased quite a bit over time, and…I'm actually very nervous. Maybe also a bit afraid… afraid that I will fail. I am not sure if I will recall…"
> First author: "[…] it is okay if you don't recall the formula, maybe you recall some parts of it or comprehend what the formula said. That's all fine and you're already learning. […] even if you wouldn't recall the formula, you'll be okay… you can stop whenever you want."
> Belinda: "Okay, thank you... [sighs] …" [reads the questions and attempts to solve the tasks, sighs heavily and buries her head into her hands, but continues, persevering for 20 minutes]
> Belinda: "I can't do this. I am trying but I'm frustrated, I'm also afraid to fail, it makes me think of my fear instead of focusing on the questions. Can I stop please?"
> [Task is stopped. Conversation continues with support for anxiety, not relevant to task]

The case of Belinda highlights how this instructional strategy had a severe impact on one participants' math anxiety during the learning process, leading to them dropping out in the posttest.

Conclusion and Future Directions

While PF designs tend to produce positive effects on student understanding, they also generate moments of failure and feelings of uncertainty. This is not a criticism *per se*: after all, learning math *is* difficult. However, the concern is that certain learners might experience increased math anxiety and more negative opinions regarding their abilities and knowledge. Even if learning can be increased with such designs, do we not also court the risk of losing potential STEM students? As Maltese and Tai (2011) suggests, it may be possible to simultaneously *increase* students' math achievement yet *decrease* their interest in majoring in STEM fields.

Further research should be done to determine whether the present results can be generalized. Future experimental studies should contrast math anxious and non-math anxious students in a PF design (i.e., a 2x2 design, PS-I vs I-PS, math-anxious vs non-anxious) to investigate if math anxiety leads to lower posttest scores. Nonetheless, the present results offer support for our central argument that math anxiety plays a significant and thus-far unexplored role in instructional designs that generate moments of uncertainty and failure.

Course instructors and teachers should be aware of these findings, such that appropriate help and support can be provided to. In an ideal setting, students can experience curiosity and benefit from such designs, yet "ideal" is not something we can intentionally design for. Increased attention to affect in the learning of math, and particularly to math anxiety, would bring us closer to our shared goal of "educational innovation for all."

Author Contributions

VG: Project Administration, Conceptualization, Methodology, Writing- Original draft. DT: Writing- Reviewing and Editing, Resources. CF: Investigation, Formal Analysis.

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The Role of Action-Prediction in Mathematical Reasoning

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Abstract: Action-cognition transduction (ACT) posits how body movements support actors' inference making by activating feedforward and feedback mechanisms in consideration of plausible outcomes. Following ACT, we investigated whether prompting people to predict future body states (i.e., feedforward processes) facilitates mathematical reasoning. In this randomized 2x2 factorial experiment, undergraduate students (N = 127) *performed directed actions* (Yes/No) or *generated predictions* (Yes/No) prior to justifying the veracity of geometry conjectures. As predicted by ACT, directing participants to mimic cognitively relevant directed actions facilitated mathematical insight, though moderated by task demands. Moreover, merely prompting participants to predict movements, with or without performing directed actions, also enhanced proof performance. This study provides insights into how body-based simulation induces inference-making in support of conceptual understanding for mathematical transfer and generalization.

Introduction

Theoires of grounded and embodied cognition (GEC, Barsalou, 2008) adhere to the premise that cognitive processes emanate from and are influenced by one's body-based actions and simulations of actions. Goal-directed actions engage both feedforward and feedback processes that assess current states of the world in order to anticipate all of the plausible future actions, thereby integrating information from both actual and anticipated outcomes (Pezzulo, 2008). The continuous interplay between acting in the world and anticipating consequences of those actions illustrates the close reciprocity between sensorimotor and cognitive processes (Neisser, 1976).

In the current experiment, students observed the movements performed by animated avatars and were prompted to predict which body movements the avatars will make next. It is hypothesized that engaging in these action-predictions activates spatial-motoric processes that facilitate one's reasoning about space and shape (Nathan & Walkington, 2017). By connecting anticipatory nature of actions with reasoning processes, this study investigated whether action-prediction influences people's mathematical reasoning in geometry proof.

Theoretical framework

One of the core assumptions for embodied learning is that cognitive processes operate as a *predictive architecture*. People do not passively wait for input to act but continually anticipate what is to come in streams of sensory input, and we are poised to respond (Clark, 2015). *Action-Cognition Transduction* (ACT; Nathan, 2017) is consistent with this philosophical view of cognition, by framing action and cognition as reciprocal processes operating in close concert: Thoughts drive goal-directed actions; and actions induce cognitive states commensurate with those goal-directed actions. ACT offers an account of how actions and simulations of actions activate feedforward (i.e., predictors) and feedback (i.e., reaction) mechanisms that anticipate and respond to outcomes, thereby influencing the actor's behaviors and cognitive states.

When the actions are deemed as *mathematically relevant* they can contribute to enhanced mathematical reasoning. This occurs in cases of spontaneous co-speech and co-thought gestures (Nathan et al., 2021). It also occurs in cases when people are prompted to perform specific mathematically relevant *directed actions* as part of a designed intervention (Nathan et al., 2014). Some studies have shown that directed actions can prime gesture production during learners' explanations, which, in turn, contribute to superior cognitive performance (Donovan et al., 2014). Similarly, Nathan and colleagues (2014) found that compared to those who performed unrelated arm movements, participants who were directed to perform conceptually related movements were more likely to generate key mathematical insight for conjectures. However, similar to Walkington et al. (under review), relevant directed actions by themselves may not directly improve mathematical reasoning, but do so through moderated effects of "gestural replays" of these actions during their multimodal explanations.

Prior results suggest that relevant directed actions can prompt reasoning through nonverbal means. However, their connection to more complex processes like proof production might require additional pedagogical tools to fulfill their purpose. Prediction, or the combination of directed actions and prediction, might be needed to support students' reasonings about mathematical transformations. Thus, we investigated three research questions: (RQ1) Does predicting actions impact students' geometry insight, proof, or gesture? (RQ2) Does performing

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relevant directed actions impact students' geometry insight, proof, or gesture? (RQ3) Does predicting relevant directed actions that they perform impact students' insight, proof, or gestures?

Methods

Participants

Participants included adult students (N = 127; 63.0 % female) recruited from a large university in the Midwestern United States. Out of these participants, 33.9% had not taken Calculus I, 46.5% had completed or were enrolled in Calculus I or II, and 19.6% had taken or were taking a mathematics class above Calculus II.

Procedures

Participants were randomly assigned into one of four groups using a 2x2 between-subjects design: (1) perform *directed actions* (DA=Yes; DA'=No) and (2) generate *predictions* (P=Yes; P'=No). They took part individually with an interviewer. After going through the instructions and completing a practice-trial example conjecture, participants started the actual conjecture tasks. Participants were prompted to read a mathematical conjecture (see an example in Figure 1). Next, they adhered to one of four conditions: (1) Condition DA+P' participants (n=30) mimicked the complete series of three directed actions without any prompt to make predictions (see directed actions in Figure 1); (2) DA+P participants (n=30) mimicked an incomplete sequence of directed actions and were then shown the "?" symbol and asked to predict a "possible" third movement; (3) DA'+P participants (n=37) were not exposed to any directed actions but were asked to "imagine" movements that could enact the geometric transformation of each conjecture; (4) DA' +P' (i.e., the control group; n=30) participants received no directed actions and were not prompted to make predictions. Finally, participants completed each conjecture by answering a prompt to consider the statement's veracity (i.e., *always true* or *false*) and to provide a verbal justification. Each participant completed a set of eight conjectures with order counter-balanced.

After giving video-recorded responses to the eight conjectures, each participant was asked to complete surveys about demographics, general geometry knowledge, and spatial reasoning. Prior study have revealed that gender, math expertise, and spatial ability are correlated with geometric reasoning (Nathan et al., 2021).

Figure 1

An example conjecture "If you halve the length and the width of a rectangle, then the area is exactly halved."

Note. These directed actions are intended to convey a key insight related to this conjecture – that the area would actually be smaller than a half by halving both the length and width.

Coding

Video recordings of participants' responses were transcribed and coded. Insight (reliability κ = .93) was measured by the participant's understanding of key mathematical ideas for each conjecture. Each participant's verbalized proof (reliability κ = .96) was coded following Harel and Sowder's (2005) three criteria: (1) *generality* of the argument, (2) use of *operational thinking*, and (3) exhibit a chain of *logical inference*.

Representational gestures (Alibali et al., 2001) were classified as either non-dynamic or dynamic depictive gestures (reliability κ = .95). *Non-dynamic gestures* reflect only static properties of the mathematical entities, such as tracing along a shape. *Dynamic depictive gestures* enact motion-based transformations of mathematical entities, such as dilating triangles (Garcia & Infante, 2012).

Results

Data analysis employed mixed-effects logistic regression models for binary outcomes on insight, proof, non-dynamic and dynamic depictive gestures. Models were fit using the *glmer* command of the *lme4* package in R. *Participant ID* and *Conjecture* were included as random effects. All models included the *experimental condition* as the primary predictor. Three student characteristics, *gender*, *students' most advanced previous math course*,

and *spatial score,* were retained in the models as covariates that significantly improved the fit of our models. Finally, we report odds ratios that are exponentiated raw coefficients.

Research Question 1: Effects of prediction on performance

To address RQ1, we used the experimental condition prediction (P) vs. no prediction (P') as the main predictor. The regression model predicting insight showed that having a math course above Calculus II strongly predicted insight (OR = 4.48, d = .82, p <.001). Similary, having a math course above Calculus II (OR = 1.59, d = .25, p = .048) and high spatial scores (OR = 1.17, d = .09, p = .001) were associated with valid proofs. Consistent with the primary hypothesis of this investigation, students who predicted the movements, whether or not they actually performed them, were significantly more likely to formulate a mathematically valid proof (OR = 1.45, d = .21, p = .035), even when controlling for gender, prior math courses, and spatial ability.

Additionally, the models predicting gestures show that the spatial score was positively associated with dynamic depictive gestures (OR = 1.17, d = .08, p = .007) while negatively associated with non-dynamic gesture (OR = .9, d = -.05, p = .018). However, the prediction condition (with prediction versus no prediction) was not a significant factor for predicting the production of dynamic depictive gestures or non-dynamic gestures.

Research Question 2: Effects of directed actions on performance

To address RQ2, we used the experimental condition of performing cognitively relevant directed actions (DA) vs. no directed actions (DA') as the main predictor. As with the model used for RQ1, having a math course above Calculus II predicted insight (OR = 4.56, d = .83, p < .001). And the spatial score still predicted proof performance (OR = 1.16, d = .08, p = . 002). The models predicting gestures showed that males were less likely to produce dynamic depictive gestures (OR = .63, d = -.25, p = .045). Spatial scores predicted dynamic depictive gestures (OR = 1.17, d = .09, p = .006), while negatively associated with non-dynamic gesture (OR = .90, d = -.05, p = .017). However, the experimental condition (DA vs. DA') was not a significant predictor of insight, proof, or gestures. The results, which were not collected during game play, are not consistent with studies of embodied video game play showing advantages of directed actions (Nathan & Walkington, 2017).

Considering the overall high performance on geometric reasoning (i.e., around 70% produced correct insight), we further analyzed participants' behaviors (n = 381) on three conjectures that showed a relatively lower percentage of correct proof performance (less than 33%) but did not show a floor effect (higher than 10%). The results showed that performing directed actions predicted insight (OR = 1.85, d = .34, p = .043) for these difficult conjectures. However, there were no differences in proof performance or gesture production with or without relevant directed actions. These results show that participants performing relevant directed action were more likely to generate insight compared to those who did not while justifying difficult conjectures.

Research Question 3: Effects of predictions of directed actions on performance

To address RQ3, we used four experimental conditions as the main predictor. Having a math course above Calculus II was still a strong predictor of insight (OR = 4.45, d = .83, p < .001). When controlling for prior math courses, there was a trend that participants were more likely to produce correct insight if they predicted the relevant directed actions that they performed (DA+P; OR = 1.65, d = .28, p = .081). For proof, males and high spatial scores predicted proof performance (OR = 1.61, d = .26, p = .045; OR = 1.16, d = .09, p = .002, respectively). Similarly, there was a marginal trend suggesting that participants were more likely to construct a valid proof if they predicted movements without directed actions (DA'+P; OR = 1.54, d = .24, p = .080).

Gesture models show that males were less likely to produce dynamic depictive gestures (OR = .63, d = -.25, p = .045). High spatial score was associated with dynamic depictive gestures (OR = 1.17, d = .09, p = .006) but negatively associated with non-dynamic gestures (OR = .91, d = -.05, p = .021). However, the experimental condition was not a significant predictor of either dynamic or non-dynamic gestures.

Discussion

One of the central premises of embodied theories of learning is that people continuously operate in an anticipatory manner (Clark, 2015). This predictive stance allows us to engage in simulated actions that model how the state of the world—us included—will change in response to our behaviors. Because our motor system is constantly projecting how our actions will change the world, Action-Cognition Transduction (Nathan, 2017) is one account for how actions can construct grounded, situated "abstr-actions" (Abrahamson et al., 2020).

In answer to RQ1, as predicted by ACT theory, prompting people to predict actions led to significant advantages for formulating valid mathematical generalizations. In response to RQ2, mimicking cognitively relevant directed actions helped students generate accurate mathematical insight about difficult conjectures. The benefits for difficult tasks suggest this is where cognitive processes may benefit most from both actions and

simulating actions. Concerning RQ3, predicting cognitively relevant actions that were also performed showed only marginally significant benefits above and beyond predicting those actions. These findings suggest that action-prediction may facilitate participants' mathematical reasoning by simulating the future states of geometric transformations needed to support mathematically valid generalizations and proofs.

These findings contribute to the emerging theories of grounded and embodied cognition (GEC) in two ways. First, our results provide direct evidence to support ACT theory: motor behaviors and cognitive processes are closely coupled; movements – even when they are simply imagined – can benefit cognition. Second, this study extends prior research by providing an interactive environment where students engaged in actions and action-predictions as a path toward more advanced reasoning. Prior research has shown that students' proof performance was improved when they were told that the directed actions were mathematically relevant (Nathan et al., 2014). Because action-prediction is an integral component of most action sequences, it is rare to methodologically isolate the influences of action-prediction from action on thinking, as was done here.

This study has several limitations. One is that there may be additional interpretations of these results other than ACT, as a rich set of cognitive and post-cognitive frameworks for embodied learning emerge (e.g., Abrahamson et al., 2020; Danish et al., 2020). Another is to explore replication of these findings with a broader set of tasks and participants, and in face-to-face settings.

Nonetheless, these findings offer implications for mathematics education. First, there is educational value in engaging learners in mathematically relevant actions. Second, math educators can capitalize far more on the value of imagination and action-prediction for fostering reasoning that supports inference making. Third, the emerging designs of embodied interventions offer students active contexts and invite students to step into their roles as interactive learners who utilize rich body-based resources for supporting mathematical transfer.

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When Care is Not Enough: A Call for Critical and Sociopolitical Conscious Care

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Abstract: Noddings' (1988) argument for reframing of the aims of education around care centers modeling, dialogue, practice, and confirmation. Roberts (2010) calls for *culturally relevant critical teacher care* (CRCTC), which integrates tenets of culturally relevant pedagogy (Ladson-Billings, 1995) and critical race theory. In this study, we use culturally relevant critical care within the context of multiple teacher education programs. Results include a) considering socio-political contexts of learning and being when enacting care and b) modeling care and vulnerability. This work contributes to a revisioning of Noddings' (1988) framework to be more inclusive and racially conscious.

Major issues addressed

In Noddings' (1988) argument for reframing the aims of education around care, the pedagogical practices of modeling, dialogue, practice, and confirmation take center stage. She defines modeling as when "teachers treat students with respect and consideration and encourage [students] to treat each other in a similar fashion" (p. 223). She defines dialogue as ongoing conversation where "conclusions are not held by one or more of the parties at the outset" (p. 223). In dialogue, teachers model respect and consideration by co-constructing solutions with students. Noddings states, "in a classroom dedicated to caring, students are encouraged to support each other; opportunities for peer interaction are provided, and the quality of the interaction is as important as the academic outcomes" (p. 223). By confirmation, Noddings describes a dynamic whereby teachers empower students to identify and clarify their purpose in life and work to support them in that effort. These practices both constitute specific teaching moves, and they work in concert to re-establish classrooms as places where teachers work with students to establish more ethically- and morally-just learning spaces.

Noddings' (1988) care framework has provided meaningful guidance for educators seeking to care for their students. Research exploring the use of this framework over time varies in both application and understanding of care. For instance, one qualitative study (Walker & Gleaves, 2016) explored higher education teaching faculty perceptions of care in teaching. Results indicated that caring teachers had four key characteristics: (1) a relationship at the center (i.e., quickly learning students' names, responding to emails in a timely manner, initiate contact with students when challenges arise); (2) compelled to care (i.e., spending multiple hours supporting students, facilitating learning in various ways, explicitly support student diversity); (3) caring as resistance (i.e., defend students when needed, question policies); and (4) caring as less than. This final point referred to teachers who felt passionately about teaching but who felt the need to justify their positions through awards or publications rather than focusing on students. Another study (Anderson et al., 2020) that focused on student perceptions (n = 55) of good teaching at a New Zealand research institution found: "[Students] described good teachers as people who care about their discipline, care about teaching and care about students, powerfully influencing students' engagement with subject matter, enthusiasm for learning and aspirations for the future" (p. 1). Perceptions of care from both the teacher and student perspective have variations, but they appear to focus on relationships. However, other studies focused on the use of care with marginalized populations highlight the need to support students beyond the care framework. For instance, one ethnographic research study (Hos, 2016) explored the experiences of refugee students who were recent immigrants to a U.S. urban secondary school. The study found that the teacher exhibited ethical care for these students, and yet these students needed additional support in order to be successful in their new lives in a U.S. school. Another study exploring the intersection of race and care analyzed the experiences of middle school girls from Puerto Rico (Rolón-Dow, 2005); this research advocates for the use of "counternarratives to provide more intimate, caring connections between teachers and the Latino communities where they work" (Rolón-Dow, 2005, p. 77). While a care framework is still necessary, the need to expand its application is critical for supporting all learners.

These studies demonstrate the benefits of care within teaching, while also identifying the need to examine a) how care is being defined and bounded and b) question who is defining care. Care is typically defined and enacted within powered relationships and structures within education (Noddings, 2012; Roberts, 2010). An authentic narrative of care must consider factors beyond the classroom that impact student learning

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and could redefine how care is understood by educators and students alike. This understanding of care shifts the role of protagonist to students within teacher-student relationships, where students help define care within the contexts of their lives (Roberts, 2010). Framed within the context of teacher preparation, culturally relevant critical care requires both providing this form of care to teacher candidates and also supporting candidates' learning and teaching practices focused on culturally relevant critical care. For our study, we sought to understand socially conscious perspectives of care within teacher education programs during the first year of the COVID-19 pandemic.

Potential significance

This study highlights the need for teachers to listen to the expressed needs of their students, particularly as those needs relate to the sociopolitical context of the time. Demonstrating care for students should not be a simple show of values, which could be detrimental in promoting imbalanced power dynamics (Noddings, 2012) or deficit models of students, perpetuating racist thinking (Matias & Zembylas, 2014). Rather, care entails co-construction of learning between the teacher and the student. This collaborative relationship can relate to assignments, instructional activities, and discussions. Au (2017) calls for teacher activism to disrupt the injustices seen in schools and districts across the U.S. to "help build student and teacher critical consciousness around what is happening right now in the United States. For instance, we ought to complicate students' understandings by analyzing the history, economics, politics, environment, and human experiences of the U.S.-Mexico border" (Au, 2017, p. 148). Addressing immigration is only one issue that is relevant to our students and teachers alike. These social and political issues must be integrated into the curriculum as we prepare teachers to respond to the calling to be an educator. This collective consciousness focused on working for justice can help to create honest, authentic, and caring learning environments that honor the lived experiences of our diverse students. Doing so can contribute to a revisioning of Noddings' (1988) framework to be more inclusive and racially conscious.

Theoretical and methodological approaches

Research studies that focus on critical care for students utilize a variety of terminology in their understanding of care and advocacy for students. Rector-Aranda (2018) calls for teacher education programs to integrate *critically compassionate intellectualism* (CCI), which combines critical pedagogy, authentic caring, and social justice curriculum. Authentic caring is defined as relationship-focused teaching that promotes a respectful teacher-student relationship filled with admiration and love (Cammarota & Romero, 2006). Additionally, Roberts (2010) calls for *culturally relevant critical teacher care* (CRCTC), which integrates tenets of culturally relevant pedagogy (Ladson-Billings, 1995) and critical race theory. This framework entails a focus on students' voices, counternarratives, and student futures in addition to a consideration of political and ideological thinking, especially related to race and power (Roberts, 2010).

One caution in the literature is to avoid deficit model thinking of students shrouded as caring. For instance, Matias and Zembylas (2014) argue that predominantly white teacher candidates must interrogate their emotions of care and sympathy, particularly towards students of color, and how these emotions intersect with whiteness. These authors argue that antiracist teachers must explore their own narratives around caring that "are sometimes hidden expressions of disgust for the Other" (p. 319). They advocate for patience on the part of teacher educators in working towards an authentic care narrative:

> We, as teacher educators, have to be prepared to accept that this process is long and painstaking, and it will be full of emotional landmines, but it is of utmost strategic importance to expose the insidious emotional power of racism and its affective investments in white teacher candidates' identities (Matias & Zembylas, 2014, p. 333).

This call to action regarding antiracist pedagogy in teacher preparation can help inform understandings and enactments of care in teacher education.

Methods and Data Sources

This qualitative study analyzed transcript data from seven focus group interviews. These interviews occurred with students from five separate methods courses at four universities, in the fall semester of 2020. These universities spanned the Northwest, Midwest, and East Coast of the U.S. All students were enrolled in a teacher preparation program at their respective institutions.

The data analysis entailed a multi-step, collaborative process. First, the research team collaborated in real time via Zoom to review focus group transcripts, which had been uploaded to Dedoose. The research team utilized protocol, or a priori, coding, in which we identified a set of pre-established codes that could be assigned to the data based on the literature review and our own experiences as researchers in this study. This form of

coding is recommended for research teams analyzing data collaboratively (Saldaña, 2016). This form of coding was also useful due to the use of Noddings' (1988) preexisting care framework from which we were framing our exploration. In addition to the protocol codes, the team also conducted open coding of the data, where parts of the qualitative data were broken down into meaningful codes for comparison across the data set (Saldaña, 2016). After this first cycle of collaborative coding, the research team individually coded the remaining transcript data utilizing the existing codes. After all data were analyzed by each researcher, the codes were transformed into broader themes that assigned meaning to our initial codes.

Major findings

Considering sociopolitical contexts of learning and being

In creating a setting for care, we wish to highlight the ways in which teacher educators were aware of the social and political contexts in which their students existed. We frame this first theme as teacher educators considering the contexts of learning and being because of ways that the socio-political contexts of students' lives impacts their learning and the ways in which they exist in the world. Further, we argue that not considering our students' socio-political contexts of learning and being at best creates contexts of siloed care, where the care we show students does not help them navigate the world outside of our classrooms, and, at worst, perpetuates racism, sexism, homophobia, xenophobia, transphobia, and additional phobias. In this way, we view critical care as a method for dismantling systems of oppression through the individual relationships we build with students.

Some of the ways that teacher educators demonstrated their consideration of their students' socio-political contexts of learning and being were supporting students as they navigated the dual contexts of a global pandemic with COVID-19 and the Black Lives Matter social movement following the murder of George Floyd. One student reflected on their professor's support during these contexts:

> And I think I sat in a call with him and I just started crying about like how hard my teaching and teach classroom placement has been going because of my situation. I was homeless. I like got kicked out. My mom kicked me out of my house because I'm dating a Black woman. And then my dog almost died because people wouldn't, the vets wouldn't take my dog in because my fiancé was Black. And it was all in the midst of the Black Lives Matter protest and it was just really fucked up and like in the midst of all of this, I was just trying to figure out how to do schoolwork.

In this quotation the student does not necessarily highlight what responses the teacher educator had, but that they felt open to reaching out and discussing the contexts in which they were struggling. The socio-political contexts that teacher candidates participated in did not only emerge when discussing their personal struggles, but also when thinking about teaching as a practice. Another teacher candidate from a different institution talked about how their practice as a teacher existed in the context of historical racism and racial injustice.

> I just speak a lot of truth when it comes to racism and making sure that people are seen, especially if it's the indigenous people or Black people and just making sure that the validity and white fragility isn't just taking over the conversations because I'm - and I know that my ego showed up - and my triggers of, like, I'm sick and tired of white fragility taking over the conversation and me being attacked - took over the conversation and I definitely apologize for that.

In this quotation, the teacher candidate speaks to how teaching practice cannot exist outside of the socio-political contexts in which students and teachers exist. Doing so perpetuates white fragility and racism. This quotation recognizes teaching as an act in participation with the world and how teaching can be an act of social justice, seeking to influence and change the socio-political contexts in which we live.

Modeling care and vulnerability

Another key theme that arose in the data was modeling care for students. This modeling was largely on the part of the teacher educator modeling care for the student teacher. However, there were instances where the student teacher also mentioned experiences where they were modeling for their own K-12 students as well. Modeling occurred in multiple ways: modeling vulnerability through reflective practice, modeling teaching methods, and modeling social and emotional health.

First, when teacher educators modeled vulnerability, the student teachers voiced really appreciating this learning experience. The vulnerability within these classes was not only for the teacher educator, though; students also highlighted feeling vulnerable as learners, particularly when they had to watch and analyze videos of their own class, but this experience appeared to be a positive one. For instance, one participant said:

> It was a lot of the meta-analysis where we would record our own classes, and then the next class period, watch ourselves and go, oh, what were we doing and what we weren't we doing, so I think that

> meta-analysis via video was odd for me to analyze a video of our own class period, but I think it was also really helpful.

Furthermore, the vulnerability of the teacher educator in this meta-analysis was also valued by the students. For example, one participant discussed an instance when the teacher educator highlighted in the video the point at which she gave instructions to the class as being a poor example of how to provide instructions. The student participant reflected:

> She gave us all of these instructions that we were supposed to do in a video and then we were talking about it afterwards. And she was like, that was just that was bad, like, don't, don't do that...There was no way you guys were going to be able to focus on all of that stuff because I had you all doing like four or five things once. And it was really helpful for her to do that because, I mean, obviously I had partaken in the activity, cuz I was in class. And I think when I was doing it, I think I remember trying to do all the things, but I didn't cognitively realize that it was difficult. I think I was just attempting to do it all for her. But then, having her step back and be like, this is too much, don't put that on your students was really helpful for me when I have been planning lessons since then, to be like okay, I need to step back and make sure to pare down a lot of what I'm expecting from people, expecting for my students and having to see her struggle with that…was super helpful and something I've implemented.

The student appreciated the reflectivity of the experience of watching their own learning, but they also mentioned the transferability of this experience into their own teaching practice.

Further, another student highlighted the struggles one teacher educator was having in facilitating online discussions: “It felt nice knowing she was in the same, our professor was in the trenches with us in some sense, and I think that was really admirable to watch her go through.” The teacher educator and the student teachers were learning together how to navigate online learning spaces, and the vulnerability of this experience demonstrated the care the teacher educator had for the students, and vice versa. An additional student said of another teacher educator: “[He] is very, very good about introducing his own vulnerability to the classroom and leading with that...it's definitely one of the biggest lessons that I've taken from this whole program is how our students are not going to be vulnerable.” Perhaps the vulnerability modeled by the teacher educators in these courses will help students model their own vulnerability for their K-12 students. One specific quality of vulnerability that we wish to highlight is how modeling vulnerability was done as part of a process of building trust and creating a safe space from which the sociopolitical contexts of students’ lives can be incorporated, discussed, and supported. It was necessary for teacher educators to model vulnerability and establish safety as a component of the classroom community in order for students to then make themselves vulnerable. Doing so, we argue that teacher educators need to be responsive to these lived realities in order to care for students.

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International Society of the Learning Sciences

Inform, empathize, inquire: How youth use participatory storytelling to engage with social issues

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Abstract: We explored how youth created participatory stories—a genre of interactive fiction that logs players' choices as data to be analyzed—to advocate for social change. We designed a workshop to guide 22 high-school-aged youth in creating participatory stories about social issues of their choice. Analyses of their vision statements, stories, and reflections, revealed three ways that youth used this medium: to inform players, to provoke empathy, and to inquire into human behavior related to their chosen social issues. This study shows the potential for participatory storytelling to amplify youth's agency to take social action.

Introduction and background: Storytelling and social change

Whereas research has examined youth's creation of games and stories to engage audiences in reasoning and empathizing about social issues (Dasgupta & Hill, 2017; Lee & Garcia, 2014), few tools exist that allow youth to conduct socially engaged inquiry. We examine how youth created *participatory stories*, a genre of interactive fiction that logs player data, to both engage audiences with social issues, and to generate player data to pursue personal inquiries into those social issues.

Participatory stories build on the emotional impacts and empathy-building qualities of stories (Junker & Jacquemin, 2017; Koopman & Hakemulder, 2015), immersing players in a role, and prompting them to make choices that have narrative consequences. When stories are themed around social issues, these choices allow audiences to reflect on how their actions contribute to those social issues, and to even replay and observe different outcomes. Designers can furthermore create participatory stories that investigate particular questions, and analyze players' data to gain insight into the answers. Such inquiry, performed by and/or for those impacted by a social issue, can be an act of social change, in that it can engage and highlight marginalized perspectives (Freire, 2018).

To understand the potential of this novel medium as a tool for social action, we ask: (1) How do youth use participatory storytelling to address social issues that matter to them?

Methods: Context, participants, and data

Workshop design

The authors designed and facilitated—with 3 other colleagues—a virtual summer workshop (1 hour-long Zoom meeting/week for 4 weeks) that guided high school aged youth in creating participatory stories to address social issues of their choice. Through whole group and breakout room activities, we introduced youth to the value of player data in games for social change, and facilitated their identification and selection of social issues (Day 1). We guided youth in using the free interactive fiction creation platform, StudyCrafter (studycrafter.com, see Figure 1) (Harteveld et al., 2017), offered written feedback on their ideas, and assisted them in recruiting players by sharing links to their stories to members of our graduate programs (Days 2 and 3). Each story accumulated ~4-25 players by the end of the workshop (stories completed and posted earlier had more time to attract players). Finally, youth shared insights from their player data, and on their experiences (Day 4). Between sessions, we used Slack to prompt youth to share updates, assist them with technical issues, and offer feedback on their work.

Participants, data and analysis

Participants were 22 high school youth (50% female, 10 Asian, 6 Latinx or Black, 3 Caucasian, 1 Middle Eastern) accepted into a competitive STEM program hosted by a public university in a large Eastern United States city. Our workshop was one of their program requirements, the main of which involved working with faculty on STEM research projects (e.g., cancer research, bioengineering). Our data consisted of (1) youth's vision statements, in which they responded to the prompts: "I'm interested in… My target players are… In playing this (story), I want players to feel/be curious about… What I want to learn from players' input is….";

Figure 1

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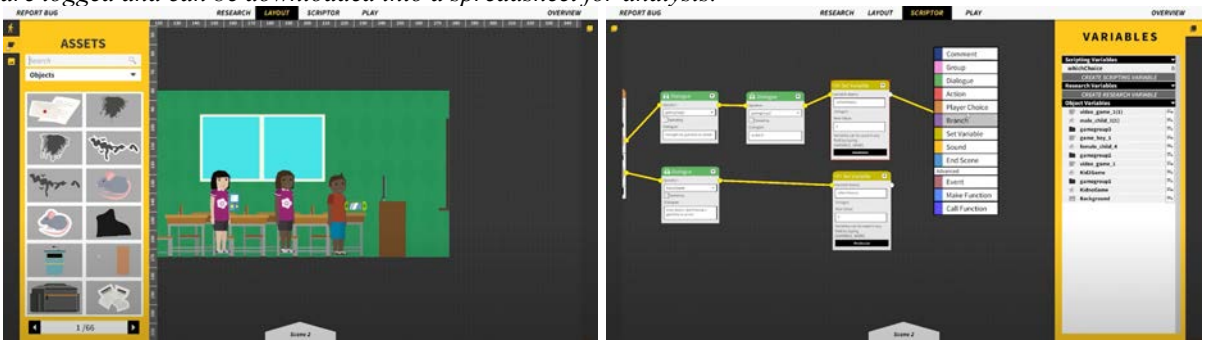
Left: StudyCrafter's asset library and scene layout interface; Right: Scriptor tools for coding interactivity and scene transitions. A typical StudyCrafter story unfolds through text-based narration and character dialogue. Through players' selections of text-based choices, the story can branch along different paths. Players' choices are logged and can be downloaded into a spreadsheet for analysis.



(2) youths' StudyCrafter stories; (3) youth's reflections on their design process, shared in the Zoom chat during workshop sessions, and in Slack between sessions. Because three youth did not complete their projects, and two worked as a team, we analyzed 17 stories in total and their associated artifacts.

To describe how youth used storytelling to address their chosen social issues, we first categorized youth's chosen social issues in terms of their broader domain (education, environment, etc.). Using an open coding approach, three researchers then read and discussed each of youth's vision statements, StudyCrafter stories, and final written reflections to identify salient or recurring themes (Corbin & Strauss, 1990). To achieve inter-rater reliability, we used a consensus building process (Baxter & Jack, 2015), in which three researchers developed and iteratively refined categories through joint discussion of each set of artifacts.

The result was three, non-mutually exclusive categories describing the spectrum of youth's purposes for their stories (see Table 1): to inform, to provoke empathy, and to inquire. We present a qualitative descriptive analysis (Sandelowski, 2000) of selected stories chosen to best illustrate how youth used the medium to fulfill these different purposes. All names in the findings are pseudonyms.

Findings

Overview

Youth chose topics from their personal or community experiences, which covered the domains of environment (e.g., climate change attitudes) (N=5), education (e.g., school budgeting priorities) (N=4), mental and physical health (e.g., supporting friends suffering from depression) (N=4), socioeconomic (e.g., healthcare access inequality) (N=3), and technology issues (phone addiction) (N=1).

All 17 stories sought to *inform* players about a social issue, such as by providing information about its prevalence or impact (e.g., I want players "to really consider all angles of [an environmental] problem [and] to understand the [impacts on all involved.]"). A subset of these 17 stories had the additional goal of encouraging players to *empathize*, such as by allowing them to experience a situation from the perspective of someone impacted (e.g., I want players to feel "the emotions and thought process that a family with limited resources would go through."). A further subset of stories also aimed to use player data to *inquire* into some question about the chosen issue (e.g., I want to know "When most people think they should get [mental health] help," and when to "push others to get help."). Categorized in terms of the main purposes that youth described, 12 stories sought mainly to *inquire*; 4 sought mainly to provoke *empathy*; and 1 story sought mainly to *inform*.

Stories that inform and empathize

While each of the stories sought to inform players of a social issue, only one youth in our sample, Emily, had 'to inform" as her sole goal. In her story, the player is the town mayor, and needs to decide how to address the issue of increasing sargassum algae on its beaches while mitigating impacts on tourism. For Emily, awareness of the complexity of this environmental issue was the ultimate goal. As she writes, she wanted players "to really consider all angles of the problem before making a decision for them to understand the complexity of these issues."

Four stories had the additional goal of generating players' empathy for an issue. Youth who created such stories expressed a desire for players to feel "stressed," and "upset," and to appreciate the unfairness of certain situations. These stories had players experience issues such as mental health stigma, inequitable resource access, and the lack or burden of power felt by people with different societal roles (e.g., managing a school budget, deciding to help a friend with depression, considering unaffordable medical treatment). For example, Yuka wanted

her players to feel "conflicted by the difficult choices ppl make abt their health based on affordability." In her story, players make a family's budgeting decisions, each of which is a compromise between the family members' individual health needs (therapy, medication). Players then observe the unavoidable impacts of their choices (the father's ER visit, the mother's burnout, the daughter's failing grades).

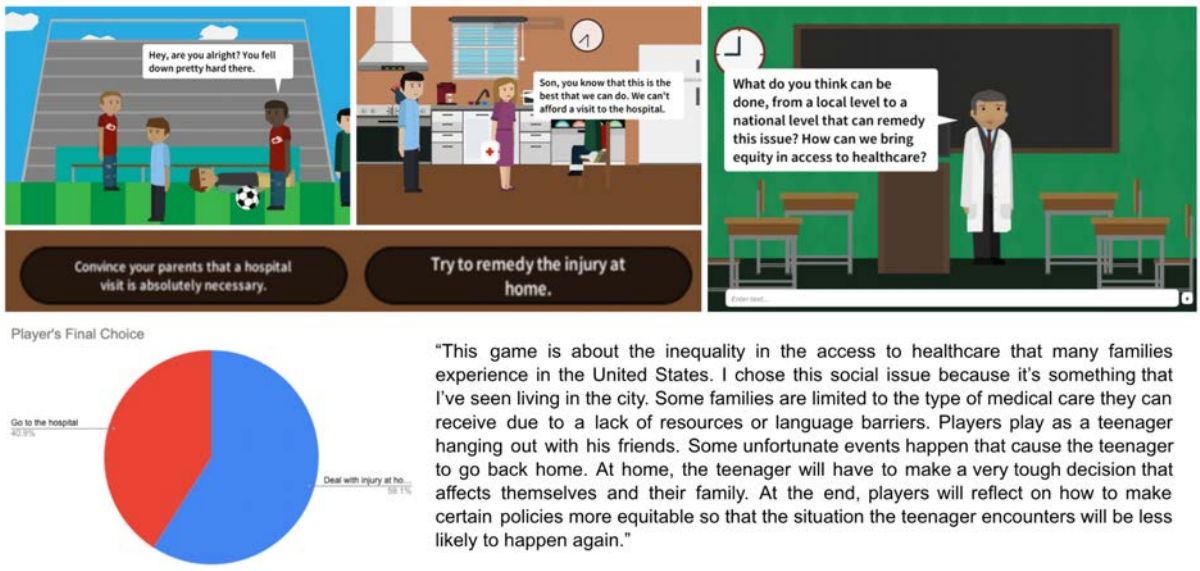
Similarly, Angela sought to generate sympathy for those impacted by socioeconomic disparities. In her story, players follow two characters—one wealthy, the other in poverty—and make a series of choices for them (e.g., to take a job, to apply for college). By making different decisions on replaying the story, it becomes clear that these choices are inconsequential to the characters' outcomes. Thus, Angela sought to challenge the myth of meritocracy by showing that "no matter how much [the characters] try, the economic disparity between them clearly hold the poorer one back." By offering inconsequential choices, her design sought to give players the sense that there is no escaping the path determined by one's existing resources.

Stories that inquire

Twelve of the youth's stories were designed to generate data that would address a question about their chosen social issue. For example, Sang's story (see Figure 2) had players take on the role of an injured teen who must decide whether to ask for medical treatment that his parents cannot afford. While this story aimed to inform players about healthcare equity, and to promote their empathy for people with limited healthcare access, it also collected data on players' choices to better understand the healthcare choices people make when financially constrained. Sang created a pie chart of his 25 players' choices, and observed that 40% chose to go to the hospital while 60% chose to deal with the injury at home. He hypothesized that "people were valuing their family over themselves and/or the injury not being serious enough to warrant a visit," and wondered about the "severity of an injury that is necessary to warrant a visit to a clinic no matter what financial situation." These observations prompted Sang to propose a follow-up inquiry that he might conduct through an iteration on his story: "I would make the injury more severe to see if there would be a more even split among players on whether they would go to the hospital or not. With a minor ankle injury, it's easier for players to think that a hospital visit isn't necessary. But, a more severe injury would eliminate that variable and give much harder choices with bigger consequences."

Figure 2

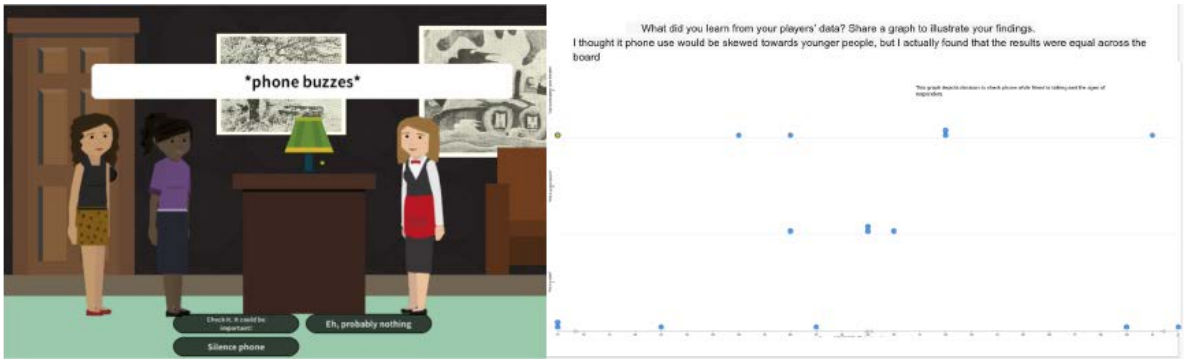
Top: Scenes from Sang's story about healthcare inequities, with both closed and open-ended player choices. Bottom left: The data generated from players' choices; Bottom right: Sang's vision statement.



Calla's story about phone addiction (see Figure 3) had players make various choices while at lunch with a friend (e.g., how to respond to and steer the conversation). During three moments, they must decide whether to check or silence their phone notifications. The game ends with an open-ended question: "Would you do anything differently if you were to play again?" Calla used her player data to measure the extent to which she raised awareness of phone addiction, noting that since "I don't mention anywhere that I am testing phone use, it was interesting to see how many people noticed they were using their phones a lot." Calla also used a dot plot to compare players' choices based on age, remarking that "I thought [the numbers of players choosing to check their phone] would be skewed towards younger people, but I actually found that the results were equal across the board."

Finally, when Calla's playtesters noted that they "couldn't really tell if their friend enjoyed the outing," Calla identified a design iteration to include a "way for the [friend] to react positively or negatively." As she reasoned, "it would be helpful (...) to have negative responses to demonstrate the rudeness of some of the choices."

Figure 3
Left: A scene from Calla's story about phone addiction, displaying a closed-ended choice. Right: Calla's dot plot of her player data, and a statement of her main findings.



Discussion and Significance

This study illustrates the potential of participatory storytelling for engaging youth in acting on social issues that concern them. By having players make decisions in particular roles and situations, youth creators used this medium to raise awareness of issues, to provoke empathy for those impacted, and to generate data for inquiry. Youth's analyses of their player data supported deeper explorations of their chosen issues, and also prompted ideas for iterations to improve the clarity of their message, and new directions for inquiry. These findings suggest that participatory storytelling can amplify youth's agency and voice to advocate for change. While some of our participants' stories were unclear or incomplete, our findings suggest that with sufficient guidance and support, participatory storytelling can be an effective tool for socially engaged inquiry by all youth.

Endnotes

(1) Authors 1 and 2 contributed equally to this manuscript.

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Becoming a Critical Action Educator: A Comparative Analysis of Formative Interventions in Canada, China, and India

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Abstract: We present a comparative analysis of professional learning communities (PLC) of teachers in Canada, China, and India, in the context of a project called the Critical Action Learning Exchange (CALE). CALE is an international community of educators dedicated to designing, enacting and sharing critical action curricula that empower students in responding to complex socio-environmental issues such as climate change, social justice, pandemics, and more (Carvalho et al., 2021). We analyze the three PLCs through the lens of activity-theoretical formative intervention research (Engeström et al., 2014). Comparison of the three cases identifies a series of key factors for the successful professional development of critical action educators and informs the design of future CALE elements.

Introduction

This paper presents a comparative analysis of three formative interventions for the professional development of critical action educators. Activity-theoretical formative intervention research has its roots in cultural-historical activity theory (CHAT), building on the works of Vygotsky, Ilyenkov, Leont'ev, and Davydov, with the goal of understanding transformations in activities that are undergoing some sort of risk, crisis, or pressure for change (Engeström et al., 2014). Our study investigates formative interventions in professional learning communities (PLCs) of educators in Canada, China, and India, in the context of a project called the Critical Action Learning Exchange (CALE). CALE is an international community of educators dedicated to designing, enacting and sharing critical action curricula that empower students in responding to pressing, complex socio-environmental issues such as climate change, social justice, pandemics, economic inequality, and more (Carvalho et al., 2021). Educators that join CALE are presented with a pedagogical framework for critical action education, and a platform for peer support in the form of an online community for collaborative design, implementation, exchange, and advancement of curriculum that empowers students as agents for positive social change. Critical Pedagogy (Freire, 1970; Kincheloe, 2004) is applied within the context of empowering teachers to help students overcome the sense of powerlessness regarding overwhelming socio-environmental issues, and feel empowered as agents capable of contributing to solving those problems. Our hope is that a comparative analysis of the formative interventions in these PLCs helps us to identify key components, features, needs and obstacles of these communities that inform our own understandings of how teachers can develop new pedagogies and practices, and guide future implementations.

Theoretical framework

The research literature describes professional learning communities (PLCs) as groups of professionals collaborating in an ongoing, learning-oriented, critical interrogation of their practice (Toole & Louis, 2002). Supovitz and Christman (2003) stress the need for the community to be grounded in supportive structures and strategies. To design PLCs that help teachers adopt new approaches that reinforce students' sense of agency and collective responsibility, CALE draws upon the theoretical perspectives of Critical Pedagogy (CP) and Knowledge Building (KB). CP is based on a philosophy of praxis that stresses the importance of an educative process that interweaves theory, action, and reflection as a means to advance the broader society towards social change and justice (Freire, 1970). This perspective is grounded on the concept of *conscientização*, which Prilleltensky (1989, p. 800) describes as "The process whereby people achieve an illuminating awareness of the socioeconomic and cultural circumstances that shape their lives and their capacity to transform that reality". *Conscientização*, therefore, aims beyond critical thinking to include a sense of *critical consciousness* that enables students to make judgements on their current and ideal realities and empowers them as agents for positive change. KB, in turn, offers an important theoretical foundation for CALE's communities of practice, including fundamental principles of collective responsibility and epistemic agency, and constructivist practices to promote continuous improvement of ideas through dialogue and collective investigation (Scardamalia & Bereiter, 2010).

Engeström (2011) proposes formative interventions as a methodology that emphasizes the agency of practitioners, students, and users in the design process. The emphasis on fostering and leveraging the agency of participants in designing their own inquiry process makes this methodology particularly adequate to our research of a community of critical action educators who are dedicated to investigating their own practice. The formative intervention methodology relies on two epistemological principles, *double stimulation* (Vygotsky, 1978) and the principle of *ascending from the abstract to the concrete* (Ilyenkov, 1982). Through collaborative inquiry, participants generate future-oriented concepts and designs that open possibilities for changes in their own practices and processes, while allowing researchers to investigate the generation of actionable knowledge. Formative interventions use double stimulation to illustrate conflicts of motives. The first stimulus is typically a conceptual *mirror* that "reflects" the problematic situation being experienced. In trying to tackle the problem, the community may resort to external artifacts, or *visions*, which function as a second stimulus that supports or sustains the transformation of practices (Engeström et al., 2014). These stimuli help participants to visualize their collective *zone of proximal development* (ZPD) which is "the distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind potentially embedded in the everyday actions" (Engeström, 2014, p. 138).

Methods

Members of CALE PLCs participate in professional development activities to advance their understanding of critical action education and engage in designing new curricula (Carvalho et al., 2021). Participants can find technology support within the CALE online environment, where they can share their experiences designing and enacting new critical action lessons and engage in further authoring, discussion, and resource sharing. In the CALE PLCs, our goal has been to understand how educators' critical interrogation of their practice leads to transformative action. This question has guided us to model distinct interventions that accounted for each PLC's socio-cultural context. The underlying questions we have asked in developing our modelling workshops were: (a) What interventions are productive in a particular context? (b) How can those interventions be conducted to generate actionable knowledge that enables transformation of participants' teaching practices? (c) How can our workshop model help teachers become critical action educators? Three teacher cohorts were organized, each of which can be considered an autonomous PLC in its own right: (1) 45 teachers in Canada who focused on climate change education; (2) 68 teachers in southern China who are also engaged in designing climate action curriculum; and (3) 60 teachers in Bangalore, India, coordinated by local partners.

The formative intervention in Canada was organized in four sessions, carried out in Summer 2021. A pre-survey and critical questions functioned as *mirrors*; lectures and resources on critical action pedagogy and the CALE pedagogical framework for designing critical action curricula (Carvalho et al., 2021) were offered to generate *visions*, and Zoom breakout rooms, Google Jamboard, and Google Docs functioned as a *discursive space*. As members of this PLC were interested in understanding the importance of changing teaching practices relating to climate change education and student climate anxiety, the socio-cultural context was adjusted to provide critical questions to help educators conceptualize and respond to these interests.

The formative intervention in China was organized in six one-hour workshop sessions that were conducted after a week of pre-workshop discussions and introductions. The aim of the pre-workshops was to function as a *mirror,* aiming to engage teachers with new ideas about 21st-century competencies. In the following five sessions, a pattern was implemented with detailed and specific expectations of topics and activities. Weekly questions were offered as *mirrors*, content videos, supplementary resources, and "micro-lessons" functioned as *visions*, and a second *mirror* of each week were reflexive questions on learning strategies. Zoom meeting rooms and Google Docs were provided as a *discursive space*.

The formative intervention in India was organized in four sessions. One distinction between the interventions in Canada and China was the inclusion of paper handouts that aimed to help participants interrogate their current educational approaches and reinforce their sense of identity as a professional learning community. The first two sessions were planned to function as *mirrors* of participants' current teaching practices and offer possible *visions* in the form of lectures, examples of critical action curriculum, and discussions with a teacher guest. The final two sessions included a representation of the ideas and understandings of participants as *mirrors* and reiterated the discussion of *visions* to reinforce the pathway toward transformations.

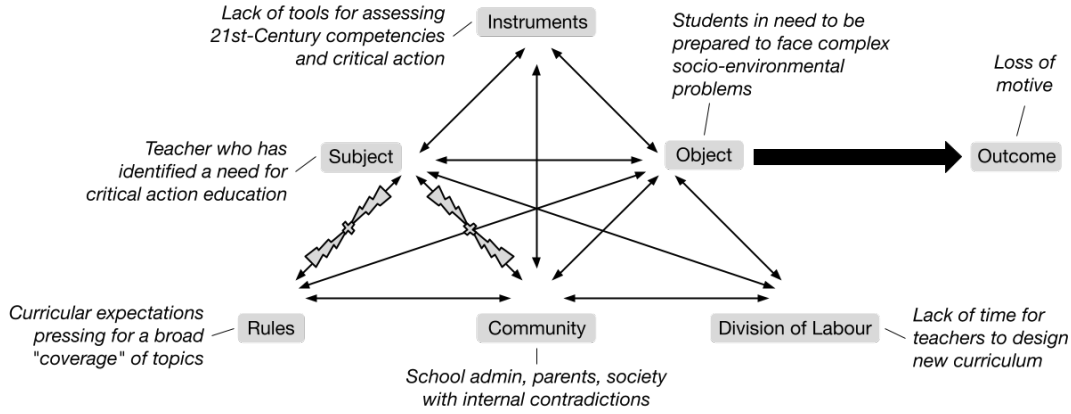
Findings

We describe our findings in terms of core concepts from activity-theoretical formative intervention research methodology. *Contradictions* and *conflict of motives* are concepts that relate to the initial state of the system. *Contradictions* refer to the main conflict identified by the researchers in the activity system. This takes form as a kind of working hypothesis, which is then submitted to the participants as an object of reflection to help them

articulate their own interpretation of the contradictions they face—referred to as *conflict of motives*. Finally, through the process of double stimulation, participants envision alternative possibilities and future directions, which constitute the *collective ZPD* (Engeström, 2014).

The *contradictions* in formative interventions are typically identified and represented through the modelling of an activity system (Figure 1). We identified the following contradictions in activity systems for all three communities, providing a set of working hypotheses: (1) the curricular expectations, which demand that teachers "cover" a broad range of topics, discourage the time-consuming deep exploration of topics needed for critical inquiry; (2) there are conflicting pressures on teachers, between the demand that students are equipped with "21st-century competencies" (e.g., critical thinking and collaboration) and the heavy content standards measured by student success on standardized tests or competitive selective processes for higher education. These contradictions were presented to participants as introductory objects for critical reflection and discussion.

Figure 1
Contradictions in the activity systems of the CALE PLCs in Canada, China, and India.



Participants' critical reflection on artifacts that functioned as *mirrors* of their contradictory states was found to be consistent with the working hypothesis. Participants reported some degree of anxiety or confusion, having identified a need for incorporating 21st-century competencies and critical action into their curriculum while also confronting barriers to doing so (e.g., heavy content expectations). After having identified and articulated these *conflicts of motives* with the help of activities that functioned as a first stimulus (*mirrors*), the three PLCs engaged in activities that operated as a second stimulus (*visions*). Through this process of double stimulation, participants were able to articulate their collective *ZPD*, which represents possible future directions for their activity. The collective *ZPD* of the three PLCs varied significantly, distinguishing the communities and pointing them in particular future directions. Participants of the Canadian PLC focused on ideas for increasing collaboration, exchange of ideas and resources, and sense of community. The primary focus was on climate anxiety and climate action, with the recognition that it is much easier to develop supplemental activities than ones that are central to the curriculum (i.e., that cover content through engagement in critical action and inquiry). Teachers in the Chinese PLC identified the enhancement of students' communication and collaboration skills as a fundamental need that underlies critical action inquiry. The assumption, manifested frequently, was that students are currently lacking those skills, which creates obstacles for critical inquiry. This was clearly a "slide back" from our initial discussions about pedagogy, to address an even more basic characteristic of Chinese classrooms (particularly at the high school level)—that they do not present a conducive climate for collaboration and inquiry. Students and teachers alike have strong epistemic commitments to a didactic approach to lectures and exams, and this climate must be addressed before any form of inquiry can be attempted. Finally, in the Indian PLC, after some reluctance to begin designing activities, there finally emerged a particular interest in art-making as a strategy to engage students in critical action. Accordingly, the initial activity designed and enacted by teachers used the *rangoli* traditional Indian art form as a medium for students to investigate and address diverse socio-environmental problems, such as the Indian farmers' crisis, population explosion, gender inequality, and more. This activity was a success, providing an illustration and grounding for other teams of teachers to begin their own process of designing for critical action.

Discussion

The use of a formative intervention approach has helped us to articulate important components of the design of effective PLCs in general, and of communities of critical action educators in particular. The study also highlights

some obstacles and eventualities that should be considered when designing such communities. One key design principle identified by this study is related to the importance of cultural responsiveness. The investigation of communities embedded within distinct cultural contexts (i.e., Canada, China, and India) reinforces our understanding that critical action education does not and cannot mean the same thing for different contexts. The principle of cultural responsiveness is especially relevant in the case of international collaborations, where teachers operate within very different cultures and educational systems, with strong norms of practice and diverse pedagogical understandings and epistemic commitments. Although the core principles of critical pedagogy have a universal character, their embodiment can take distinct forms that must be co-constructed with community stakeholders. In the formative intervention methodology, one important objective is to understand how an organization changes its existing state—deemed as problematic by the community itself—to a targeted improved state. It thus becomes crucial to recognize that each cultural context may contribute to producing very distinct starting and/or final states. This study also found that the target itself has to be adjusted to present a viable pathway, in accordance with the communities' respective starting places.

Finally, we must recognize that the forms of discourse and interaction employed in the intervention must also be culturally responsive. To engage participants in acknowledging and responding to the double stimulation and progressing through reflective activities, it is crucial to design pathways and employ forms of discourse that find resonance within the cultural context. In each CALE PLC, we recognized distinct forms of interaction and discourse. Canadian teachers preferred to be left to their own devices and did not stand for many lectures. They were good at self-organizing. In China and India, there was a more formal characteristic, where stronger central leadership was valued, and small groups still required close support. Chinese teachers valued the final presentations with feedback from visiting experts. Indian teachers felt the need for a strong "CALE identity", including certificates of membership. While such elements do not solve the problem of advancing critical pedagogy, it would certainly not be possible to solve it without them.

Conclusion

This study is significant in its application of a methodology from cultural-historical activity theory to the context of teacher professional development in critical pedagogy. It brings several distinct theoretical perspectives (i.e., critical pedagogy, activity theory, arts-based pedagogy, learning communities) to bear on the formation of three distinct professional communities, and studies the discourse and progression of those three through a lens of cultural responsiveness. The study helps respond to the persistent challenges of supporting teachers in developing new pedagogical understandings and practices. It will hopefully inspire other studies and serve as a reference for cross-cultural research within the learning sciences.

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Understanding the Factors Influencing Persistence: What Can Novices Learn from Experts?

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Abstract: Experts become experts in part because of their willingness to engage in thousands of hours of deliberate practice. What motivates them to persist in the face of constant failure? This question was addressed in a study of experts and novices in the domains of mathematics and English literature. We compared how experts persisted and spoke about their failures while thinking aloud during problem-solving on difficult tasks, in and outside of their domain of expertise. Experts persisted longer and gave different reasons for their failures than novices did, and their implicit theories of intelligence explained some of these patterns. Our findings document how an expert's failure attributions and implicit theory of intelligence may help them persist when tackling challenging problems in their domains.

Introduction

Experts are those who persist past proficiency to a level of competence in knowledge or skill that exceeds most others (Bransford, 2000). Their extensive knowledge libraries enable them to quickly understand challenging problems in their domain, and to select and apply relevant strategies to solve them (Ericsson, 2014). Thus, experts can efficiently solve complex tasks novices cannot. Beyond the cognitive, motivational behaviors of experts contributes to their ability to persist to achieve the elusive goal of expertise. *Everyone repeatedly fails on the path to expertise.* Chase (2013) showed experts exhibit persistence in the face of constant failures. The current study is the first attempt to replicate her findings in a larger sample, and we extend her work to directly investigate the role of motivation in persisting on challenging tasks and explaining attributions made during failure. Specifically, it views motivation through the lens of implicit theories of intelligence (Dweck, 2000).

Literature Review

Chase (2013) investigated the role of motivation in supporting persistence and understanding one's failures on the long path to expertise. She found experts and novices differed in how they attributed failure during problem solving. Attributing failure to external factors can support learners' self-esteem, while alternatively, attributing failures to internal factors can negatively impact persistence and performance (Weiner, 1979). Specifically, experts in a domain attributed their failures externally, such as to the complexity of tasks or limited resources of the environment, which they could accurately judge given their knowledge. Because of this, they persisted longer in tackling these problems. By contrast, novices in a domain attributed their failures internally, to their lack of intrinsic ability. Thus, they were less likely to persist in tackling these problems.

To further bolster the current understanding of the relationship between failure attributions and persistence, we considered an important construct in the motivation literature, Dweck's (2000) notion of implicit theories of intelligence. In this theory, individuals who hold an incremental theory view intelligence as a pliant trait developed through effort, while those who hold a fixed theory believe intelligence is stable within individuals and cannot be changed through effort over time. We predict those with more incremental theories of intelligence about their performance in a domain are more likely to persist in the face of repeated failure, and to continue to grow in their competence to eventually reach expertise.

O'Keefe et al. (2018) established that novice persistence was influenced by their theory of interest, which is parallel to theories of intelligence. Whether the focus is interest or intelligence, fixed mindsets believe the focus is stable and unchanging, while incremental (growth) mindsets see it as malleable and changeable with effort. But interest in a domain may not be enough to propel learners through expertise development. A learner's identification with a discipline can also impact their persistence, and this may be nurtured through experiences with the domain directly or by teaching it to others (Mercier et al., 2006). Whether learners see the experience of failures during exploration of a topic as a normal part of the process or as a reason to give up can vary (Williams-Pierce, 2019). These various potential responses to failure impact persistence after failure as well (Chase, 2013). As failure is inevitable, whether failure can be a productive source of future learning or not (Kapur, 2014) motivates our focus on experts as a model of how novices can persist following repeated failure.

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The current study is at the intersection of the expertise and motivation literature. We build on Chase (2013) because its foundational results have not been replicated to the best of our knowledge. This is important because of the very small sample size of the original study -- 10 math experts and 9 English experts. Following her study, we posit individuals might show differences in persistence and attributions of failure made while solving challenging problems in the domains in which they are experts versus the domains in which they are novices. Furthermore, we attempt to extend prior work by proposing individuals possess different theories of intelligence (Dweck, 2000) in their domain of expertise and versus domains in which they are novices. This puts them on the path to expertise in the former domain, whereas they will struggle to stay on it in the latter domain.

Objectives

The current study investigated the patterns of persistence and failure attributions in math experts vs, English experts. It also measured whether individuals have an incremental vs. fixed implicit theory of intelligence. This design enabled us to address the following research questions:

1. Do experts exhibit different patterns of persistence than novices when solving challenging problems?
2. Do experts exhibit different patterns of failure attributions than novices when solving challenging problems?
3. Are experts more likely to spontaneously revisit problems in their domain even when they are not "on the clock"?
4. In their domain, do experts have more incremental implicit theories of intelligence than novices?

Methods

Participants

Mathematics and English experts were recruited from a U.S. university to participate in this IRB-approved study. The experts were defined as faculty, postdocs, graduate students, or undergraduates researching or studying in a domain. This included 31 participants, 17 mathematics experts, $M = 25.65$ years, $SD = 3.12$ years and 14 English experts, $M = 28.36$ years, $SD = 4.77$ years, who completed both sessions of the study.

Design and Procedure

Participants were instructed to think-aloud during 12 minutes of problem-solving for each task and were allowed to cease problem-solving before time was up, if they desired. In the first session, half the participants in each expert group completed the math task first followed by the English task. The mathematics problem required proving a statement about prime numbers. The English problem required interpreting a poem with oblique language. The other half completed the English task first, followed by the math task. All participants then completed an online demographics questionnaire. They were then requested to return for a second research session. Finally, they were compensated $15 for the first session.

After at least 24 hours elapsed, participants returned for the second session. They revisited the tasks in the reverse order in which they originally completed them. They then responded to an online questionnaire including one question regarding whether they spontaneously revisited each task in between the two sessions. The remaining questions were drawn from a version of Dweck's (2000) theories of intelligence questionnaire, They were duplicated and specialized to query their implicit theories of intelligence for mathematics and for English. Participants were compensated $20 for the second session.

Data coding

Failure attribution statements from the verbal protocol, such as "I'm really bad at this" and "This problem is unnecessarily difficult", were categorized as internal or external, respectively, depending on the themes brought up by experts in the think-aloud sessions. These were used to compute a locus score for each task, defined as the number of external attributions minus the number of internal attributions, divided by the total attributions made during the task. Thus, positive scores indicate more external attributions of failure, and negative scores more internal attributions. Intercoder reliability was strong for failure attribution coding ($\kappa = .97$), and any discrepancies between coders were resolved via discussion.

Results

Expertise and persistence

Addressing the first research question, we performed a repeated-measures ANOVA with between-subjects

factor Expertise (math, English) and within-subjects factor Task (math problem, English problem) on the dependent variable persistence time. There was a main effect of Expertise, $F(1, 16) = 14.91$, $p < .001$, and also a main effect of Task, $F(1, 16) = 12.27$, $p = < .001$. Critically, the Expertise x Task interaction was significant, $F(1, 16) = 11.05$, $p = .0012$. As Table 1 shows, for the math problem, math experts persisted longer than English experts, as the earlier study found. However, for the English problem, the two groups persisted for a comparable amount of time in trying to solve it. This represents a partial replication of Chase (2013).

Table 1
Mean Persistence Time (seconds)

	Math Problem *M (SD)*	English Problem *M (SD)*
Math Experts	674 (119)	687 (81)
English Experts	480 (239)	670 (119)

Expertise and failure

Table 2 presents the mean locus score for each problem and expert group. Recall positive scores indicate that more external attributions were made, and negative scores indicate more internal attributions were made. We analyzed these scores in a repeated-measures ANOVA with Expert (math, English) as a between-subjects factor and Task (math problem, English problem) as a within-subjects factor, and locus score as the dependent variable. The main effect of Expertise failed to reach significance, $F(1, 20) = 2.80$, $p = .11$. The main effect of Task was statistically significant, $F(1, 20) = 7.72$, $p = .007$. Critically, the Expertise x Task interaction was significant, $F(1, 20) = 8.115$, $p = .005$. This replicates the Chase (2013) finding that the English experts could properly evaluate the difficulty of the problem, and therefore attributed their failure in interpreting the poem to its difficulty -- and not to their own, internal limits. However, the effect did *not* cross over: for the Math problem, both the Math experts and the English experts attributed their failure to solve the problem as reflecting their own lack of knowledge or ability, and not the inherent difficulty of the required proof.

Table 2
Mean Locus Score

	Math Problem *M (SD)*	English Problem *M (SD)*
Math Experts	-0.037 (0.86)	-0.047 (0.84)
English Experts	-0.57 (0.58)	0.12 (0.93)

Expertise and spontaneous revisiting

The third prediction was that experts will be more likely to spontaneously revisit the problem in their domain in between the sessions than the problem outside their domain? Descriptively, math experts showed the expected pattern: 30% chose to revisit the math problem in between the two sessions, whereas only 12% chose to revisit the English problem. Descriptively, however, the expected pattern was *not* present for the English experts who behaved unexpectedly: 36% chose to revisit the English problem between the two sessions. However, the same percentage (36%) chose to revisit the math problem.

Implicit theories of intelligence

Recall that we specialized the Dweck (2000) measure of implicit theories of intelligence for the math and English domains, and administered these measures during the second session. Higher scores indicate a more incremental (and less fixed) implicit theory. We analyzed these implicit theory scores in a repeated-measures ANOVA with Expert (math, English) as a between-subjects factor and Domain (math problem, English problem) as a within-subjects factor. The main effect of Expertise failed to reach significance, $F(1, 20) = 0.13$, $p = .72$, with the two groups evidencing comparably incremental implicit theories of intelligence. The main effect of Domain was statistically significant, $F(1, 20) = 4.95$, $p = .03$, with participants endorsing a more incremental theory of intelligence in the English domain than in the math domain. Critically, the Expertise x Domain interaction was significant, $F(1, 20) = 6.01$, $p = .016$; see Table 3. The math experts showed a more incremental implicit theory of intelligence for the math domain than the English experts did. By contrast, the English experts showed a more incremental implicit theory of intelligence for the English domain than the Math experts did.

Table 3
Mean Implicit Theory of Intelligence (higher scores indicate a more incremental theory)

	Math Domain *M (SD)*	English Domain *M (SD)*

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Math Experts	4.96 (0.79)	4.96 (0.70)
English Experts	4.52 (1.27)	5.31 (0.76)

Discussion

The current study replicated Chase (2013) and extended it to investigate implicit theories of intelligence (Dweck, 2000). The observed interaction of expertise and task domain on persistence time shows English experts tend to spend more time working on challenging in-domain problems than challenging out-domain tasks. If experts do indeed persist for longer in their domains of expertise, *how* are they able to do so in the face of constant failure? Consistent with the results of Chase (2013), English novices make internal attributions for the failures they experience, i.e., they blame their own lack of ability. By contrast, English experts know enough to understand the difficulties they experience as a consequence of external factors such as the difficulty of the problem or constraints on problem solving time. Spontaneous revisitation of either problem in the days between the first and second sessions was not statistically related to the domain of expertise or the domain of the problems. Descriptively, math experts tended to revisit the in-domain task more, while English experts revisited both tasks equally. The lack of significant findings here could simply reflect the small sample size. Although we have run 50% more participants than Chase (2013), both the math expert and English expert groups are small in size, limiting our power to detect significant differences between them. Finally, English experts tend to have increased incremental implicit theories of intelligence in comparison to novices. These results help illustrate the relationship between expertise and domain and how their interaction affects problem-solvers' beliefs about their intelligence in specific contexts.

The path to expertise is long, populated by challenging problems, and fraught with failure. We found that for a given domain, experts tend to have a more incremental implicit theory of intelligence and novices a more fixed implicit theory. Given this finding, and the other results here, how can we design interventions to support novices when they inevitably face failure? Perhaps these methods are relevant to consider in tandem with the expertise literature to supplement the effectiveness of deliberate practice.

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Teacher Sensemaking of Potential Educative Features in Science Curricular Materials

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Abstract: Educative curricular materials have been suggested as a primary lever for shifting instruction in science education, however, little is known about what NGSS-based curriculum materials communicate to teachers and how. This study explored how 9 in-service middle school science teachers made sense of and used educative features in two NGSS-aligned science curriculum materials. We interviewed the teachers about how they interacted with 12 potential educative features when planning and enacting a lesson. In this paper, we focused on one feature, "Lesson-level Performance Expectations." Our analysis identified three ways that the feature contributed to teachers' enactment and growth: the written performance expectations 1) shaped teacher-student interactions, 2) directed teachers' attention to the dimensions of NGSS in teaching and learning, and 3) were used to gauge progression of learning. These findings suggest multiple ways that educative features could open up opportunities for teacher learning.

Introduction and theoretical background

The adoption of the NGSS (NGSS Lead States, 2013) in the U.S. has led to significant nation-wide efforts to develop high-quality science curriculum materials that meet the high demands of these standards. The curriculum materials that emanated from the new standards share a set of design principles intending to shift science instruction from having students "learn about" content to having them "figure out" key ideas through their increasingly sophisticated participation in science and engineering practices (Edelson et al., 2021). These design principles include: 1) a phenomenon-based approach that students actively make sense of puzzling scientific phenomena throughout the unit, 2) engaging students in scientific practices (e.g., modeling, argumentation, explanation) to collaboratively build knowledge, and 3) valuing students' ideas and questions and making learning experiences coherent from students' perspectives (e.g., Krajcik et al., 2014; Windschitl et al., 2018).

Designing and enacting curriculum materials has been a recurring vehicle for driving instructional change in science education. However, in order for curriculum materials to be taken up as resources for transforming science instruction, we need to carefully consider the dynamic interactions between the teacher, students, and the new curricula. Specifically, Remillard (1999) argued that in order for curriculum materials to effectively support instructional transformation, features of the materials must speak *to* the teacher, rather than only speaking *through* the teacher (i.e., by directing teacher actions or providing materials for students). Features that speak *to* the teacher have been called *educative features*; they may provide specific content support, communicate curriculum designers' rationale for pedagogical choices, or help teachers envision and mobilize materials within their specific classroom context (Davis & Krajcik, 2005; Remillard & Kim, 2020).

This study builds on existing scholarship on teacher's sensemaking and use of educative features by investigating how in-service teachers interact with educative features in NGSS-aligned curriculum materials. The need for this work is twofold. First, the emerging scholarship around teachers' use of educative features has been predominantly focused on pre-service teachers. This work suggests that there is much to be understood is about how pre-service teachers attend to features that are intended to be educative (Arias et al., 2016) or use them in ways that lead to adaptive enactments across diverse teaching contexts (Drake et al., 2014; Land et al., 2015). These questions are even more critical to consider for in-service teachers, as open-education resources that are NGSS-aligned have become increasingly available (e.g. Edelson et al., 2021) and the use of curriculum materials are a key lever for shifting how in-service teachers engage students in science. Second, to date, there has not been a systematic investigation of what and how NGSS-based curriculum materials communicate to teachers about the instructional shifts that the NGSS require. At the heart of the vision of NGSS is the assumption that teachers, the curriculum materials, and students work together to create and then take up opportunities to co-construct explanatory accounts for relevant phenomena (Edelson et al., 2021). Thus, if NGSS-aligned curriculum materials are designed to be taken up in various ways by teachers, depending on their understanding of their students, the

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schools, and communities in which they teach, then a wide array of enactments are to be expected, and the various educative features that are embedded within these curricula should be designed to support meaningful adaptation. Here, we build on the rich scholarship in mathematics education on teacher's interactions with curriculum materials (see Remillard & Kim, 2020) and present an exploratory study that examines how in-service teachers make sense of educative features in a set of NGSS-aligned curriculum materials. In this short paper, we present findings from our analyses of one feature that revealed both variation and complexity in terms of teachers' sensemaking and reported use for planning.

Methods

We interviewed nine middle school teachers about how they interacted with two NGSS-aligned science curricular materials developed as part of a curriculum & professional development project. These two middle school units use a phenomenon-based approach to coherently support students' sensemaking and knowledge-building through collaborative scientific practices over time. One unit was focused on cell development (biology, grades 6-8), and the other was focused on ecosystem interactions (biology, grades 5-8).

Based on a review of existing literature about educative curriculum materials in science and mathematics (e.g., Davis & Krajcik, 2005; Remillard & Kim, 2020) and a review of 4 sets of NGSS-based curriculum materials from two developer organizations including OpenSciEd, we found 12 features that were consistently identified as potentially educative. Examples of these features were lesson-level performance expectations (Krajcik et al., 2014), assessment guidance, pedagogical rationale and additional guidance for specific activity structures such as Scientists' Circle discussion, and examples of teacher questions and student answers for class discussions.

Two members of the research team conducted teacher interviews over Zoom. 9 middle school teachers participated in the interviews, which lasted for approximately 1.5 hours and were recorded. Teachers' experience ranged from 4 to 18 years of teaching. The teachers had enacted either one or both of the focal units using the curriculum materials, except two teachers who were planning on teaching the units. All but one of the teachers who taught the units had attended a professional development session about the units before implementing them.

The goal of the interviews was to learn how teachers used the curriculum materials of a specific lesson to plan and teach. After several general questions about their teaching experience and overall approach to material use, the interviewers specifically pointed out each of the 12 potential educative features and asked: Did you use this feature? Was it helpful, neutral, or did it detract from your ability to plan/teach in the way that you wanted to? How and why? Teachers were also asked if they had any suggestions to improve the specific feature.

After transcribing the interviews, the six-member research team used an inductive comparative coding approach to analyze how teachers interacted with the 12 potential educative features. Each week, at least two members open-coded a portion of the interview data and brought it to the full group meeting. The team discussed patterns and variations, occasionally conducting an additional round of open-coding to clarify patterns or resolve discrepancies and uncertainties. From the analysis, we identified major ways that teachers interacted with each of the features. In this process, we regularly compared patterns across participants, and compared our emerging categories to findings from similar studies in the literature (e.g., Drake et al., 2014; Land et al., 2015).

In this short paper, we focus on teachers' use of one feature, "Lesson-level Performance Expectations" (Lesson-level PEs; Krajcik et al., 2014) because eight of the nine teachers described it as one they regularly used when planning for and/or enacting instruction. In addition, teachers' sensemaking about this feature reflected adaptive use of the materials. Thus, the variations in teachers' responses offer depth to the existing reports in the literature for how teachers read and learn from educative curriculum materials.

Findings: Teachers' sensemaking of lesson-level performance expectations

The Lesson-level PEs were presented in side-by-side sections titled "What students will do" and "What students will figure out" on the first page of each lesson in the curriculum (see **Figure 1**). The "What students will do" section color-coded the PEs along the three dimensions of the NGSS—science and engineering practices (color-coded in blue), disciplinary core ideas (orange), and crosscutting concepts (green). The "What students will figure out" section summarized the substance of the ideas that were to be expected as students would meet the PEs.

Eight of the nine teachers reported that they actively used the Lesson-level PEs during lesson planning and/or teaching. Only one teacher stated that they usually skipped this section of the curriculum because the content was repeated later. Our analysis identified three ways that the PEs contributed to teachers' self-reported enactment and growth: (1) shaping teacher-student interaction, (2) directing attention to the three dimensions of the NGSS; and (3) providing high-level information for gauging the progression of student learning.

Figure 1
Examples of Lesson-level Performance Expectations in the Curriculum

Shaping teacher-student interaction

Four of the nine teachers (Teacher JK, RP, RS, & JG) stated that the Lesson-level PEs directly impacted their classroom interactions with students. RP said that she used the PEs to set "talking points" and develop questions to ask in class discussions to support student sensemaking. JK said that she used the PEs for co-constructing a classroom tool called "project tracker" with students to support their reflection on their learning from each lesson and their progress toward unit-level objectives to understand puzzling science phenomena. RS shared that she summarized key activities in the PEs and posted those as "learning objectives" for students in the class. In these cases, the written PEs were used to mediate classroom interactions between the teachers and students.

Directing attention to the dimensions of NGSS

Five of the nine teachers (Teacher JK, RP, AH, DV, & JG) stated that the color-coded Lesson-level PEs supported them in developing their (and sometimes their students') capacity about the three dimensions of NGSS. They reported that it was helpful to have the dimensions highlighted in the NGSS colors so that they could easily find and work on the different dimensions in their planning and teaching and grow their capacity around them. For example, RP said, "So, I'm seeing some of the SEP *[science and engineering practices]* there. I really look for those things. I'm like, 'Ok, that's the SEP, this is the DCI *[disciplinary core ideas]* and the crosscutting concept.' *[...]* I really focused on the SEP and the DCI *[before]*. I felt like that's all I could really handle. Going forward, though, I am getting better at incorporating the crosscutting concepts." Another teacher, DV, said, "I find this one *["what students will do" section]* really useful because it's all in one place. It shows me the important DCI pieces, the important practices, and the key crosscutting concepts."

Two teachers (AH & JG) said that they used the articulated PEs to support the growth of their students around the NGSS dimensions. For example, AH said, "What I'm going to be working on this year is making sure that I focus more on the CCC *[crosscutting concepts]* and the science and engineering practices. *[...]* They're crosscutting, like, I can see them and I can watch how students grow in them all throughout the year. For example, today, we're looking at identifying patterns *[one of the NGSS crosscutting concepts]* and they *[students]* just, they couldn't. And I'm like, okay. So, hopefully, as I force more pattern recognition on them, that CCC is going to improve. So, you can see where students are about that, and you can see how they grow." Like this, the teachers used the color-coded PEs that matched the three dimensions of NGSS to assess and promote students' and their own growth about the dimensions and to better connect the three dimensions in their instruction.

Gauging progression of learning

Seven teachers (Teacher JK, RP, RS, AH, DV, JH, & JG) stated that the Lesson-level PEs helped them set direction and check the progress of their instruction; to check if they were on the right track and decide what to do next. Sometimes the written PEs worked as a reminder for them to address important ideas and concepts. For example, DV said, "Like, if we're on the right track. And as you get later in the unit, I would start to look at this more like a checklist." RP said that she often checked on the PEs while teaching to make sure that she was using time "correctly and usefully for students." Teachers also used the PEs to report their objectives and progress to their administrators, especially about which NGSS components they were addressing in each lesson. In sum, the PEs worked as a reference and guidance for the teachers to "move forward."

Discussion

The eight teachers who reported using the Lesson-level PEs in their planning did so in a variety of educative and adaptive ways. The feature informed their understanding of content and pedagogy in the context of the lesson and informed how they might customize enactment to their own specific classroom context.

Unit materials typically include learning goals aligned to standards, and therefore, this feature is familiar for teachers. Using this feature to, "Gauge progression of learning," aligns with the general role that learning

objectives serve in teaching: to help prioritize selection of content and use of time, develop classroom activities, and evaluate student progress in light of the objectives. This use also reflected teachers' need to meet school policies of writing learning objectives on the board.

The other two ways that teachers used the Lesson-level PEs ("Shaping teacher-student interaction" and "Directing attention to the dimensions of the NGSS") offer insights into how this information plays an "educative" role. In particular, RP's use of the right-hand list of "What students will figure out" to structure questions and talking points for discussion reflects its utility in shaping her practice of providing opportunities for students to reason through science ideas using talk, a central principle of instruction that meaningfully supports the NGSS's intent (Windschitl et al., 2018). Similarly, JK's use of the feature to help develop the project tracker highlights its utility in supporting another core instructional principle, students building ideas incrementally and through critique (ibid). In this way, the Lesson-level PEs provided educative support in shaping teachers' instructional practices. Similarly, regarding, "Directing attention to dimensions of the NGSS," both RP and AH reflected on how the color-coding of the crosscutting concepts in the Lesson-level PEs helped them to structure their own learning about how to incorporate crosscutting concepts in their instruction as well as helping them evaluate students' growth in using crosscutting concepts. Thus, this feature helped leverage their own pedagogical growth, an important prerequisite for teacher learning from curriculum materials (Arias et al., 2016).

We posit that the combination of the two lists—"What students will do" and "What we will figure out"—was important in making this feature educative and in driving the observed variations in reading and use. The familiar structure of a PE and color-coding offered connections to formal standards, while the bullet points on the right-hand side offered a snapshot of what enacting those standards in a classroom context could look like. Teachers attended differentially to one side or the other, depending on their needs. At the same time, the combination reflects a novel way of thinking about learning goals in that it emphasizes the "means" as well as the "outcomes" that the NGSS PEs are meant to achieve. Embodying the pedagogical practices that support these "means" is a critical challenge in the shift to NGSS (Windschitl et al., 2018); this study suggests that the Lesson-level PEs may be one feature that can provide educative supports for in-service teachers in shifting their instruction in meaningful ways.

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Postcards and Photo Walks: Telling Community Data Stories Through Photography

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Abstract: Representations of the health and resources of neighborhoods, particularly those made without a community's input, can be misleading, and can perpetuate inequities. We designed and implemented a two-week-long grade 8 unit to explore how photo walks—an arts-based methodology that involves capturing and reflecting on photos along one's walking route—can engage students critically with community data. We draw on a critical data literacy perspective, which views data as situated in social contexts and challenges the notion of data as neutral. Artifact analysis and post-unit interviews with two students revealed opportunities and challenges in supporting critical data literacy through planning and participating in photo walks.

Introduction

How communities are represented is a social and ethical challenge. It is also one that cuts across both data science and the arts (D'Ignazio & Klein, 2020). While a visual artwork, such as a photograph, can tell a story about people and places, it can also be used to overgeneralize. On the other hand, quantitative data can be challenging to collect and may overrepresent a community's problems (e.g., crime rates). In this study, researchers and teachers co-designed an 8th-grade, arts-integrated data literacy unit to engage students critically with community data through photography. In our design and analysis of student work, we draw on Philip and colleagues' (2013) framework for learning about big data for democratic participation, which outlines five goals: participating in the language and tools of data science, identifying as people who can use data for purposes that interest them, engaging in a process of inquiry to understand and address social issues, recognizing how data highlights and obscures perspectives, and making sense of and communicating data using the tools of multiple disciplines. To scaffold critical engagement, we draw on methods in photography that have a history of foregrounding discussions about representation and cultural narratives. Photovoice, for example, engages those who are often excluded from producing and analyzing data in creating bottom-up change through storytelling (Wang & Burris, 1997). Photo-walking, a collaborative activity that engages people in multisensory observations of their environments, further highlights how prior knowledge and experience affects data collection (Mainsah & Boe, 2019). This study builds on prior research in data literacy education that has sought to engage students critically with their communities through data (Rubel et al., 2016; Wilkerson & Laina, 2017; Kahn 2020; Stornaiuolo 2020). By comparing and contrasting the experiences of two students, we investigate *how planning and participating in photo walks prompted students to engage critically with data about their neighborhoods.*

Methods: Context, participants, and data

We co-designed and implemented a grade 8 unit called *Postcards and Photo Walks* with two teachers, one art teacher and one ELA/math teacher. Both taught at a private school in the U.S., in which the administration encouraged multidisciplinary connections between subjects. The art teacher wanted students to create an art piece that would generate pride in their neighborhoods and in their artistic abilities and that showed them real-world applications of art. The math/ELA teacher wanted students to be able to connect math to the real world. Through weekly co-design meetings over 6 months, teachers met with three researchers to identify the unit's focus on "healthy places," activities, and learning goals. We aimed to engage students critically with data through the following activities: reflecting on multiple ways to measure the health of a neighborhood, investigating community assets and issues through personal and public data, and drawing on the arts to connect personal experiences to community statistics. In this 9-day unit, students were asked to think about the question "What is a healthy place?" through photo-walking, and construct digital postcards that introduced their neighborhood to students living across the country. Due to pandemic-related restrictions in 2021, all students joined class meetings via Zoom, although some students were co-located in a classroom, while others were at home. Students contributed to class discussions and group work out loud as well as via the Zoom chat. On Day 1 and 2, students were introduced to the topic of healthy places by exploring data and engaging with a grounding artwork by the

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Anti-Eviction Mapping Project collective, titled *The Oakland Community Power Map* (AEMP, 2016). The participatory mapping installation first appeared in the Betti Ono Gallery and was subsequently transformed into a digital map to enable crowd-sourcing. The purpose was to enable residents of Oakland, CA, to resist displacement through gentrification by letting "the city know what we have, what we value, and what we want" (AEMP, 2016; p.17). We engaged students with the main prompt of the artwork, to describe and map places that have "influenced or sustained you physically, emotionally, spiritually?" (AEMP, 2016). On Day 3, students read about access to healthy foods and parks and created scatter plots using CODAP (Common Online Data Analysis Platform). On Days 4-7, they participated in a photo walk, discussed their photos in small groups, and selected a photo to represent their series. On Days 8-9, students wrote letters about their neighborhoods and participated in a voluntary salon-like exhibition, reading their letters aloud to their class peers and invited guests (project researchers and advisors). Students' artworks were collected into a class website by the research team to enable reflection across data and a way to share their work with friends and family.

Participants were 23 eighth graders from a private Catholic middle school located in a large urban area with a predominantly Latinx and Black or African American population (85%). About 70% of students are on a free or reduced price lunch program. Our data consist of (1) 45-minute, semi-structured interviews with two female students (whom we name Asami and Katara), in which we asked each student to reflect on their experiences during the unit; (2) two hour-long post-implementation interviews with each teacher, in which we asked them to reflect on how the unit met or failed to meet their learning goals, and on notable observations of student learning; (3) artifacts produced by the 2 students interviewed (letters, photography, maps, graphs, artist statements, and contributions to class discussions written in the Zoom chat); and (4) field notes from observations conducted over Zoom of 5 class sessions. Using a case study approach (Yin, 2009), we analyzed Asami and Katara's contrasting experiences working with data through a process of planning and participating in photo walks.

Findings

Both Asami and Katara produced and used data for personally meaningful purposes, recognized data as useful for understanding and addressing social issues, and drew on the tools of math and art to understand and represent data (Philip et al., 2013). *The Oakland Power Map,* a grounding artifact for critical data literacy, prompted discussion about who is able to produce data to address social issues and why it matters. According to the art teacher, the purpose of the artwork "clicked right away," with many students, who shared that "their neighborhood is [also] considered dangerous but that when you get there it's a beautiful place, with beautiful neighbors." Katara and Asami subsequently produced data about both community resources and problems, challenging single stories about their neighborhood. Their written letters also supported the importance of identifying more than just community problems. Katara wanted to "touch on stereotypes, specifically in [her county] because it has a reputation of being like a bad ghettoish community, but if you live there you'd see ...it's more like a kind of family…" Asami wanted to write something that was "very honest but also relatable to people like me who live in [my community]." Next, we explore how Katara and Asami integrated art and math to support these personally meaningful purposes.

Case 1: Photographing frequency and variability of sidewalk cracks

Figure 1

Katara's neighborhood walk (left), photographs of sidewalk cracks (right), and artist statement (bottom).

For this project, I chose to indicate life expectancy in my community with the quality of our sidewalks. Since sidewalks are used quite often, it is important to take care of them and make sure they function without issue. People that use walking aids, such as canes and scooters, have to watch sidewalks more carefully in case of cracks that can cause them to fall. In my community, cracks in sidewalks are quite common; it's easy to trip if your aren't paying attention. Although it is a small detail, having nice sidewalks improves a place's appearance while keeping its members happy and healthy.

Planning photo walks: Recognizing data as useful for understanding social issues

All students engaged in multiple planning activities to inform their photo walks. First, they drew maps of their neighborhood and explained their choices. Katara, for example, wanted to represent her own experiences *and* the

diversity of neighborhood resources. She identified places in her neighborhood that she regularly went to and that contributed to the health of her community (e.g., movie theater, grocery store, and park). She connected each place to different variables (e.g., population size, access to outdoor spaces, and affordable groceries) and thought critically about measurement. For example, she argued that "people [in her community] have options for what food to buy and consume" not only because a grocery store is geographically accessible but also because it offers quality food (e.g., "it tastes nice) and affordable prices (e.g., "lots of stuff up for sale"). Using her map, she then argued that her neighborhood was healthy because of the quantity of services available to meet public needs.

Next, students explored public data about their neighborhood to inform the subject of their photo walks. They made scatter plots to investigate variables such as average life expectancy and high-school graduation rates. Some students like Katara also proposed variables that were not represented in the data, graphing the change they wanted to see. Clean streets, for example, was a topic that Katara felt was "unique, that not a lot of people would think about...smaller things that would not really be thought of when you're looking at a map of a community." She reasoned that "cleanliness correlates to life expectancy because if there's a place with a lot of trash that means it's not really well kept by sanitation workers and it can grow mold and bacteria and be like a farming point for diseases which isn't healthy." According to Katara, analyzing data informed her photography by giving her "a general understanding of what to expect or what not to expect; it's like a hypothesis of the project."

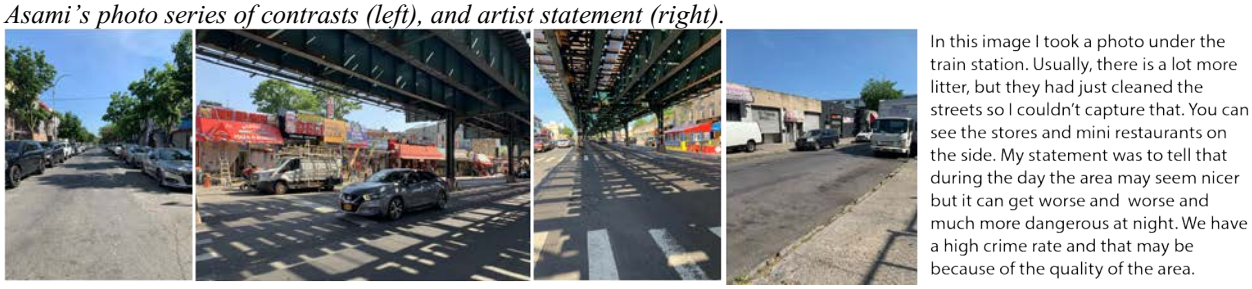
Participating in photo walks: Drawing on the arts to understand and represent data

During her photo walk, Katara's hypothesis was challenged by a lack of evidence. "I had trouble at first trying to see what I could take photos of…" she explained. But the lack of observable evidence of litter prompted her to shift perspectives, to engage in deep noticing, and to argue for the relevance of a different "small," overlooked issue. Sidewalk cracks, she explained, were problematic in her community because "sidewalks are used quite often" and people with disabilities are especially vulnerable to tripping (e.g., "if you're using a wheelchair or some kind of walking device, sidewalk cracks can be dangerous"). To support her claim, she generated data on sidewalk cracks by photographing the frequency and variation of cracks around her home. Using a consistent point of view, repeated sampling, and organization of images, she summarized this problem as a pattern rather than a point (see Figure 2). Each image showed variation in the number, size, shape, and location of cracks. Her focus on texture further highlighted the age, material, and quality of sidewalks. As a result, her photo series engages the audience in more than counting cracks. By mapping different areas in her neighborhood, explaining where she collected data, and visualizing variation in cracks, she enables informal inference-making about her neighborhood.

Case 2: Photographing neighborhood contrasts

Figure 3

Asami's photo series of contrasts (left), and artist statement (right).



In this image I took a photo under the train station. Usually, there is a lot more litter, but they had just cleaned the streets so I couldn't capture that. You can see the stores and mini restaurants on the side. My statement was to tell that during the day the area may seem nicer but it can get worse and worse and much more dangerous at night. We have a high crime rate and that may be because of the quality of the area.

Planning photo walks: Recognizing data as useful for understanding social issues

Asami's map highlighted *her* "tight community," which included a church, nearby homes of family members, the train, and local delis. She chose to represent only the few blocks around her home, centering the everyday places and experiences that help keep *her* healthy and occupied (i.e., exercising, commuting to school, seeing family). While Asami also investigated public data about her city, interpreting interactive data visualizations and making scatter plots, she largely drew on personal experiences to inform the subject of her photo walk. At the same time, analyzing neighborhood data confirmed her understanding that crime was a problem in her neighborhood and helped her identify significant consequences (e.g., lower average life expectancy). During class discussion, for example, she argued that average life expectancy was a good way to measure the health of a place because "you live longer when you live in a healthier environment. The area you live around affects how you feel. The cleaner

areas in my data have a longer life expectancy than others. [My community] had 4 points below the life expectancy of [other areas]."

Participating in photo walks: Drawing on the arts to understand and represent data

In her photo walk, Asami contrasted her neighborhood with a nearby industrial area known to be dangerous. The first two images show her everyday walk to the train and nearby businesses, while the second shows a neighborhood, a few train stops away, that she avoids due to a dangerous underground club. Her goal was to represent her community as a whole, showing positive and negative characteristics (see Figure 2):

> I went around the block looking for places that had some litter in it or have a bit nicer, more vibrant colour…there are nice stores, you have the train station, but you have this litter and then there's of course danger in the area, so having those contrasting things shows how the community really is as a whole.

Contrast is a theme in her artist statement and letter, and also emerges in how she talks about community action and health. She recognizes that there are decisions and resources that individuals cannot control but also opportunities for action, "work[ing] together...not throwing stuff on the ground, adding more trash cans, decreasing crime rates."

Discussion and Significance

Planning and participating in photo walks prompted students to engage with social issues through a process of inquiry (Philip et al., 2013). In planning their photo walks, Katara argued that her community was healthy based on the number and variety of available services on her map, connecting places to variables such as population size and access to parks. Asami argued for using average life expectancy as a measure of health, drawing on neighborhood data and personal experiences as evidence. When confronted with a lack of evidence, Katara identified evidence of an alternative topic and Asami recognized and attempted to explain a sampling problem (i.e., time of day). In their photo walks, both students demonstrated attention to informal inference-making (Makar & Rubin, 2018), visually summarizing data as a pattern or comparison and discussing context. These findings highlight future opportunities to reinforce statistical concepts, such as sampling and variation, by iterating on data analysis and photo walks.

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Paths through Data: Successes and Future Directions in Supporting Student Reasoning about Environmental Racism

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Abstract: We report on a curriculum development project in which students explore environmental racism through data. Recognizing that quantitative data alone is insufficient to understand the sociohistorical contexts of racism, we draw from syncretic approaches to learning that put everyday experiences and qualitative evidence into direct conversation with quantitative datasets through storytelling. Through two focal cases, we demonstrate how one student leveraged personal experience to engage in deep integrative analysis of data, while another with fewer perceived personal connections to environmental racism focused more specifically on patterns, with less structural or racial analysis. Implications of the analysis include the need to carefully attend to the use of quantitative data related to race and to scaffold the integration of other sources of information with quantitative data sets.

Introduction

There are increasing calls for students in STEM classrooms to reimagine the use of data (Lee & Wilkerson, 2018), as well as to engage with issues of social and racial justice, like environmental inequities (e.g., Varelas et al., 2017). These two foci can be brought together through student exploration of socioscientific data. Recent studies have shown that race is a stronger indicator of exposure to pollution than income (Tessum et al., 2021). Yet, literature points to challenges in engaging students with issues of racial justice in STEM. Even when engaging with social phenomena, data literacy activities may fail to attend to the structural and ideological contexts in which data is situated and the embedded issues of power (Philip, Olivares-Pasillas & Rocha, 2016). Quantitative data alone is insufficient to understand racism; it must be supplemented with other information about local and historical contexts (Gilborn, Warmington and Demack, 2018).

The *Writing Data Stories* project seeks to address these challenges by engaging youth in expansive forms of learning that integrate analysis of data with students' own experiences and cultural repertoires of practice. We report on a youth workshop exploring environmental racism through data science inquiry in which students shared their own experiences, investigated and manipulated data sets, and engaged in journalistic research. We found that engaging students' personal experiences with environmental racism deepened their treatment of data as well as their analysis of historical and structural factors related to race. In some cases, however, students had more limited personal connections to the topic; in these cases, their investigations focused on correlative relationships among variables and included structural or racial analysis.

Theoretical Framework

Our work is grounded in a syncretic approach to development (Gutiérrez, 2008, 2014) that leverages the expansive forms of learning that occur when youth integrate everyday and school-based contexts and practices. Such approaches seek to reorganize the relationship between everyday and scientific practices while preserving tensions between them, maintaining the value of the everyday genre vis-a-vis the dominant form. In doing so, youth develop a deeper understanding of concepts and texts, consider the different spheres of life in which these texts function and are valued (or not), and have opportunities to use their knowledge to participate in disciplinary domains and civic life more broadly (Gutiérrez, 2014).

We build from lines of work that have established how students can leverage their personal connections to (and tensions with) data to make sense of it and how students can collect, explore, and manipulate data to create representations that matter to them (see Wilkerson & Polman, 2020). As they work with data, students can engage in data moves (Erickson et al., 2019), such as filtering to isolate cases of interest, grouping data in particular ways, or adding to and merging data sets to include new information. In our work, we are particularly interested in the ways that students use their everyday experiences as a resource to motivate or deepen their engagement with data sets. Students can transform data sets to reflect their own sociohistorical lives and engage in syncretic data reasoning, the ongoing interplay between everyday experiences and analysis

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of data.

In this work, we explore how students write "data stories." Data stories are a type of syncretic text that uses narrative to integrate data, personal experiences, and other forms of social, cultural, and historical knowledge and research (Wilkerson et al., 2021). Although narrative is not often employed in STEM contexts, students can use storytelling to organize their understanding of data based on previous experiences, thereby making sense of the connections between descriptive and inferential statistics and understanding data analysis as complex endeavor guided by human decisions (Gillborn, Warmington & Demack, 2018). For the topic of environmental racism, students can use data stories to critically examine how race has structured communities' exposure to environmental health hazards and to advocate for related social change.

Research Questions

Given our interest in the construction of texts that bring together disparate ways of reasoning, we ask:

1. What experiences do youth leverage to generate research questions about environmental racism?
2. How do youth use qualitative and quantitative evidence to reason about and advocate against environmental racism through the creation of a data story?

The *Writing Data Stories* project takes a syncretic approach to integrating narrative and data. This paper reports on a week-long, online summer workshop on the topic of environmental racism. Participants (n=12) ranged in age from 12 to 14, were from both dominant and non-dominant backgrounds, and were mostly from the greater Bay Area. In the workshop, students explored case studies of environmental racism around the world, interviewed family members, and listened to a presentation from a local African American environmental activist. They used the Common Online Data Analysis Platform (CODAP) data visualization tool (Finzer & Damelin, 2016) to engage in open-ended investigation and manipulation of public data sets on social indicators (e.g., income, race, asthma) and environmental indicators (e.g., air pollution, water pollution, pesticides) in addition to conducting internet searches and other forms of journalistic research. Many examples in the course and the initially provided data sets were grounded in the physical geography and history of the Bay Area. As a culminating project, participants developed a data story about a research question of their own choosing.

Data sources included video recordings of the class sessions and one-on-one conferences with students, student artifacts, and post-session student interviews. We analyzed these data for the subset of consented students who participated in all workshop activities (n=6). We identified the *questions* that these students posed and coded for the *experiences* that inspired the questions (e.g., personal experience, internet research, preliminary observation from provided data sets). We then identified the *claims* that students made in response to their question, coding for the type of *evidence* they leveraged (e.g., provided data set, external data set, personal experience, qualitative research) and the presence of any *data moves* (e.g., sorting, grouping, filtering, merging). Using the coding, we created a timeline of each student's reasoning about environmental racism and constructed a narrative case describing how their thinking developed over the course of the workshop. We then selected two students who served as contrasting cases and reflected broader patterns in the larger data set.

Findings

We describe two cases that represent distinct approaches that emerged in our analysis. One student, Elena, drew from her own experience and the narrative of an activist to explore pollution in North Carolina. She engaged in a wide range of data moves, merged new information with data sets, and considered race in her reasoning. Another student, Narun, generated his question about the relationship between air pollution and poverty from his initial observations of patterns emerging from the data set. In contrast to Elena, he incorporated fewer data sources and did not mention race as a factor in his reasoning. We describe these two examples below.

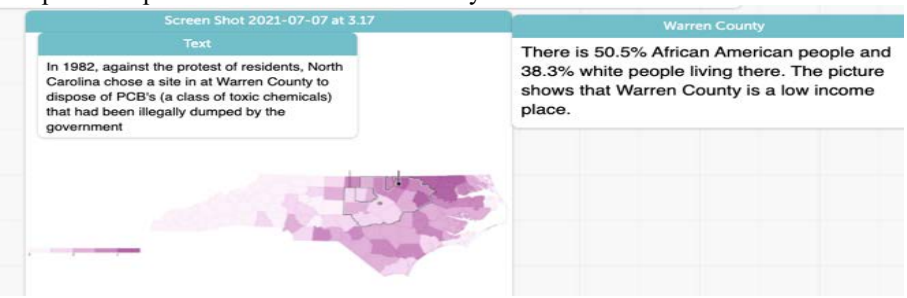
Case 1: Elena

Elena is fourteen years old, and her family immigrated to California from Central America. Early in the workshop, she reported on her own family's exposure to air and water pollution as farm workers in California's Central Valley. For her project, Elena chose to explore the history of Ben Chavis, an African American environmental activist from North Carolina she learned about through internet research (see Figure 1). She commented "I felt that I already had, like, covered the topic of the Latin community…and I wanted to also cover other kinds of races. [The activist of color who spoke to the group] talked about how they put factories next to an African American community and it inspired me." By grounding her story in the actions of activists protesting against the dumping of toxic waste in their community (see Figure 1), she sought to relate her family's own experience to those of other minoritized groups, revealing broader systemic injustice.

Elena explored a data set on pollution in North Carolina, engaging in multiple data moves that were motivated by Ben Chavis's story. She first *filtered* the data, selecting Chavis's home county and comparing it to

a nearby county with higher income, marking both on the map with a specific color. She then *merged* the data, looking for another source that reported the racial composition of the two counties (see Figure 1). Her argument thus coordinated data about income, race, and toxic waste to support Chavis' argument that the dumping incident constituted an act of racism. She also investigated the chemicals that were dumped at the site (PCBs) and searched internet articles for evidence of racial strife in the area, integrating quantitative and qualitative data to explain the historical event.

Figure 1. Data maps and explanations used in Elena's story

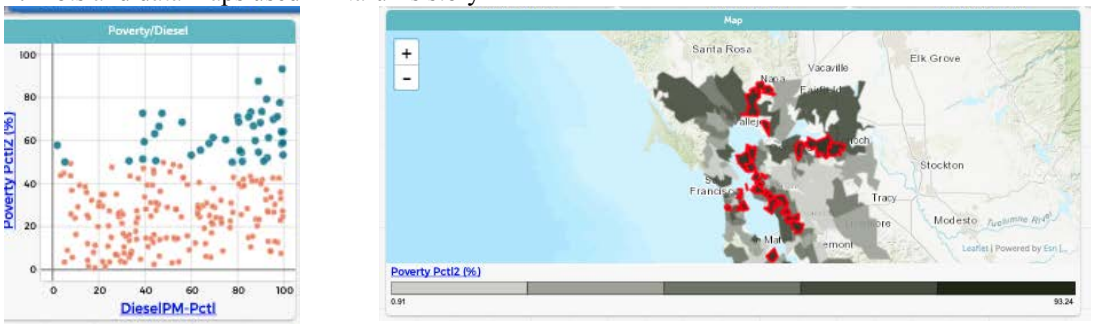


Case 2: Narun

Narun is thirteen years old, is of South Asian descent, and lives in a wealthy suburb of the Bay Area. In his interview, he reported that he did not have much personal experience with pollution. Early in the workshop, he reported researching Flint, Michigan. He commented "I think it was a racism case. It was basically a town in Michigan where they cut off clean water for the citizens of the town." However, in his own project, Narun chose to investigate the relationship between income and pollution in the Bay Area. He reported that he chose this topic because "whenever I'm in San Francisco or the Bay Area, I see lots of homeless people outside and it doesn't feel too good. It's important because being homeless is very difficult." Thus, he grounded his investigation in a situation that observed that invoked his empathy and concern.

Narun reported in the interview that he "looked at a bunch of …factors, but chose to do poverty and air pollution." He looked for which type of air pollution had the strongest relationship to poverty, and settled on diesel emissions. In his final presentation, he filtered to show the top quintile of poverty and demonstrated it on a map and a graph (Figure 2). He then drew relationships, referencing the map to claim that "poverty is high along the coast…and you also see that air pollution is high there too." However, Narun did not report on the racial composition of these counties, even though it was provided in his data set, nor did he discuss the history of residential segregation and industrial development in the area, even though it was presented in the workshop. Narun's analysis of poverty and income was well-reasoned and supported by the data; yet, it was incomplete in that it did not examine the relationships between race and income. While we have no direct evidence of why he did not incorporate race, we propose that we may not have adequately scaffolded the use of quantitative data and other sources of information related to race. We draw implications from this case in our discussion.

Figure 2. Plots and data maps used in Narun's story



Discussion

Through this analysis, we add to lines of work that have demonstrated the value of syncretic approaches to science learning. Specifically, we have shown how Elena's family experience with racism promoted the use of data moves (Erickson et al., 2019) that deepened her work with data, as well as expanded her understanding of environmental racism as a form of systemic injustice across minoritized communities. This case demonstrates

how a data story can act as a syncretic text (Gutiérrez, 2008) in which students integrate personal experience, data, and multiple types of evidence to forward claims about environmental racism. Such a text reorganizes disciplinary learning by elevating personal experience, narrative, and historical understandings as valued and connected resources for supplementing quantitative data sets in STEM contexts. Syncretic learning was supported by the open-ended nature of the inquiry, which allowed students to choose a topic that related to their own experiences, suggesting the value of integrating more student choice into explorations of data.

Yet, our analysis showed that some students explored income without considering race, which aligns with previous work showing race is often avoided in STEM contexts (Philip, Olivares-Pasillas & Rocha, 2016). A key implication of this analysis is that teaching about racial justice does not necessarily prepare students to adopt this lens in their own data reasoning and research. In considering Narun's case, and others like it, having less personal experience with structural forms of injustice like environmental racism may have made these students less likely to conduct an analysis with a racial lens. As a result, we are dedicating more time to discussing, modeling, and critiquing the use of racial categories and integrating more related data visualizations in our curriculum, as well as explicitly discussing the relationships between race and income.

Additionally, we are ever more aware of the limitations of quantitative data in exploring issues related to race (Gilborn, Warmington and Demack, 2018). This analysis surfaced a clear need to give more support to students to understand the social, political, and historical factors that could help explain the quantitative patterns they observed. As we develop the curriculum, we are carefully considering how to support students in linking historical policies and social structures to present-day environmental inequities. Contextualizing data in this way requires an interdisciplinary approach that draws tools from history/social studies to help students to understand how structural racism has been organized in the past and continues to be organized in the present, as well as tools from ethnic studies to help students to understand their own identities and relationships to systems of power. Overall, these findings underscore the importance of drawing from diverse pedagogical and disciplinary approaches that support students in considering race from multiple perspectives while analyzing quantitative data sets. Understanding the structural causes of current environmental inequities is critical to helping students to imagine more just futures and engage in related social action.

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Making Home…Work: Codesigning Teacher Tools to Support At-Home Learning

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Abstract: Learning sciences research has demonstrated the importance of personal guidance, where a teacher can help connect new knowledge to a student's own experiences and interests to promote deeper understanding. However, homework is often done in isolation where students lack the type of guidance a teacher would provide in the classroom. To explore ways to design technologies to allow teacher to provide effective homework guidance, we interviewed and conducted co-design sessions with middle school science teachers about their views on supporting student learning in the classroom and during homework. We found teachers place high value in students doing homework but have minimized giving homework due to practical and equity issues. The limitations of existing technologies to address this issue and the recent increase in teachers' use of online tools present an opportunity to reimagine the design of these tools by building on teacher views of how to revitalize homework.

Introduction

Students benefit from learning experiences tailored to their individual needs, particularly when it includes social interactions that foster the co-creation of knowledge (Miyaki & Kirschner, 2014). Often teachers engage in interpersonal social dialogue with students to provide *personal guidance*, where teachers use socially situated ways to build upon students' knowledge, interests or prior experiences to maintain engagement with the material and help construct lasting knowledge (Bernacki et al., 2021). However, homework activities are often done in isolation where teachers and families can struggle to support students or provide adequate guidance (Cooper, 2015). The use of online learning technologies surged during the pandemic and has driven more teachers to use these to facilitate learning at home, an increased use that is likely to persist (van der Spoel et al., 2020). However, recent work found that teachers struggle to foster collaboration or make meaningful connections to their students using these tools (Midcalf & Boatwright, 2020). These limitations, along with teachers' increased experience with online tools present an opportunity to reimagine the design of such tools to provide socially interactive personal guidance to students during homework. As part of a larger project, our goal is to co-design a tool for middle school science teachers that meets their needs for providing personal guidance during homework. To inform that work, we worked with science teachers through interviews and co-design sessions and examined, (1) how and why science teachers provide homework, and (2) how teachers would want a tool to aid creating homework and provide personal guidance.

Theoretical Framework

Our work takes a sociocultural perspective on learning (Miyaki & Kirschner, 2014), a perspective that recognizes how a student's acquisition and integration of domain knowledge is built upon their sociocultural experiences and social interactions. Classroom learning is socially situated, and students benefit from co-creating knowledge through social exchanges with teachers and peers (Cress & Kimmerle, 2018). As teachers plan classroom activities, they consider how to facilitate students to co-construct knowledge through interpersonal social interactions with peers (Cohen et al., 2003) which helps build lasting and deep knowledge. Teachers actively support their students' classroom learning by making references to student interests and experiences, verbally adapting content vocabulary, responsively attending to student questions and misconceptions, and prompting discussions and reflections on learning (Bernacki et al., 2021), these socially oriented interactions are tailored around the teacher's own knowledge of their students and thus constitute *personal guidance*.

Homework is a valuable instructional tool that can enhance students' learning, have a positive influence on students' academic achievements and self-responsibility, and can be particularly effective when connected to classwork and tailored to students' individual needs (Cooper, 2015). However, complex and challenging science homework, involving writing opinions on new topics, discussing ideas about reading and videos, and explaining science concepts, can require substantial scaffolding and guidance (Horsley & Walker, 2012). Given the focus in science education on collaboration and discussion (NGSS, 2021), socially interactive learning and personal guidance is critical for science learning at home as well as in the classroom. However, teachers struggle to design

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learning materials that would provide such personal guidance for homework, particularly in science, technology, and mathematics (Cooper, 2015, Horsley & Walker, 2012).

Recent online videos, articles and interactive media like Kahoot!, Kami and Gizmos, allow teachers to provide a range of content in a more efficient way than traditional book or worksheet homework. Some learning systems provide students automated feedback on answers, step-by-step problem-solving help, mastery tracking, or adjust activities according to performance (Aleven et al., 2016). However, these systems often provide scaffolding and differentiation based on student performance metrics and may be missing many aspects of the personal guidance a teacher would provide in the classroom. To meet this challenge, we begin with the research question (RQ): *How can we design a digital tool for teachers to provide personal guidance for their students in science homework, based on their students' learning preferences and needs?*

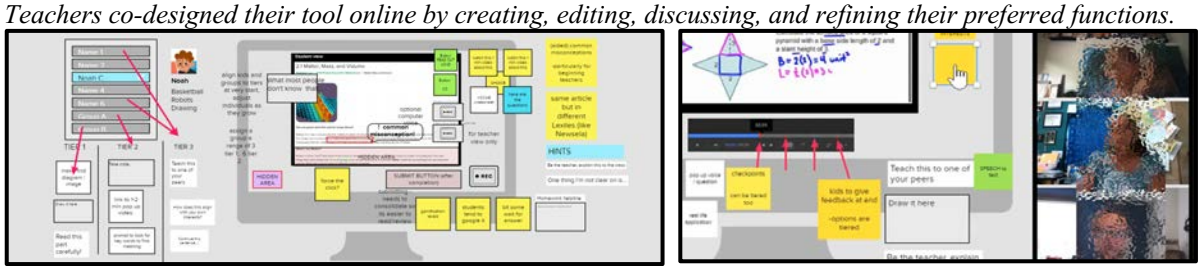
Method

To answer our research question, we conducted two phases of participatory design research with middle-school science teachers to probe for *what* personal guidance teachers would like to provide, and *how* they might use a tool to augment homework to support their students' at-home learning. We began by conducting 1-hour semi-structured interviews using Zoom with (n=9) middle school science teachers and probed for their views on the types of personal guidance they give in the classroom and their views on homework. We analyzed and transcribed the video data using a Thematic Analysis approach (Braun et al., 2018) to qualitatively identify patterns in the data from the teachers' perspectives. Four researchers, including the first author, generated semantic codes using an inductive approach and organized the data into major categories, such as 'Sharing Ideas' and 'Adapting concepts' from which we built, discussed, and refined emergent themes from meaningful patterns in the data.

We then used the teachers' reflections to guide the design of a set of functional features such as a 'record button', or an 'annotation pop-up'. These were each represented as simplified representations in three co-design sessions each with 2-3 teachers (n=7) on online whiteboard tool 'Mural', and could be edited and moved according to the unfolding discussions (see Figure 1). The teachers discussed what, how, and why each of the features would aid their homework creation and suggested additional features with the goal of building their own ideal homework authoring tool. Each of these 2-hour co-design sessions were analyzed using a similar Thematic Analysis approach as before. We used these new themes to (i) reflect and expand on our previous findings and (ii) to understand the pragmatic needs of the teachers specifically for such a digital tool.

Figure 1

Teachers co-designed their tool online by creating, editing, discussing, and refining their preferred functions.



Findings

Our interviews showed that (1) teachers see homework as a valuable but have minimized the use of it, (2) the pandemic revealed issues with at-home learning, expanded teachers' software usage and revealed new needs, and (3) teachers want to address homework issues through offering social tools and automated personal guidance.

Teachers view homework as an important tool to build on classroom activities and as a formative review of their students' understanding to address in the classroom. They also view homework can provide unique opportunities for students to reflect or analyze work at their own pace and to tie it to their own interests. Teachers prefer to avoid having students grapple with completely new concepts by themselves and some provide specific guidance in the classroom to prepare them for a homework task, however many remarked that there is rarely time to provide any form of personal guidance. Additionally, teachers have minimized the use of homework as they believe students face varying equity issues between students due to time constraints, technical resources, and lack family support. Teachers felt these inequities caused vast differences between student's homework and classwork.

During the pandemic teachers expanded their use of educational multimedia for at-home tasks and now regularly combine videos, articles, and interactive online content to meet their student's learning needs and amplify student engagement and learning. They also indicated that becoming more familiar with online tools during the pandemic makes them feel more confident and interested in using an authoring tool for providing

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personal guidance to in-home learning. However, expressed difficulties in providing personal guidance with existing tools, such as not being able to verbally walk-through tasks or support their students' engagement in the content. Given their new emphasis on incorporating multiple content sources, teachers indicated in the workshops they now need ways to rapidly curate and customize homework from a range of sources.

Teachers co- designed ways to help keep their students' engagement by adding social interaction options more typical of in-class personal guidance, such as vocabulary support, references to past experiences, and vocalization options. Audio-based, social tools were particularly desirable options, where the student could have the text read aloud to them, receive vocalized help with new vocabulary words, or the teacher could include personal messages. Teachers also wanted timesaving help from a system that would automatically add elements of personal guidance to the homework based on student's backgrounds, interests, and preferences they suggested would be surveyed by the system. This differs from many existing systems that base automatic 'personalization' on performance metrics alone and many teachers felt current online learning options do not support their needs.

Discussion

In this study we examined teacher perspectives on how they provide personal guidance in the classroom and their views on at-home learning, and co-designed a digital tool to aid providing personal guidance for students doing homework. We found that (1) the pandemic exacerbated existing issues with doing schoolwork at home, but also expanded teacher's experience and reliance on digital media, and (2) teachers want to address practical and equity issues of homework and want technologies that help them do so.

Exacerbated issues and increased needs

During the COVID-19 pandemic many technologies and online platforms may have rushed to meet the sudden increased demand of home-based learning, but teachers were frustratingly unable to provide the responsive, personal guidance and differentiated instruction they would provide in the classroom. Classwork and homework activities fused, with the teachers using the same online resources such as interactive exercises, videos or sets of articles for both classwork and homework, often leaving the students to work alone on the tasks in their own time. Many of the issues that were previously confined to homework became unavoidably present during class time.

The teachers happily described their recently discovered online resources for instructional content and media, from platforms such as such as Neslea, EdPuzzle, Edgenuity and even YouTube. Many had occasionally used some of these prior to the pandemic, but the teachers have now explored several new platforms and have greatly increased their usage. They may have developed a a more discriminating view on how such platforms provide content and how they personally use them, likely to influence how they provide future homework. They also commented on their students' increased access to computers at home, having been provided in part by many school districts during the pandemic. With teachers' increased knowledge and habits using online resources and student's increased access, the demand for homework tools that truly extend the ability of the teacher to provide guide their student's learning has never been greater.

Teachers want technologies to address practical and equity issues of homework

In the interviews teachers reported how they increasingly *minimize* the use of homework due to inequities in student's time and technical resources, but in the later co-design workshops they presented a greater optimism in being able to alleviate issues through the use of technology, especially in the use of automated personal guidance. One reason teachers feel limited by standard tools and technology is while they provide features for scaffolding and differentiation, the process of doing so is not only labor intensive but also do not provide the types of personal guidance they use in the classroom to effectively support. For the teachers, digitizing the personal guidance of the homework would not only provide levels of individualized guidance otherwise too impractical and time consuming to do, but also affords the chance to gain insights into the student's process of doing the homework, with a view to gain insights about student thinking and potentially reveal misconceptions to address in class. Although students' access to technology at home may have been substantially improved through the pandemic, many issues of inequity may still be unaddressed. However, teachers saw the ability of the system to provide personal guidance for individual's needs, preferences and circumstances would contribute significantly toward addressing some inequities and supporting those in most need.

The findings provide us with **theoretical insights** into how teachers implement homework, and that teacher views on inequities and limitations shape their decisions on the amount and type of homework they assign. The study's themes on teacher preferences demonstrated practical and equity issues related to homework, teachers' need for automation in providing personal guidance and visibility of their effectiveness at home. These results contribute to literatures on science and STEM learning by extending our understanding of how teachers need to

provide socially supported personal guidance for science homework that builds stronger connections to the material and support deeper conceptual learning.

We feel this work also uncovers **practical implications** on how to bring teacher-led personal guidance to a student's at-home learning environment in an effort to revitalize the use of homework. The timing of our study during the COVID-19 pandemic also revealed an urgency for improvements. These insights also have implications for learning sciences researchers in focusing our attention to teachers' needs to support their students' learning, and in guiding the design of learning environments to meet these needs. Teachers feel limited by current methods and need systems that: (1) aid teachers to rapidly curate and customize their own homework content across a range of resources; (2) augment teacher's ability to add personal guidance to homework based on student backgrounds, interests and preferences; (3) provide visibility of the students' homework process to inform future support; (4) provide students options to choose between a range of tools, response formats and timing to complete homework. We also consider these theoretical and practical implications may contribute outside of science homework and inform other home-based learning such as asynchronous class participation.

Conclusion

In this study, we explore teacher perspectives on providing guidance in the classroom and in homework, on how technologies may help them provide personal guidance and improve equity issues related to homework, and on perceptual and practice changes taking place due to the COVID-19 pandemic. One major limitation of this study is the small sample size, and that the majority of our sample includes teachers with significant experience in the classroom. As such, the findings have limited capacity for generalization and may not apply well to the perspectives and needs for inexperienced teachers. We also recognize limitations to our design implications as they are not derived from examining teachers' use of functioning tools or technology to support homework, but stem from teachers' desired affordances of a hypothetical teacher tool. While this work uncovered teacher's views and solutions based on their emotional and pragmatic needs, in future work we plan to explore and test the design guidelines through further participatory research with working prototypes of the tools they conceived.

In summary, we found that teachers need systems that augment teachers' ability to provide personal guidance in socially meaningful ways and they may welcome new technologies to facilitate homework creation that provides better and more equitable guidance for students during homework. These findings also suggest that providing technology-supported personal guidance may help teachers address existing practical and equitable issues in providing homework and revitalize its use as a meaningful extension of the science classroom.

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Collaborating Online Through a Pandemic: Designing Virtual Spaces for Rightful Presence

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Abstract: Since spring of 2020, our 'new normal' world pivoted towards online spaces. This changed *where* formal teaching and learning interactions unfolded, and also shifted the conditions for participation in teaching, learning and research activities calling into question how and where inequitable power dynamics are (re)produced in these 'new' spaces. In this paper, we reflect on the affordances and constraints of community-engaged research with middle school youth in online virtual design meeting 'rooms.' Drawing on critical postmodern and queer feminist constructions of space, the university researchers explicitly worked towards Rightful Presence when structuring and facilitating the online design meeting room. We argue that virtual spaces are not neutral and are shaped through settled power dynamics that can further (re)produce inequitable conditions for participating and/or open new possibilities for disrupting settled adult-youth powered relations by both youth and adults.

Introduction

Since the spring of 2020, the COVID-19 pandemic has required that schooling, research, and most in-person interactions pivot to virtual environments. Re-orienting towards online and remote learning changed the spaces within which we interacted; in-person classrooms and afterschool spaces were replaced with virtual Zoom 'rooms.' This not only shifted the conditions for participation in school-based teaching and learning interactions (Morales-Doyle et al., 2020) but called into question the ethical and pedagogical considerations for community-based research practice partnerships (Switzer et al., 2021). How, with whom, and with what trade-offs might different kinds of education research encounter, during such a pivot? This conundrum is especially pertinent for community-engaged research projects involving historically minoritized youth.

Community-engaged research informed by a critical participatory design (Bang & Vossoughi, 2016) and the Rightful Presence (Calabrese Barton & Tan, 2020) justice-oriented framework necessitates challenging settled adult-youth power dynamics by explicitly supporting youth agency and voice towards recognizing and positioning youth as experts (Druin, 2002; Pinkard et. al., 2017). To do so requires that researchers both pay close attention to pedagogical considerations when facilitating the design process and consider how the spaces within which we collaborate shape the conditions for and forms of participation that are legitimated by the group (Gutiérrez, 2021). The larger project within which this study is based is aimed at creating a 7th grade biology curriculum unit centered around a community-identified health concern. To build the unit, a design team of middle school youth, science teachers, and university researchers met virtually using multiple spaces such as Zoom, Padlet, Discord etc.

In this paper we examine the ways in which virtual learning spaces present opportunities to disrupt settled inequitable power dynamics while also reproducing injustices, when collaborating with youth in critical and participatory community-engaged research. ***We explore the ways in which our curated virtual room for collaborative design shaped affordances and constraints for disrupting guest-host power dynamics, in ways that supported (or not) youth designers' rightful presence.*** Our aim is to expand and nuance how we might work towards Rightful Presence through designing more equitable virtual learning and collaboration spaces.

Theoretical Frameworks that Inform this Work

In this work we designed and facilitated virtual community-engaged collaborative design team meetings with youth, informed by theories including: 1) the Rightful Presence framework (Calabrese Barton & Tan, 2020) that explicitly works towards centering youth voice and agency, and 2) critical postmodern (Soja, 2010) and queer feminist (Ahmed, 2010) theories that recognize 'space' as the non-neutral and non-static background, implicated in shaping the conditions for participation in the design process (Gutiérrez, 2021).

Rightful Presence (Calabrese Barton & Tan, 2020) posits that (in)visible inequities are (re)produced through the practiced repetition of settled power dynamics in everyday teaching and learning interactions and that

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within schools, teachers/adults serve as the *hosts* extending student *guests* rights to learning spaces. As hosts, teachers/adults along with institutions, hold power over how learning spaces are designed, pedagogies are enacted, resources are available for youth participation, and the conditions for participation. Extending rights to youth as *guests* (re)produces powered relations that position teachers/adults as not only in control of access to resources but also the power to *rescind* youths' rights in the space. Rightful Presence requires explicitly dismantling oppressive guest-host-youth-adult powered relations within learning spaces (Calabrese Barton & Tan, 2020).

Designing for Rightful Presence in virtual meeting 'rooms' requires examining the contours and boundaries of the space within which the interactions unfold. Rather than consider space as the neutral and static background upon which life unfolds, we draw on critical postmodern (Soja, 2010) and queer feminist (Ahmed, 2010) theories to nuance how social life is shaped by and shapes the spaces within which we interact. Importantly, this "socio-spatial dialectic" is not neutral but undergirded by power dynamics from the larger social world - such as settled guest-host-student-teacher relations (Soja, 2010). Indeed, as Ahmed (2010) argues, our orientations to, in and with the world, shape the spaces in which we exist by affecting "what is near or proximate to the body, those objects that we do things with" (p. 235). Settled powered relations shape which objects come to matter as important in the space. That is, the contours of the classroom space changed such that knowledge objects emerge as matter that is valued by the students and teachers (Krishnamoorthy, 2021).

In this paper we contend that virtual spaces or 'rooms' are non-neutral and shaped through power dynamics that can (re)produce (in)justices while also creating possibilities to resist these (in)justices (Switzer et al., 2021). The virtual design team meetings - hosted on Zoom - created a new space and mode for communication that changed the conditions for participation expected of all team members (Switzer et al., 2021). As we illustrate through the analysis, the contours of the virtual meeting room designed by the university researcher hosts - oriented explicitly towards disrupting guest-host youth-adult powered relations - shaped the possibilities for social interactions that unfolded in the meetings.

Methods

Design team context

Drawing on critical and participatory design research methods (Bang & Vossoughi, 2016) to collaborate with youth (Druin, 2002; Pinkard et. al., 2017), we began co-constructing the curriculum unit in the spring of 2021 with a design team that comprised eight youth from two local middle schools, a science teacher from each school and eight university researchers. The schools were located in South Lancaster (SL) (pseudonym) - a Northeastern U.S city. University researchers included individuals from diverse ethnic, racial, gender, and socioeconomic backgrounds. The youth on the design team broadly reflected the majority Hispanic demographics of SL (77% percent of families who attend SL public schools are socioeconomically marginalized). The virtual design meeting room was not a static space, rather it encompassed multiple spaces including whole-group Zoom rooms with slides shared to the group, virtual breakout rooms with 6 - 7 participants per room, as well as additional applications that support the design work for that meeting such as: Padlet, Discord, Spotify, Sketchpad, etc. The boundaries of our virtual meeting room were constructed by university researchers each meeting and included for example, Spotify, Zoom and a Sketchpad one week, and Zoom, Spotify and Padlet another. At the same time, as hosts, university researchers actively shifted the boundaries of the virtual meeting room in response to how youth participated.

Data and Analysis

We draw on data that included university researchers' planning and debriefing meeting notes (105 pages), reflective field-notes after each design team meeting (110 pages), along with artifacts (Google slides etc.) created during the design team meetings over eight months (i.e., 16 team meetings). The analysis of this data corpus was rooted in a grounded theory constant comparative approach (Strauss & Corbin, 1998) to (a) identify moments when the boundaries of the virtual room were made visible and/or changed, through a shift in how adults and youth participated in the meeting and (b) tracing the powered relations (e.g., adult-youth-guest-host relations etc.) that were disrupted and/or (re)produced in those moments. The analysis yielded narratives of episodes that illustrated the ways adult-youth-host-guest powered relations were shaped by and shaped the contours and boundaries of the virtual meeting room.

Results

We present two episodes that illustrate two emerging themes of when (a) the contours of the virtual room were shaped by youth designers' orientations, (b) the boundaries of the virtual room shifted when youth and adults disrupted settled adult-youth powered relations.

(a) Youth designers' orientations shape what 'matters' in the virtual room

In beginning the design process, university researcher hosts structured the virtual design meeting rooms in ways that relied on youth participating by unmuting their microphones and turning on their cameras. However, youth designers resisted invitations to turn on their cameras and chose to type their responses in the Zoom chat instead of unmuting their microphones and speaking. Initially the university researchers struggled with not being able to 'see' or "hear" youth. Although youth participated through the chat function on Zoom, the sedimented expectations informed by in-person teacher-student guest-host power dynamics shaped the university researchers' understandings of youths' participation. Unlike in-person interactions, the virtual room we inhabited allowed for youth to choose how they were visually present despite the adults discomfort and expectations.

Youth designers' choice to not participate in ways expected by university researcher hosts was an act towards authoring their (the youths') Rightful Presence in the space, and informed subsequent changes to the boundaries of the design meeting room in ways that support youths' preferred participation modes. In subsequent meetings, university researchers re-structured the virtual room so that virtual objects such as the Zoom chat box came to 'matter' and were brought into proximity (Ahmed, 2010). That is, the contours of the virtual room changed because of the youths' collective orientation towards the chat box as an object of importance when communicating ideas in the space. Recognizing youths' non-participation (Switzer, 2020) as an agentic disruption of powered adult-youth host-guest relations settled through in-person interactions (i.e., where youth are not offered the choice to show their face or not) was critical towards the adult hosts and youth guests reauthoring rights that defined how designers could participate in the meetings. Shifting the contours of the virtual room - when informed by youths' orientations to virtual objects such as the Zoom chat - better supported youth to participate in ways they preferred and chose.

(b) Collectively shift the boundaries of the virtual room towards Rightful Presence

Seven months into the design team's collaboration, university researchers invited youth designers to create a logo for the project to be attached to curricular materials and websites connected with the project. As part of the design meeting, participants were invited to draw a logo in any of three spaces within the virtual design room: on Sketchpad – an online sketching app, through searching for images and posting them on Padlet, or by drawing them on a piece of paper and sharing by turning on the camera. One youth asked the hosts for permission to use a different app to sketch her logo. The space in which the youth drew her logo was outside the boundaries of the virtual room designed by the university researchers. The youth's move to ask for permission to use a different space made visible the powered guest-host relations whereby the youth guests changed the boundaries of the virtual room during the design meeting, in this case, with permission from the university researchers.

When it came time for designers to share their logos, team members took turns describing the logo they created, through the various spaces within the virtual room. However, another youth asked the university researcher hosts if they could share their designs in the Discord app – a space that was not within the boundaries of the virtual meeting room that day. As the next few minutes of the meeting unfolded, the boundaries of the meeting room shifted again, to include the Discord chat where the youth shared her design. In this moment, participants were collectively oriented towards the Discord app space, engaging through the Discord chat, while continuing to 'sit' in the Zoom room. As a result, the non-static boundaries of the virtual meeting room changed based on the youth designer's orientations to include the Discord app, thereby disrupting guest-host relations and re-authoring her rights in the space. That is, unlike moments when university researcher *hosts* restructured the virtual room in response to youth designer *guests*' non-participation, in this episode the youth designer *guests* initiated changes to the boundaries of the virtual room, re-authoring their rights in the space.

Discussion

The global pivot to online learning has forced researchers and educators alike to adapt to the 'new normal' - a world in which virtual spaces dominate human interactions. However, the design and contours of these virtual environments are not neutral, shaped through settled power dynamics from the larger social world that can work to further (re)produce inequitable conditions for participating in online activities (Benjamin, 2019). Considering how and where power is enacted in ways that (re)produce inequities online is especially pertinent for researchers involved in community-engaged research with youth collaborators.

Rather than assuming a neutral background within which collaboration occurs, we illustrated the ways in which virtual spaces - or 'rooms' - were shaped and continue to be shaped by settled power dynamics, even as newer, more just dynamics are being provoked. Collaborating in a virtual environment offered youth *guests* new possibilities for participating in knowledge creation interactions. However, designing the online environment in

ways that better supported equitable ways of knowing and being required that university researcher *hosts* were grounded in a social justice approach (i.e., Rightful Presence framework) that explicitly works in collaboration with youth *guests* towards disrupting guest-host relations. That is, hosts are responsible for being attuned to the ways in which youth choose to participate in-the-moment, such that youths' acts of non-participation (i.e., episode (a)) and their movement to spaces outside the boundaries of the virtual room (i.e., episode (b)) are welcomed as a necessary disruption of settled guest-host powered relations.

As researchers and educators committed to justice, we maintain that engaging in collective, allied political struggles towards Rightful Presence for minoritized youth in critical participatory design is a necessary and overdue undertaking. This entails a commitment to positioning youth as experts in our design work through enacting youth-centered practices. We work to cede power to the youth by intentionally and continuously minding how we might be reproducing injustices that we are wont to do, when operating from the "norm". The challenge inherent in allied political struggles is that injustices are difficult to identify, not least because powered stakeholders (i.e., university researchers in our case) are entrenched and benefit from, these historical, unjust power structures. We endeavor to hold one another accountable and continue to seek for consequential ways to seed Rightful Presence for youth in STEM teaching and learning.

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"For the RE[STORY]": How an adolescent Black girl reimagines computing technology through electronic textile quilting

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Abstract: Despite computing technologies being positioned throughout society as neutral, the dominant framing of narratives in the field through white, masculine perspectives has manifested in artificial intelligence systems categorizing Black women and girls using historically-oppressive labels. To design for and center Black girls' multiple identities in computing education, I propose electronic textile quilting—creating quilt patches that could be programmed to blink lights or play sound using sensors—as a vehicle for engaging Black girls in the process of "restorying" dominant narratives about computing. After analyzing minoritized youth's quilt artifacts, video observations and field notes, I present findings from one adolescent Black girl participant, Larry, whose quilt patch restorying a WNBA-inspired video game reframed dominant computing narratives from an exclusive lens to one of gender representation. Through analyzing how narrative framing shapes which stories are told, youth can better discern how dehumanizing ideologies manifest in the design of emerging technologies.

Introduction

Despite computing technologies being positioned throughout society as neutral/objective, the dominant, "default" framing of the field through narratives centering white, masculine perspectives have manifested in artificial intelligence systems (e.g., Google search and automated image labeling) categorizing Black girls using dehumanizing, historically-oppressive labels (Noble, 2018). This study aims to design for the multiple identities of Black girls while interrogating and transforming the ways they are socioculturally "coded" through computing technologies. To conceptualize how marginalized youth's computing identities are raced or gendered, I draw from both disciplinary (Bell, Van Horne, & Cheng, 2017) and narrative (Sfard & Prusak, 2005) perspectives of identity. Broader societal narratives and their framing serve as identity resources in STEM and computing-related learning environments that position students relative to one another as well as the discipline at large, and through restorying, youth "narrate the word and the world, [analyze] their lived experiences and then [synthesize] and [recontextualize] a multiplicity of stories in order to form new narratives" (Thomas & Stornaiuolo, 2016, p. 318).

In this study, I explored the restorying practices of Larry (a pseudonym created by one of the adolescent Black girls participating in this study) in her creation of an interactive quilt patch inspired by her personal interests in basketball and gaming, which she titled "For the RE" (a play on the phrases "for the rebound" and "for the restory"). As a medium and context for engaging Black girls in the restorying process, I propose electronic textile (hereafter, e-textile) quilting, which involves designing and creating fabric-based, quilt patches that could be programmed to blink lights or play sound using sensors (e.g., Authors, 2021). As predominantly Black and Brown youth from a local, informal STEM program designed e-textile quilt patches, I ask: When restorying dominant narratives about computing technology, how do youth *frame* those narratives? Through analyzing how narrative framing shapes which stories and perspectives are told (and which are silenced), youth and researchers can better discern how dehumanizing ideologies manifest in the design of emerging technologies.

Theoretical framework

One of the resources people use to make sense of the events around them are frames—available storylines organizing their understanding of events—which help "specify how broader narratives come to have meaning in local spaces" (Gresalfi & Hand, 2019, p. 496). When designing equitable computing learning environments for youth to learn disciplinary concepts and practices and develop practice-linked, disciplinary identities (Bell, Van Horne, & Cheng, 2017), it is important to consider how broader cultural narratives and frames (e.g., ideas and stories about computing people and marginalized communities) shape youth's computing identity construction. When viewed through a lens of techno-determinism, computing technology is framed as an objective tool that can affect society without being shaped by society itself (Benjamin, 2019); however, when framed through the lenses of racism and sexism, computing technology is revealed to uniquely marginalize women, people of color, and gender non-conforming people (Jones & melo, 2020). In this study, I use the concept of framing to examine how marginalized youth make sense of narratives about computing technology, both dominant and reimagined. By providing Black and Brown youth opportunities to restory dominant narratives about computing technology, they will be able to deconstruct harmful narratives about those technologies (and how those narratives are framed in

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popular discourse) in order to reconstruct both narratives and future technologies in speculative, empowering ways.

In considering historical media and technologies for challenging oppressive narratives, Black women have used quilting as both an art form and sociopolitical tool to resist oppression and collectively record and share their cultural histories (Cash, 1995). In other words, Black women and girls have *been* restorying dominant and hidden narratives related to their experiences since their enslavement in this country, using quilting, fabrics, and each other to build sisterhoods and rewrite their stories (Cash, 1995). E-textiles, this study's medium for quilting, are fabrics embedded with microcomputers, lights, and sensors stitched together with conductive thread and programmed to perform various actions (Buechley, Peppler, Eisenberg, & Kafai, 2013). Given the success of combining narratives and e-textiles in supporting girls of color's STEM interests and identities (Pinkard, Erete, Martin, & McKinney de Royston, 2017), e-textile quilting serves as a novel approach for engaging marginalized youth in computing and restorying dominant computing narratives.

Methodology

Through examining minoritized youth's restorying practices through social design experimentation, this study intends to "[identify] and [address] consequential issues [...] that limit opportunities for learning and becoming," (Gutiérrez & Jurow, 2016, p. 593) particularly in the context of learning computing. In collaboration with two graduate student interns, we designed a workshop for a four-year STEM program at a local science museum. We implemented the workshop over the course of two weeks during Spring 2021 (10 hours) and 3.5 hours daily during Summer 2021 (35 hours) with the goal of sixteen, 14-15-year-old minoritized youth designing interactive, e-textile quilt patches that restory dominant narratives about computing technology. To support the identity and community building of participants, youth participated in regular icebreaker activities (e.g., creating "I Am" poems), as well as engaged in discussions about dominant, hidden, and counternarratives about computing technology and quilting, and how both can be leveraged as vehicles for restorying.

Data collected includes youth's artifacts (i.e., quilt patch with explanation video, online design journal, and exit tickets), video observations and field notes, and researcher memos, which were analyzed using constructivist grounded theory (CGT). A methodology for situating research in "the historical, social, and situational conditions of its productions" (Charmaz, 2017, p. 199), CGT uses comparative methods iteratively throughout the research process by inviting researchers to alternate between collecting and analyzing data. I decided to focus the analysis for this study on Larry, who out of the five adolescent Black girls in the workshop expressed having the most prior interests and knowledge about computing technologies. Through conducting three iterative cycles of multimodal analysis on Larry's restorying process, I reveal how narratives about computing are framed throughout Black girls' lived and shared experiences, as well as how those experiences are drawn from in order to restory and reframe computing technology.

Findings and Discussion

E-textile quilts as multimodal texts for reframing dominant narratives

Table 1

Multimodal analysis chart for Larry's quilt patch titled "For the RE"

Photos of quilt patch	Description of quilt patch design and interaction
	An orange WNBA logo is sewn on the left side of a tan-colored background, with the words "1999" written inside the basketball. To the right of the WNBA logo is a small piece of white fabric with the words "New Basketball Games" written in orange. Large orange words boldly titled "WNBA 2K" are glued on a rectangular piece of blue fabric and placed on top of the bottom of the WNBA logo. A brown basketball is sewn on the bottom-left corner of the "WNBA 2K" title. Between the "New Basketball Games" and "WNBA 2K" felt pieces is the Micro:bit, with a left arrow displayed on the LED screen. When the left button is pressed, the words "Now introducing…" flash across the screen, which is followed by a right arrow. When the right button is pressed, the words "WNBA 2K" flash across the screen. When the yellow touch sensor is pressed, an LED image of an explosion appears and then you then applaud. After clapping one's hands, the "explosion" blinks.

When designing a computational, e-textiles quilt patch that restoried a dominant narrative about computing, Larry was able to interrogate and reimagine the way narratives about computing technology are framed throughout media. In the video explanation for her quilt patch (see Table 1), Larry restoried the dominant narratives that video

games and basketball are "just for boys" by designing her quilt patch as an advertisement for an imagined WNBA 2K video game. Wanting her project to challenge developers creating the first NBA 2K video game in 1999—while also neglecting to create a WNBA version—she demonstrated how computing technologies like video games communicate messages to girls that they aren't afforded equal opportunities to play as their favorite basketball players from the WNBA.

Larry demonstrated how the multimodal nature of restorying through e-textile quiltmaking made it an ideal context for reframing the narratives the media communicate about computing technology. People make meaning about sociopolitical issues through "media-generated images of the world," and the "lens through which [they] receive these images" reveals the perspectives of those with the power to control the narrative (Gamson, Croteau, Hoynes, & Sasson, 1992, p. 374). However, the process in which these images and narratives are normalized can be invisible to people. When reflecting on the role designing her quilt patch played in helping her reimagine computing narratives, Larry shared that it helped her "recognize different narratives [from her everyday experiences] and break them down and see how changing something small would affect everything." By sewing and coding an interactive quilt patch based on her identity as an adolescent Black girl who likes basketball and video games, Larry was able to observe narratives surrounding these interests and frame those observations from multiple, distinct perspectives (including her perspective, the perspective of others, and the perspective of her imagined audience).

"There wasn't anything like that for us": Reframing computing technology from a lens of exclusion to a lens of representation

When framing narratives about computing technology like video games through lenses of exclusion and representation, Larry was able to tease apart both dominant and hidden narratives, particularly whose stories, identities, and interests are most reflected in the design of certain video games. "These stories compare to the history of computing and the belief that primarily or only men are involved in it. It's a counter narrative that women can be interested in video games, more specifically NBA2k games and that they also should have a game that includes their stories," Larry shared halfway through the workshop in response to the question "How do those stories/experiences compare to the history of computing technology?". This finding reflects both the underrepresentation of Black women in computing and gaming (Gray, 2020), as well as the need for more research examining their unique computing education experiences (Solomon, Moon, Roberts, & Gilbert, 2018). When observing narratives surrounding video games she played personally—such as the "world-renowned, best-selling NBA 2K basketball video game series" as stated on their website—Larry did not see the basketball part of her identity included in the gaming industry, despite identifying with other Black women who play basketball (e.g., women in the WNBA). Through speculatively travelling back in time and designing an advertisement for a game that doesn't exist (yet), Larry illustrates how restorying allowed her to (1) reframe computing through a lens of representation and belonging and (2) reimagine a technology that highlighted the stories of women and girls like her.

After being able to note and shift the way computing technology was framed through restorying the dominant narratives affiliated with it, Larry also expressed a desire to "go more into depth about more dominant narratives," so she could "teach more people about it and have more awareness of the issue" (7/30/21, exit ticket). Narratives connect to broader societal and cultural belief systems, stereotypes, and imaginaries, and given that they are leveraged by people to make sense of themselves and others (Gresalfi & Hand, 2019), providing minoritized youth with opportunities to restory deficitizing narratives can support them in developing their identity trajectories. Upon completing the workshop, Larry shared that she felt more "comfortable" and "okay" with being who she is around others. "The topic I made my quilt about heavily applies to me, and I have challenged this dominant narrative before without realizing," she reflected in her final exit ticket. This finding illustrated how designing a computational artifact that framed computing narratives from a lens of representation allowed Larry to restory learning computing to learning how to represent herself and her community.

Implications for the Field

The restorying approach centers the historical and present lived experiences of marginalized communities (in this case, Black girls) as its methodological contribution for reimagining STEM and computing education through social design experimentation (Gutiérrez & Jurow, 2016), which argues that "the coordination of past, present, and future-oriented actions and identities sets the conditions for new forms of agency central to realizing possible futures" (p. 567). Traditional, normalized forms of learning that are grounded in racist ideologies continue to "spirit murder" Black girls and boys by "robbing dark people of their humanity and dignity and [leaving] personal, psychological, and spiritual injuries" (Love, 2019). Through centering disciplinary narratives and how those

narratives impact the identity construction of Black and Brown youth, restorying provides youth opportunities to write themselves into computing stories. Methodologies that disrupt and think beyond dominant forms of learning (e.g., interdisciplinary activities such as e-textile quiltmaking) can provide not only authentic but also legitimate approaches for minoritized youth to imagine alternate outcomes about STEM and computing, technology, and their communities.

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Comparing Subjective and Objective Estimates of Effort and Performance on Adaptive v. non-Adaptive Computerized Tests of Statistics Knowledge

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Abstract: We examine associations between subjective (self-reported) and objective (derived from behaviors or performance) indicators of effort and ability and whether the format of a computerized assessment (adaptive v. non-adaptive) moderates these associations. Participants (N=219; M_{age}=19.83) were randomly assigned to one of two conditions in which they completed either an adaptive or a non-adaptive version of a 20-item computerized assessment. They then self-reported their effort and the number of items they believe they answered correctly on the assessment. Self-reported effort was not significantly correlated with the behavioral indicator. However, self-reported ability was positively correlated with participants' test score, even after controlling for test condition. Test condition appeared to moderate the association between subjective and objective estimates of ability with participants with higher ability in the non-adaptive condition estimating a greater number of items answered correctly. Further work should examine whether effects of test condition differ for certain student subgroups.

computerized assessment, adaptive test, test mode, self-evaluation, effort, subjective v. objective estimates

Introduction

There are many advantages to computerized adaptive exams from a quantitative standpoint, but little is known about how they affect test-takers' experiences. Computerized adaptive exams have grown in popularity over the years since as they allow for more efficient assessment by using fewer items or less time to achieve the same level of measurement precision (Weiss & Kingsbury, 1984), can be scored promptly, and are usually thought to involve more secure test administration (Klein & Hamilton, 1999). As a result of the shorter testing time and the approximate matching of item difficulty to the test-takers' ability, they are thought to deliver a better test-taking experience than more traditional computerized linear fixed-form ("non-adaptive") exams. However, matching of items based on students' ability on adaptive exams may cause confusion for certain test takers, leading them to assume they have less aptitude than on test scores would in fact suggest.

Past research on the effects of different test formats on test-takers (i.e., "test mode") has largely focused on the influence of test mode effects on learners' performance with respect to computer versus paper-and-pencil administration modes (Clarina & Wallace, 2002). To the best of our knowledge, few studies have examined whether test mode effects differ on adaptive compared to non-adaptive computerized. Given that more and more tests are delivered on computers, particularly because of the COVID-19 pandemic's shift toward online and distant evaluation (Middleton, 2020), this seems a pressing question. Aside from test mode, certain factors unrelated to the construct or ability being tested may influence test-takers' score (Haladyna & Downing, 2004). According to the *demands-capacity model of test-taking effort* (Wise & Smith, 2011), students who have high ability may exert low effort on test items if they perceive items as too difficult. Thus, understanding how aspects of students' subjective experience of test-taking interacts with mode effects is important, particularly in an adaptive test, where test-takers are matched to items based on performance.

Research Aims

The present study seeks to examine the association between participants' self-reported and actual effort and ability on two versions of a computerized test. We expected to find that such associations may differ based on the test mode condition (adaptive v. non-adaptive).

Self-reported and Behavioral Estimates of Effort and Ability: Differences based on Test Mode

- **RQ1**: After controlling for test mode, to what extent are each of the following factors correlated with each other?
    - self-reported effort

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- self-reported predictors and self-evaluations of ability
- effortful responding behavior (RTE)
- estimated ability (theta)

- **RQ2**: Do these factors differ significantly as a function of test mode (adaptive v. non-adaptive)?

Self-reported and Behavioral Estimates of Effort and Ability: Moderation of Test Mode

- **RQ3**: Does the association between effortful response behavior (as indicated by response time effort) and self-reported effort differ based on test mode (adaptive v. non-adaptive)?
- **RQ4**: Does the association between participants' actual performance (as indicated by an item response theory derived theta estimate) and self-reported estimates of test-takers' performance differ based on test mode (adaptive v. non-adaptive)?

Methods

Participants were recruited predominantly from an undergraduate participant pool at a university in the Midwestern U.S. (N = 251; *Mage* = 19.86 years, *SDage* = 1.23; *%Female* = 69.7). Table 1 provides sample demographics. Participants were excluded if they did not complete all 20 items on the test (n = 13) and those with response time effort (RTE; Wise & Kong, 2005) less than .50 (n = 19) were also flagged for being unmotivated. The remaining analytic sample (N = 219; *Mage* = 19.83 years, *SDage* = 1.23; *%Female* = 68.9) did not differ based on age, gender, or race/ethnicity from the sample recruited.

Table 1

Sample descriptives

Variable	Count	Percent
Gender		
Female	175	69.7%
Male	76	30.3%
Race/Ethnicity		
American Indian/Alaska Native	0	0%
Asian/Asian American	41	16.3%
Black/African American	7	2.8%
Latinx, Chicanx, Hispanic, or Spanish origin	9	3.6%
Middle Eastern/North African	6	2.4%
Native Hawaiian/Other Pacific Islander	1	0.4%
White/European American	168	66.9%
Other	8	3.2%
Prefer not to say	3	1.2%
Multiple	0	0%

Participants were randomly assigned to complete one of two versions of a 20-question test of statistics knowledge: a computerized linear-fixed item test ("non-adaptive") and an adaptive test ("adaptive"). The study had IRB approval and all participants consented prior to participation.

Subjective effort (Self-reported mental effort)

A four-item self-report measure was administered after participants completed the 20-item test of statistics knowledge. Responses to the items (e.g., "*I tried hard to answer the questions correctly.*") were provided using a 1-5 Likert scale (*1 = Strong disagree, … 5 = Strongly agree*). Past work has found good internal consistency of the measure (Cronbach's alpha = .88; Ober et al., under review).

Subjective ability (Estimated number of items answered correctly)

Following the 20-item test of statistics knowledge, participants were asked, "*Out of the 20 questions you completed just now, how many did you answer correctly?*" Responses options ranged from "0 - None of them" to "20 - All of them".

Objective effort (Response time effort)

We used response time effort (RTE; Wise & Kong, 2005) to indicate responses that appeared motivated and effortful. Across all questions, fewer than 25% of all responses were submitted in under 30 seconds. Thus, any response that took under 30 seconds was marked as unmotivated. Participants with more than 50% of responses marked as unmotivated were flagged for removal.

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Objective ability (Test scores)

An estimate of the participants' objective ability was derived from a comprehensive assessment suitable for AP or an introductory college-level statistics curriculum. Test scores ("theta estimates") were computed based on a Rasch model, a type of item response theory model that can be used to compute estimates of ability based on test-takers' responses and item parameters, such as the item's difficulty (Embretson & Reise, 2000). More positive values indicate greater ability.

Results

As mentioned previously, we were interested in examining the associations between self-reported estimates of effort and ability in relation to more objective estimates. We first sought to establish the extent to which these variables were correlated with one another (**RQ1**). Controlling for test mode (adaptive v. non-adaptive), self-reported mental effort (based on an average scale score) was not significantly correlated with the behavioral indicator of effort used in this study (RTE; $r = .13$, $p = .057$). The behavioral indicator of effort (RTE) was not significantly correlated with any of the other measures. Instead, participants' self-reported effort appeared to be positively and weakly correlated with both the participants' estimated ability (after completing the 20-item test; $r = .17$, $p = .014$) and their test score (based on the theta estimate; $r = .13$, $p = .047$). Participants' estimated ability was positively and moderately correlated with their test score ($r = .54$, $p < .001$).

Next, we were interested in determining whether these variables significantly differed on the basis of test mode (**RQ2**) using independent samples t-tests. We found that participants in the non-adaptive test condition ($M = 4.19$, $SD = .93$) tended to report exerting more mental effort than those assigned to the adaptive test condition ($M = 3.81$, $SD = .75$; $t = 3.28$, $p = .001$, $d = .437$). By contrast, participants in the adaptive test condition ($M = .80$, $SD = .14$) tended to have higher estimates of behavioral effort as indicated by RTE than those in the non-adaptive condition ($M = .75$, $SD = .13$; $t = 2.93$, $p = .004$, $d = .395$). When comparing estimates of ability, we found that participants in adaptive test condition ($M = 11.34$, $SD = 3.87$) tended to report receiving a lower number of items correct out of 20 compared to participants in the non-adaptive condition ($M = 9.75$, $SD = 3.59$; $t = 3.12$, $p = .002$, $d = .425$). Comparing test scores (theta) appeared to reaffirm participants' self-evaluations with those assigned to the adaptive test condition ($M = -.18$, $SD = .79$) receiving lower scores than those in the non-adaptive condition ($M = .07$, $SD = .61$; $t = 2.70$, $p = .008$, $d = .359$).

Given the differences in each of the estimates of effort and ability based on test mode, we next wanted to determine whether test mode moderated the association between the subjective and objective estimates of each. Two separate ANOVA models were tested with the subjective estimates of effort and ability as outcomes (i.e., self-reported mental effort, estimated number of items answered correctly) with predictors including the respective objective estimate (i.e., RTE for effort, theta for ability), treatment condition (i.e., adaptive or non-adaptive), and an interaction between the two. In the model predicting self-reported effort (**RQ3**), there was a significant effect of treatment ($F(1, 215) = 12.67$, $p < .001$, *partial eta*$^2 = .056$) but no effect of either RTE ($F(1, 215) = 1.70$, $p = .194$, *partial eta*$^2 = .008$) or an interaction of treatment and RTE ($F(1, 215) = .22$, $p = .638$, *partial eta*$^2 = .001$).

We followed a similar procedure to examine variation in participants' self-evaluations of ability (**RQ4**). There were significant main effects of test score ($F(1, 215) = 97.17$, $p < .001$, *partial eta*$^2 = .311$), treatment condition ($F(1, 215) = 4.09$, $p = .045$, *partial eta*$^2 = .019$), and the interaction of the two ($F(1, 215) = 5.14$, $p = .024$, *partial eta*$^2 = .023$). The interaction term indicated that participants with higher test scores in the adaptive condition tended to report answering fewer questions correctly than those with higher test scores in the non-adaptive condition. Given the matching of items based on performance in an adaptive test, this is to be expected.

Discussion

The results provide information about how associations between subjective and objective estimates of effort and ability differ based on whether a computerized test is adaptive or not. Self-reported effort did not have a significant relationship with behavioral indications of effort, according to our findings. Even after controlling for the test format, individuals' self-reported ability was positively correlated with their test score. Participants with higher ability in the non-adaptive condition estimated a greater number of items answered correctly than those in the adaptive condition, suggesting that the test condition moderated the relationship between estimated number of items answered correctly and test score.

Self-assessment requires one to accurately monitor and appraise their effort and ability (Andrade, 2019) and can vary from person to person (Baars et al., 2014win). According to previous research, certain demographic factors (e.g., age, gender, parental education), the classroom learning environment (e.g., prior educational experience, interactions with teachers, engagement in learning), and the assessment context (e.g., low- or high-stakes) all influence self-assessment accuracy. Student background factors (e.g., subject matter experience) and

current behaviors (e.g., course involvement) are hypothesized to influence the inaccuracy and overconfidence bias of self-assessment, as well as effort and ability on a specific task (Ober et al., 2022). Furthermore, there is evidence that female and underrepresented students in STEM may tend to underestimate their effort and ability on evaluative tasks (Jacobs, 2005). This is regarded as one possible barrier that inhibits individuals of underrepresented groups from pursuing STEM careers (Museus et al., 2011). As such, future work in this project domain will examine the extent to which the effects of test mode are moderated by student background characteristics. Such findings in this area could contribute to a growing understanding of how assessment contexts contribute to differences in the accuracy of students' self-assessment and the implications of using it for instructional practice.

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An Exploratory Study on Students' Digital Curation Competency and Experience in a General Education Course

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Abstract: Essential in this information landscape, digital curation is broadly defined as the practices of digitally organizing and re-presenting the cultural record of humankind for creating value and impact, producing visual and textual information for presenting a narrative to audiences. Despite the prevalence of our daily-life curatorial practices and being well-suited to a diversity of disciplines, training in digital curation knowledge and skills has not been democratized to be inclusive for students from non-technical backgrounds. This pilot study 1) proposes a maker activity, namely creating digital galleries of cultural heritage, in a general education course, 2) examines to what extent this learning activity helps develop digital curation competency of undergraduate students, and 3) investigates how this digital curation experience benefits their professional and personal pursuits.

Introduction

In this technological age, information is available in vast quantity and varying quality (Cherrstrom & Boden, 2020). In our daily life, we perform the social practice of information *curation* mostly without awareness, such as compiling relevant information for purchasing masks, organizing personal photo albums, and documenting social events in a community (Cherrstrom & Boden, 2020; Ungerer, 2016). Traditionally, curatorial activities for cultural heritage materials take place in memory institutions (e.g., museums, libraries) (Cherrstrom & Boden, 2020), while nowadays *digital curation* is broadly defined as the wide-ranging practices of "organizing and re-presenting the cultural record of humankind in order to create value, impact, and quality" (Sheffer & Hunker, 2019: p.80). Typically, it results in a series of visual and textual information for presenting a particular discipline-dependent narrative to both professional and public audiences (Cherrstrom & Boden, 2020; Sheffer & Hunker, 2019).

Due to the commonality of curatorial practices (Cherrstrom & Boden, 2020), digital curation has been increasingly integrated into students' learning process (e.g., content curation for assignments) (Ungerer, 2016). In the ever-growing information landscape, digital curation has evolved to be a transferrable skill that prepares university students for the demands of a digitally savvy workforce (Sheffer & Hunker, 2019). Training in digital curation has a strong pragmatic focus on students' competencies (Kim, 2015): their understanding of users' needs, ethical use of information, content organization and management, technical skills of using online curation tools, and so on (Cushing & Shankar, 2019; Feng & Richards 2018). This has led to pedagogical practices emphasizing hands-on experience (Cherrstrom & Boden, 2020), where students usually collaborate and work on topic-specific projects with real-world audiences (Sheffer & Hunker, 2019). Despite being well-suited to many disciplines, there is currently a lack of studies in digital curation education for students with diverse backgrounds, especially those with limited technology knowledge or support (Kim, 2015, Sheffer et al., 2019).

Towards democratizing digital curation training and making it more inclusive (Hu et al., 2017), this exploratory study proposes a maker activity namely creating digital galleries of cultural heritage, and examines how it could help develop digital curation competencies of undergraduate students with diverse backgrounds, and how this digital curation experience would benefit them. In the context of an undergraduate general education course, we pose the following two research questions:

RQ1: To what extent can digital gallery creation help develop students' digital curation competencies?
RQ2: What are the benefits of digital curation experience as perceived by students?

Findings to the first research question will improve our understanding about the extent to which students can develop digital curation competency through the maker activity of creating a digital gallery, whereas the second research question can offer empirical evidence on the values of democratizing digital curation education. Our findings will also yield pedagogical implications on how to optimize students' learning experience.

Research Context and Methodology

This pilot study was conducted in a university-wide undergraduate general education course in Hong Kong on the topic of digitizing cultural heritage. The course learning outcomes include having students "design user-centered digital products for presenting heritage information" and "apply principles and ethics of information to heritage preservation". The capstone of this course was a group digital curation project in which each group of 3 to 5

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students collaborated to create a digital gallery for a self-chosen cultural heritage. Built towards this assessment, classes comprised both weekly lectures on key topics (e.g., ethics of digital preservation) and tutorials with hands-on digital curation activities. Omeka.org, an open-source tool commonly used in digital curation education (Sheffer & Hunker, 2019), was used as the platform for creating the digital gallery, owing to its ease of use, flexibility, and affordances in presenting multimedia materials (Hu et al., 2021). Towards the end of the course, each group submitted the link of their public-facing digital gallery and a report documenting and explaining their work. They were informed that the best-performing galleries would be selected by the teaching team for display at a public showcase of student works. Fig. 1 shows some example galleries.

Owing to similar content and pedagogical implementations, students from the 2018 (n = 97) and 2019 (n = 102) cohorts were grouped into one population. With informed ethical consents which assured students whether they participated in this study would not affect their course grades, a total of 199 students (female = 60%) in 58 groups joined this study voluntarily without remuneration. 36% of them were Science, Technology, Engineering, and Mathematics (STEM) majors, while the rest (64%) were non-STEM (e.g., Arts, Business, Journalism, etc.).

This study employs qualitative methods including artefact analysis (RQ1), for the usefulness of artefacts in assessing student competencies (Kim, 2015), and thematic coding (RQ2). To answer RQ1, based on constructs in existing studies on digital curation (e.g., Sheffer et al., 2019), we developed a rudimentary analytic framework with six categories (e.g., user needs assessment) each indicating a digital curation competency (underlined in Table 1). Then, a more fine-grained coding framework was established from a bottom-up, data-driven approach, generating individual codes (e.g., awareness of users' needs). For RQ2, we collected open-ended responses from an optional course-end survey asking about students' perceived benefits of their digital curation experience. Adopting the grounded theory approach (Strauss & Corbin, 1994), excerpts were extracted and iteratively coded using the coding framework (Table 2). To ensure anonymity, a research assistant removed the students' names from the data before analysis. To ensure reliability, 25% of the artefacts (RQ1) (15 groups) and excerpts (RQ2) (n = 40) were randomly selected and independently coded by two researchers knowledgeable in digital curation, attaining excellent levels of agreement with Cohen's kappa of 0.90 and 0.96 respectively (MuHugh, 2012).

Figure 1

Homepage of Example Digital Galleries Created by Students

Preliminary Findings

For RQ1, upon analyzing each group's digital gallery and the corresponding report, we counted the number of groups (total = 58) satisfying each code (Table 1). First, most of the groups not only identified their target user groups (#1.1 in Table 1) (95%), e.g., "elderly residents" (Group 1), "foreign tourists" (Group 58), but also listed these users' information needs (#1.2, 86%), e.g., "proper ways to use the [heritage]" (Group 52), "detailed descriptions of the [heritage]" (Group 47). This shows students' basic understanding about user-centered design (Nelson et al., 2011). In terms of metadata quality, the majority (91%) followed the standard taught in class (#2.1), which has been widely adopted in the cultural heritage domain (Hu et al., 2021). Most groups completed their metadata fields (#2.2) (72%), while it was common for the remaining groups to leave some fields empty without justifications. These indicate the need for more time and efforts on teaching metadata as a functional competency in digital curation (Feng & Richards, 2018). Next, while all groups supplied photos or pictures for presenting their heritage items (#3.1) (some examples shown in Fig. 2), only less than half of the groups (40%) presented audio-visuals (#3.2), which were mainly for introducing the heritage's history (e.g., Group 20) or giving a guided tour (e.g., Group 57). It is thus desirable to encourage students to leverage multimedia materials in the future. As for facilitating users' information discovery (#4), many groups (69%) showed awareness of how users could leverage the default "basic search" (e.g., Group 25) and "advanced search" (e.g., Group 8) functions on Omeka. About two-thirds of them (64%) were also aware of user' browsing experience (#4.2), but only about half (48%) implemented tags, free short texts annotating heritage items (#5.3), for facilitating browsing. This demonstrates that students had the basic understanding of designing public-facing products of digital curation from users'

perspectives but were not sufficiently versatile in making use of all available functions (Cherrstrom & Boden, 2020). For information ethics (#6), a considerable number of groups (59%) showed awareness of ethical concerns (#6.1), mostly on avoiding copyright infringement, such as using materials with Creative Commons licenses (e.g., Group 8), seeking usage permission from the owner of resources (e.g., Group 22), and creating original materials (e.g., Group 35). Nonetheless, only one-thirds (31%) included copyrights statements in their digital galleries (#6.2). This suggests that more training on implementing intellectual property rights is needed.

Table 1

Coding framework and Code Counts for RQ1 on Students' Digital Curation Competencies

Category and Code	Definition	Count(%)
1. User needs assessment	To identify target user communities and their information behaviours before and during digital curation (Kim, 2015; Nelson et al., 2011)	
1.1 Awareness of target users	Artefact shows awareness of target users without their needs.	55 (95%)
1.2 Awareness of users' needs	Artefact shows awareness of target users and their needs.	50 (86%)
2. Metadata quality	Domain-independent measures of metadata quality (Feng & Richards, 2018)	
2.1 Standards and consistency	Artefact shows proper and consistent use of a metadata standard.	53 (91%)
2.2 Completeness	Artefact shows all metadata fields have been filled.	42 (72%)
3. Multimedia elements	Multimedia representation of information (Nelson et al., 2011)	
3.1 Still images	Artefact shows use of photos and/or pictures for presenting items.	58 (100%)
3.2 Audio-visuals	Artefact shows use of videos and/or sounds for presenting items.	23 (40%)
4. Information discovery	Facilities for users' information discovery (Lazarinis, 2011)	
4.1 Searching	Artefact shows consideration of users' searching experience.	40 (69%)
4.2 Browsing	Artefact shows consideration of users' browsing experience.	37 (64%)
5. Content organization and presentation	How the curated content is structured for users' navigation (Cushing & Shankar, 2019; Sheffer & Hunker, 2019)	
5.1 Collections and Exhibits	Artefact shows use of collections and exhibits (Fig. 2).	54 (93%)
5.2 Item tags	Artefact shows use of tags on items.	28 (48%)
6. Information ethics	Consideration of information ethics in digital curation, including copyrights and fair use (Feng & Richards, 2018; Sheffer & Hunker, 2019)	
6.1 Ethical consideration	Artefact shows consideration of information ethics.	34 (59%)
6.2 With copyrights statement	Artefact shows use of copyrights statements.	18 (31%)

Figure 2

Screenshots of an Item Page (left), a Collection (middle), and an Exhibit (right) from three Exemplar Galleries

For RQ2, a total of 147 excerpts were collected from 133 students (response rate = 67%). Table 2 displays the frequency information for each code. When asked about their perceived benefits of the digital curation experience, 37% of the excerpts (n = 55 out of 147) focused on areas of knowledge acquired whereas more than half (n = 82 out of 147) (55%) were on specific skills. Knowledge-wise, nearly half (25 out of 55) reported learning about metadata (i.e., information describing other information) as a major take-away from digital curation, which is encouraging as metadata are ubiquitous in daily lives but rarely taught to an interdisciplinary audience (Hu et al., 2017). In terms of skills, the majority of excerpts (53 out of 82) were on digital content creation related skills (#8.1), including how to "design" (Student 132), "build" (S8), or "create" (S61) a "digital gallery" (S23), a "[digital] collection" (S8), a "[digital] archive" (S131), or a "[virtual] exhibition" (S110), evidencing learning outcomes on digital skills among students with diverse backgrounds (Sheffer & Hunker, 2019). Notably, some students commented that these digital curation knowledge and skills would be useful for their future "project work" (#69), "business purposes" (#130), and "real life situations" (#96), indicating the potential transferability of digital

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curation competency to learners' professional and personal contexts (Ungerer, 2016). As digital curation is common across disciplines, future endeavours can focus on domains beyond cultural heritage.

Table 2
Coding Framework and Code Counts for RQ2 on Student Perceived Benefits of Digital Curation Experience

Category and Code	Definition	Count
Knowledge	Participant mentioned gaining knowledge from the experience in:	**55**
Digital gallery	Digital gallery, digital collection, and/or digital library.	10
User-centered design	Users, users' needs, and/or user-centered design.	13
Metadata	Concepts, usefulness, and applications of metadata.	25
Information ethics	Concepts, importance, and guidelines of information ethics.	7
Skills	Participant mentioned acquiring, developing, and/or enhancing a skill.	**82**
Digital content creation	Designing, creating, and/or disseminating digital content.	53
Information literacy	Collecting, screening, organizing and/or presenting information.	20
Technical skills	Other technical skills during the digital curation process.	9
Potential usefulness	Participant mentioned the potential usefulness of the experience.	**10**
Personal	Contexts and/or scenarios related to participant's daily life.	5
Academic/Professional	Contexts and/or scenarios related to participant's studies and/or work.	5

Conclusion and Future Work

Our preliminary findings reveal that, through the maker activity of creating a digital gallery, students largely demonstrated 1) a basic understanding about concepts (e.g., user-centered design, information ethics) and 2) functional competency (e.g., inputting metadata, avoiding copyrights infringements) for digital curation. Acquiring these 21st century knowledge and skills were perceived by the students as benefits of their digital curation experience, which they deemed useful for their professional and personal pursuits. As an ongoing study, we are conducting in-depth analysis of the student-inputted metadata and their reflective writing.

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Design of Real-time Scaffolding of Middle School Science Writing Using Automated Techniques

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Abstract: Science writing skills depend on a student's ability to co-ordinate conceptual understanding of science with the ability to articulate ideas independently, and to distinguish between gradations of importance in ideas. Real-time scaffolding of student writing during and immediately after the writing process could ease the cognitive burden of learning to co-ordinate these skills and enhance student learning of science. This paper presents a design process for automated support of real-time scaffolding of middle school students' science explanations. We describe our adaptation of an existing tool for automatic content assessment to align more closely with a rubric, and our reliance on data mining of historical examples of middle school science writing. On a reserved test set of semi-synthetic examples of science explanations, the modified tool demonstrated high correlation with the manual rubric. We conclude the tool can support a wide range of design options for customized student feedback in real time.

Introduction

Constructing evidence-based scientific explanations is an integral part of science learning (Berland & Reiser, 2009; Krajcik et al., 2014), as emphasized in the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). However, students often write incomplete, non-causal accounts of scientific phenomena (Seah, 2016), and find it difficult to use data appropriately (Sandoval & Millwood, 2005). With technological advances in Natural Language Processing (NLP), recent research has integrated automated scoring of and adaptive feedback on scientific explanations (Gerard et al., 2019; Liu et al., 2016; Riordan et al., 2020; Tansomboon et al., 2017), and on essays in other genres (Zhang et al., 2019), and across languages (Toma et al., 2021). Gerard, Kidron, and Linn (2019) used c-raterML to score 6th graders' scientific explanations in their web-based inquiry science environment and provide feedback for their explanation revisions. They designed automated feedback as well as associated guidance from the teacher to encourage students to use evidence in describing relations among scientific ideas. This work exemplifies *real-time* feedback for students and teachers. Previous studies have developed tools to assess students' scientific writing based on the inclusion of concepts or terms (Liu et al., 2016). Summarization Integrated Development Environment (SIDE) combines NLP and machine learning algorithms to score students' explanations based on the identification of scientific concepts in the responses (Ha et al., 2011). Similar tools include SPSS Text Analysis (SPSSTA) which identifies terms and patterns within students' writing. While these latter systems achieve high score correlations, and sometimes aim for general feedback, they do not provide real-time feedback on specific content elements within science explanation.

In the present study, we aim to create opportunities for students to develop scientific explanations while working on a roller coaster design challenge. We aim to provide real-time feedback that scaffolds students' written explanations of science *concepts* and *relationships* (National Research Council, 2012, p. 52).

An electronic notebook for classroom use

Building on previous implementations of our middle school physics curriculum using paper notebooks (Martin et al., 2019), we have been developing a digital notebook to support students' learning. A digital notebook has multiple advantages over a traditional paper version, such as the ability for students to submit their responses for immediate feedback, use of text mining to provide students with ongoing support, and allowing students to easily revisit previous work. A key feature of the notebook that we are developing is that it can pre-process students' text. Because the digital notebook is accessible through a web browser, students will be able to utilize common features such as spell-checking and grammar-checking, which will make their writing more readable to the teacher, and ensure clean input to an NLP system to support real-time scaffolding. The digital notebook will allow students

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an effortless way to reference data, which in turn makes it trivial to remove data from their responses or mark the sentences as being too incomplete for automated feedback.

Through the notebook, students will be given simple feedback based on a combination of data mining and NLP techniques. In our first iteration, data mining will support feedback to students to encourage uniform usage of equations, and to track frequency of key words in their writing. An adaptation of existing content-assessment software (PyrEval) will support feedback on students' written use of science ideas.

Adaptation of PyrEval for real-time scaffolding

PyrEval is a freely available software tool with source code originally designed to assess the content of paragraph-length summaries of source texts, e.g., for reading comprehension (Gao et al., 2019). Characteristics of PyrEval that are a good fit for real-time scaffolding of students' writing of short passages to a prompt are:

1. PyrEval is designed to assess each idea in a student passage for the importance of the idea.
2. It is a lightweight NLP tool that can be used "off-the-shelf" (no domain-specific training is required).
3. It produces **quantitative** scores about importance of ideas, and **qualitative analyses** of specific ideas.

The original PyrEval creates a model of content importance from reference passages written by four to five experts, or by more advanced students. Importance emerges from the frequency of the idea across the references. Emergence, however, does not fit with our objective here, which aim for students to learn specific ideas defined in the curriculum. We modified PyrEval in two ways to address this objective. First, we developed a method to curate a predefined content model based on the curriculum. Second, we adapted the automated analysis to account for features of middle school writing, and to improve the accuracy of the qualitative results.

One significant challenge we faced was to adapt the pre-existing software in the absence of reference texts or a set of examples of the range of inputs the software should handle. In the following subsection, we explain how we mined an existing dataset of passages from middle school students who had a different but related curriculum to synthesize examples like those we expect to see in our new curriculum. We also describe an essay rubric we developed for the new curriculum. The rubric was used both to guide the curation of a new type of PyrEval content model, and to serve as a benchmark against which to measure PyrEval results. Later we discuss the dilemma that arises when we shift PyrEval from reliance on an emergent "*extensional*" definition of content and content importance to also incorporate an "*intensional*" definition constituted by a rubric.

A new rubric with interrater reliability on a semi-synthesized dataset

For this study, we revised historical middle school students' responses to curate data which aligns with our new roller coaster curriculum, by selecting or rephrasing observed statements. We developed a rubric to assess students' writing in the curated essays in line with our expectations for the students. Each time an essay incorporated an explanation of a relevant science concept or relationship between concepts in their essay, it received one point (see examples in Table 1). A total score for each essay was calculated by adding up the total points received. A higher total score indicated that an essay included many important ideas, whereas a score of zero indicated an absence of relevant ideas. Two researchers independently coded a random sample of 13% of the entire sample of 76 essays and achieved a Cohen's Kappa of 0.94, which is considered almost perfect agreement (Stemler, 2001). One of these researchers then coded the remainder of the data.

Table 1

Example of types of concepts and relationships that received one point based on the rubric.

Example Concepts	Example Relationships
• "**Potential energy** is the amount of stored energy an object has based on it's position."	• "the **higher** the initial drop, the **more KE** (kinetic energy) you will have."
• "...the **Law of Conservation of Energy**...states that energy can't be created or destroyed in a system."	• "The more **mass** you have, the **more potential energy** you will have."

Challenges for modifications to PyrEval

PyrEval automatically assesses content by uniquely matching ideas in a student passage to a pyramid model of weighted content units (CUs), and normalizing the summed weights of the matched CUs. PyrEval achieves this through a three-stage pipeline, where the input is a set of reference passages, and student passages (Gao et al., 2019). A pre-processing module decomposes complex sentences into clauses using a rule-based parser and converts the output clauses into semantic vectors. In the second stage, EDUA, a restricted set partition algorithm, groups similar vectors from the reference passages into CUs. In this work, we use EDUA in a new way, to provide data for manual curation of a content model of pre-defined CUs that match a rubric. The third part of the pipeline

applies WMIN, a greedy maximal independent set algorithm (Sakai et al., 2003), to match students' ideas to CUs. For our present work, we investigated which WMIN configurations would perform best.

Table 2

Two distinct configurations of Modified PyrEval from the top 10% of the grid search with the baseline scores the original configuration, and the corresponding correlations. Here, APCS metric refers to the average pairwise cosine similarity, which is the average of the cosine similarity scores of each contributor to the CU with the clause being matched. StDev metric accounts for the standard deviation of the APCS while product metric also accounts for the weight of the CU being matched. These are more coarse grained than just the cosine similarity scores.

PyrEval Configuration	Set B	Set C
(Baseline) SCVP, MinSegLen=1, k=2, s=APCS, m=APCS	0.63	0.78
SCVP, MinSegLen=5, k=2, s=StDev, m=APCS	0.72	**0.85**
FDCP, MinSegLen=3, k=4, s=StDev, m=product	0.70	0.83

Modifications of PyrEval

Three objectives guided our initial experiments to modify PyrEval. The first was to curate a new type of pyramid to achieve a balance between the kind it was originally designed to use and the manual rubric. Our second objective was to investigate how much sentence decomposition would be appropriate for middle school writers. Our past work applied PyrEval to many samples of college writing, achieving high correlations with manual rubrics, but impressionistic comparison of college-level writing with our samples of middle school writing suggested that the latter had more repetition within sentences, and simpler structure. Our third objective was to improve the precision of the automated matching of student statements to pyramid CUs by changing the WMIN scoring parameters. These objectives are highly interdependent, therefore we investigated them in parallel. For example, if a repetitive sentence is decomposed into two segments, and an accurately matching CU is found for one of them, the second segment is likely to get assigned to a CU it does not match as well.

We divided our 76 semi-synthetic essays into three subsets. Subset A (N=10) was used for automatic creation of a variety of pyramid content models that we could mine to populate a manually curated pyramid. Subset B (N=46) was used for tuning PyrEval to middle school science writing, and for refining the curated pyramid. Subset C (N=20) was held in reserve for our final testing of the tuned parameters.

Two features of an emergent pyramid were important to retain. In the original content models, CUs have a Zipfian distribution (Zipf, 1936), which leads to the so-called eighty-twenty rule where twenty percent of distinct item types (here, statements within CUs or essays) account for eighty percent of the observed frequency (i.e., of the same idea stated in different essays), along with a long-tailed distribution of items (i.e., simple clauses) that occur rarely. Pilot experiments indicated that preserving this Zipfian distribution of CUs was important for PyrEval's scoring algorithm (WMIN) to accurately match student statements to the most similar CU, or to no CU. Instead of hard similarity thresholds, WMIN tries to optimize the overall quality of matches. The second important feature of our curated pyramid was to find ***n*** wordings for each important curriculum idea.

By using subset A to automatically generate 10 pyramids, we had multiple data points for defining the distribution of CUs of each weight. We designed the curated pyramid to have the same general distribution. Manual curation of high weight CUs (weights 3-5) was fairly straightforward. We aimed for four weight 5 and four weight 4 CUs, corresponding to the most important relational components of the rubric. To create these, we mined the pyramids that were automatically generated from set A, selecting relevant paraphrases to achieve the desired weight. We found it was also very important to mine the student data for realistic low-weight ideas.

We varied five PyrEval parameters and functions with a different range of values for 675 configurations. We aimed first for high correlation of the scores assigned to the 46 essays in Set B by PyrEval with those assigned by the raters using the rubric. We also inspected random samples of matches between student segments and model CUs to assess the overall quality of the matches as poor, moderate, or good. We identified two configurations representing fairly distinct hypotheses about how to adjust PyrEval for middle school writing, based on three WMIN parameters (top ***k*** matches, node sorting metric (***s***), and match weighting metric (***m***). The minimum number of words in a segment resulting from decomposition (MinSegLen) was also changed to account for the high proportion of short segments in middle school writing.

After choosing two WMIN configurations that performed well on Set B, and that represented different expectations about middle school writing, we tested these configurations on set C. Table 2 shows the two best configurations along with a baseline configuration applied in previous work. Correlations with the rubric are shown for subsets B (development set) and C (test set). The large difference in correlation between sets B and C seems to be due to a few outliers in Set B where a repetitive sentence matched more distinct ideas in the model

that it should have; dropping two outliers raises the Set B correlation to 0.78. Our future work to design custom feedback will investigate both WMIN configurations shown in Table 2.

Conclusion

As modified for a middle school roller coaster curriculum, PyrEval scores based on our curated pyramid model correlate well with manual scores from our highly reliable rubric. In addition, PyrEval provides a qualitative trace of how it computes its scores, which provides us with ratings on each sentence in a student's passage. We have demonstrated that PyrEval can utilize a predefined content model based on the curriculum and have developed a methodology to construct the content models we will need for the curriculum under design.

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Towards Automated Analysis of Undergraduate Academic Writing using Metadiscourse, Cognitive Level and Word Network

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Abstract: Automated assessment of students' academic writing can provide timely feedback and alleviate teachers' workload. This study examined 199 undergraduate students' essays through metrics of metadiscourse, cognitive levels, and word network, and the relationships between these metrics and performances. Metrics were calculated under the framework of Hyland's metadiscourse model and Bloom Taxonomy whereas relationships were revealed by correlation analysis and classification with multiple algorithms. Findings show that students employed more interactive metadiscourse markers than interactional ones, and there were weak to mild positive correlations between some of these metrics and performance score. High-performing essays involved more higher-order thinking and stronger connections among words. Besides, classification models combining all three types of metrics were most effective in differentiating high and low-performing essays. The three types of metrics evaluated can be potentially used to provide fine-grained suggestions for improving students' academic writing.

Introduction

Students' performance in academic writing is a determinant of their academic performance, degree attainment, and even an important graduate attribute. Academic writing instruction is therefore an essential component in higher education. In the field of learning analytics, automated assessment of student writing has attracted much attention. Besides marking, automated means can also identify and compare textual features and writing strategies in high and low performance writing. These could be leveraged by writing analytic tools for providing timely, actionable feedback at scale to large classes of students (Gibson et al., 2017), and alleviating teachers' workload (Hu et al., 2016). Towards automating analysis of students' academic writing, this preliminary study aims to examine student essays from three linguistic and extra-linguistic aspects of writing: metadiscourse usage, cognitive levels, and word network. Specifically, we pose four research questions (RQs):

RQ1: What is the relationship between metadiscourse usage and performance scores of student essays?
RQ2: What is the relationship between cognitive levels and performance scores of student essays?
RQ3: What is the relationship between word network metrics and performance scores of student essays?
RQ4: To what extent can metadiscourse usage, cognitive level, and word network metrics predict high and low performances of student essays?

Results will reveal whether and how metrics of the three linguistic and extra-linguistic aspects of writing are related to writing performance and offer insights on generating automated feedback for academic writing.

Metadiscourse

As a universal feature of academic writing, metadiscourse represents textual devices for organizing text, engaging readers, and signaling writers' attitudes (Hyland & Tse, 2004). Unlike content words, metadiscourse markers do not present the topic, but guide readers through the text and help them interpret the content (Hyland, 2017). Hyland (2017) referenced the characteristics of previous metadiscourse models and proposed the interactive and interactional models. The former consists of features leading readers through the text by coherently organizing information, whereas the latter involves argumentation and expressing epistemic stance and attitudes to readers. Prior studies have analyzed metadiscourse usage in student writing, reporting that it facilitates writer-reader interaction and improves academic writing performance (Abdelrahim & Abdelrahim, 2020; Hu et al., 2016).

Cognitive Level

Academic writing entails different forms of writing targets, ranging from description to evaluation of information, which can reflect the writer's varying cognitive levels (Qiao & Hu, 2019), and hence their thinking skills (Palmer & Lomer, 2016). Based on Bloom's Taxonomy (Krathwohl, 2002), there are six cognitive domains of learning: knowledge (lowest), comprehension, application, analysis, synthesis, and evaluation (highest). As writing is a primary way of externalizing, evaluating and promoting student thinking, these cognitive domains have been proposed for assessing quality of undergraduates' writing (Penner, 2013). At a finer granularity, Qiao and Hu

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(2019) leveraged Bloom's Taxonomy to classify students' analytical writing into three cognitive levels based on semantic, syntactic, and lexical features. There is nonetheless a lack of studies examining the relationships between these cognitive levels and students' academic writing performances.

Word Network

In academic writing, some words are more likely to appear together (e.g., 'data" and "analysis"), establishing patterns throughout a text (Hong & Cao, 2014) and forming epistemic networks (Fougt et al., 2018). Epistemic Network Analysis (ENA) is a method for the identification and quantification of ties between elements in coded data and their representation in dynamic network models. It allows quantifying the relations between elements of the epistemic frame (Shaffer & Graesser, 2010). ENA has been used in analyzing student writing and visually differentiating their performance levels (Fougt et al., 2018). In this study, instead of manually coding student writing, we used word co-occurrences to form a word network (Oshima, Oshiima & Matsuzawa, 2012) for each essay and calculated the network metrics (e.g., density) for comparison across essays.

Research Context and Methods

The student essays were collected from an undergraduate general education course with students from different majors in a comprehensive university in Hong Kong where English is the medium of instruction. The course is on the topic of cultural heritage and digital technologies while the essays were submissions of an assignment on pros and cons of digitizing cultural heritage. As a typical academic writing task, this assignment required the student-writers to put forward relevant arguments and support them with evidence, experience and/or literature. Students were suggested to keep the essays around 2000 words long.

There were 199 essays (mean length = 2228.5 words) collected from two deliveries of the same course in the Fall semesters of 2018 and 2019. The course teacher assessed the essays from the aspects of addressing the topic, intellectual engagement with concepts and examples, critical thinking, and organization and language. The scores of the essays ranged from 25 to 100 (out of 100), with a mean of 75.3. The median of scores (75) was used to separate the essays into high and low performing groups. Those scoring higher than the median were regarded as high performing while those below were regarded as low performing ones.

For RQ1, we used the Hyland's (2007) metadiscourse framework (Table 1) which is both comprehensive and concise. It covers ten categories of metadiscourse markers with five under interactive and interactional models respectively. A web-based tool, Text Inspector, was used to detect metadiscourse markers based on this framework, and the frequency of markers in each category was used as metadiscourse metrics for each essay.

Table 1 *Categories of Metadiscourse Markers in Hyland's Framework*

	Category	Function	Example
Interactive	Transition	express relations between main clauses	in addition / but / and
	Frame markers	refer to discourse acts, sequences or stages	my purpose is / finally/ in conclusion
	Endophoric mrkrs	refer to information in other parts of the text	mentioned above / as follows
	Evidentials	refer to information from other texts	according to X / Z states
	Code glosses	elaborate propositional meanings	namely / such as / in other words
Interactional	Hedges	withhold writer's full commitment to statements	might / perhaps / possible / about
	Boosters	emphasize force or writer's certainty	in fact / definitely / it is clear
	Attitude mrkrs	express writer's attitude to proposition	I agree / surprisingly / unfortunately
	Self-mentions	refer to author(s) explicitly	I / my/ our / we
	Engagement mrkrs	build relationship with reader explicitly	note that/ consider / you can see that

For RQ2, we first adopted a set of keywords for each cognitive level on Bloom's Taxonomy, provided by Anderson (2001) (Table 2). Based on these terms on each level, we manually added other keywords and their different tense forms. Keyword matching was used to count the frequency of matched words on each cognitive level, forming the metrics of cognitive levels for each essay.

Table 2 *Cognitive Level and Example Key Terms*

Cognitive Level	Example Key Terms	Cognitive Level	Example Key Terms
Knowledge	recognize, recall, identify, retrieve	Analysis	analyze, distinguish, compare
Comprehension	illustrate, interpret, example	Synthesis	integrate, organize, decompose
Application	apply, carry out, implement	Evaluation	check, detect, assess, judge

To form word networks (RQ3), we first pre-processed the text data by removing stop words, stemming, and lemmatization. We then extracted pairs of words that co-occurred (e.g., "virtual" and "reality") in the same

sentence. Each essay was represented by a word network where each word in the essay was a node, and each tie between two nodes indicated the presence of this co-occurring word pair (i.e., "virtual reality"). The number of sentences in an essay containing a co-occurring word pair denoted the weight of the tie between the two nodes. For each essay, network metrics were calculated using the Python NetworkX package: density, diameter, modularity, degree centralization, betweenness centralization, closeness centralization, and clustering coefficient.

To answer the first three research questions, Pearson's correlation tests were conducted to analyze bivariate relationships between these metrics of essays and the performance scores. Classification models were constructed to classify low and high performing essays, which can reveal multivariate relationships between performance scores and combinations of metrics (RQ4). Several commonly used algorithms were applied, including Support Vector Machines (SVM), Ridge Classifier (RC), Decision Tree (DT), Gradient Boosting (GB), Random Forest (RF), and Extra Trees (ET). Ten-fold cross-validation was conducted to evaluate the classification performances which were compared across different classifiers. To compare classification power of different metrics, we also built classifier models based on each set of metrics, i.e., metadiscourse, cognitive levels and word network. Classification accuracy was used as the performance measure.

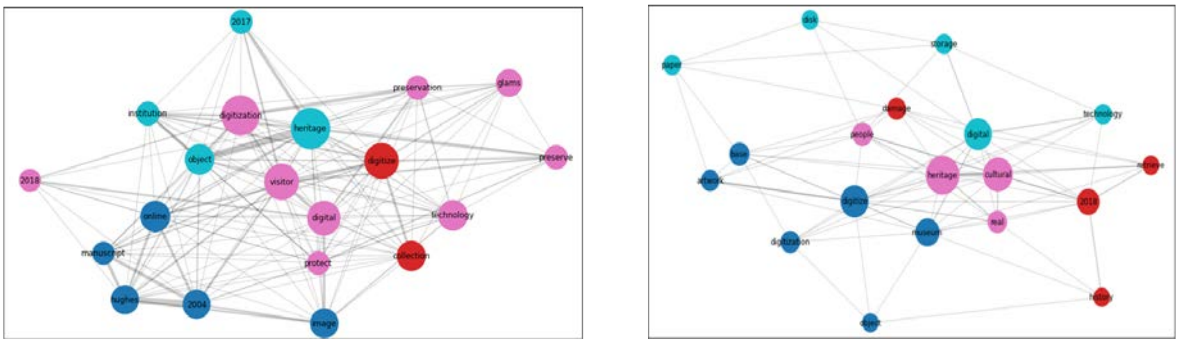
Results

The most frequently used category of metadiscourse markers was Transition (2799 times, 31% of all metadiscourse markers), followed by Hedges (1338 times, 15%), Frame Markers (1060, 12%) and Boosters (909, 10%). In total, there were 5593 (62%) interactive markers and 3534 (38%) interactional ones, indicating that students preferred using interactive metadiscourse. The usage frequencies of Evidentials ($r = 0.20$; $p = 0.004$) and Hedges ($r = 0.24$; $p < 0.001$) had mild positive correlations with the score, which corroborated the common use of nuanced stance with external support in academic writing (Hyland, 2017).

In terms of cognitive levels, Application had the highest number of keyword matches (2762, 40%), followed by Synthesis (1328, 19%) and Evaluation (893, 13%). If regarding the lowest three levels as lower-order and the highest three as higher-order thinking (Qiao & Hu, 2019), the total counts of matches were 58% and 42% respectively, where the highest two levels took 32%. These results indicate that students in general demonstrated fairly substantial higher-order thinking skills (Qiao & Hu, 2019). Correlation analysis (RQ2) yielded weak positive relationships between scores and word matches in Analysis ($r = 0.19$, $p = 0.008$) and Synthesis ($r = 0.15$; $p = 0.030$), corroborating typical requirements of academic writing (Palmer & Lomer, 2016).

The word networks turned out to be fairly dense (ave. density = 0.68 out of 1), indicating many words were inter-connected. Relatedly, the average network diameter (2.12) was small, meaning that, to connect any two words in a network, on average at most one other word in between was needed. The average degree centralization (0.04) was low, indicating the connections between words were scattered and few words dominated the connections. However, no significant correlation was found between each network metric and the performance score. To help us visually examine the networks, example networks of a high and a low performing essay are shown (Figure 1). The color of the node indicates subgroups of words generated based on their connections. The node's size is proportional to its degree centrality (i.e., no. of connections with other words), and the thickness of edges represents the frequency of word co-occurrences. As shown, the high-performing essay had more and stronger connections among words, constituting a richer network than the low-performing counterpart. Upon examining the actual words, connected words in the low-performing essay were mainly between topical words of this assignment, such as "cultural", "heritage", "digitization", and "preservation". In contrast, the network of the high-performing essay shows more varied connections such as those between "object", "visitor", "technology", and the topical words.

Figure 1 *Word Networks of A High-performing Essay (left) and A Low-performing Essay (right)*



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The classification accuracy across algorithms and metric types are shown in Table 3. The parameters of each algorithm were set with the default values and the linear kernel was used in the SVM algorithm. Results show that the SVM classifier with metadiscourse metrics and the combined metrics tied for the best performance (accuracy = 0.72). In terms of the metric types, those of metadiscourse and cognitive levels outperformed those of word network, across all classification algorithms. The comparison between metadiscourse and cognitive level metrics would involve different classifiers. Metadiscourse metrics worked well with SVM and RC, while cognitive level metrics worked better with DT and ET. Nonetheless, across classification algorithms, the combined metrics with all three metric types performed the best, indicating that different metric types might have captured different aspects of students' academic writing, and thus could potentially be used provide specific feedback on student writing in an automated manner.

Table 3 *Classification Accuracy across Algorithms and Metric Types*

Metric Type	SVM	RC	DT	GB	RF	ET
Metadiscourse	**0.72**	0.69	0.56	0.66	0.66	**0.69**
Cognitive Level	0.64	0.62	0.62	0.64	0.67	0.71
Word Network	0.52	0.56	0.51	0.52	0.54	0.53
Combined	**0.72**	**0.71**	**0.65**	**0.70**	**0.69**	**0.69**

Concluding Remarks

This preliminary study explores metadiscourse usage, cognitive levels, and word network in students' academic writing. For each of these aspects, we proposed metrics that are based on well-known frameworks and can be calculated through automated means. Results showed weak to mild correlations between few metrics and performance scores. The classification experiment indicates promising multivariate relationships between the proposed metrics and writing performance, and such relationships can be revealed through automated means (classification). Future work will continue fine tuning the parameters of the classification models for improving classification performances. We will also identify strong predictors in the classification models for providing feature-specific feedback on academic writing to students and teachers.

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Abstract: Learning scientists are increasingly shifting the epistemological and axiological basis of their research towards participatory approaches. In these approaches, tensions are viewed as sites for learning, as they reveal lines of power which can be reconfigured towards more just ends. Vignettes from a PAR project with mathematics teachers, leaders of youth-centered community organizations, and university scholars illustrate how tensions around *practicality* and *performativity* can be taken up or ignored in the research process, and the implications of these moves for new social arrangements. The importance of digging into tensions is underscored.

Introduction

Different instantiations of participatory approaches have emerged in the learning sciences, including social design experiments (Gutiérrez & Vossoughi, 2010; Gutiérrez & Jurow, 2015), community-based design research (Bang et al., 2016; Barajas-Lopez & Ishimaru, 2020l), participatory design research (Bang & Vossoughi, 2016), youth participatory action research (Cammarota & Fine, 2008) and others. A centerpiece of these approaches is a commitment to embracing tensions as sites for learning (Fine, 2018; Gutiérrez & Jurow, 2016; Mendoza et. al., 2018). Yet, it is difficult to uphold this commitment due to the discomfort it brings, as if the research is digressing and valuable time is being lost. As Fine argues (2018), however, tensions often reflect fault lines across lines of power, and are critical to revealing subjugated worldviews and knowledges.

Here, we illustrate the role of tensions in learning through two vignettes from a research study grounded in participatory action research, or PAR. The PAR project brought together high school mathematics teachers, leaders of youth-based organizations, and university scholars to theorize noticing for equity and justice in mathematics classrooms. Next, we provide a brief overview of PAR, including what we have found to be its basic commitments. Following this, we turn to vignettes to illustrate tensions, the first featuring Bang & Vossoughi (2016)'s notion of *practicality,* and second around the concept of *performativity* (Fanon, 2008). Lastly, we explore how ignoring or digging into the tensions can have implications for transformative activity.

Participatory action research

Often mistakenly treated as a methodological approach (Fals-Borda & Rahman, 1991), Participatory Action Research (PAR) is a research approach guided by a specific and unique set of epistemological assumptions and commitments. It is grounded in the participatory/cooperative research paradigm (Guba & Lincoln, 2000) characterized by an ontological commitment to systems of meaning that stem from practical, experiential, and relational activity concurrently (Heron & Reason, 1997). The centerpiece is the notion of "participation" (McTaggert, 1991) or "participatory consciousness" (Heshusius, 1994), which is "an awareness of a deeper level of kinship between the knower and the known" (p. 16). Beyond a rearrangement of subject-object relation to subject-subject relations, participatory consciousness is an embodied perspective that calls upon researchers to let go of the self and turn to the other with humility and curiosity, rather than want or need. Acknowledgement of the ways that power structures work to maintain knowers/known social positions and dominant systems of meaning-making makes PAR a critical perspective as well, focused on subverting dominant social relations and systems towards new arrangements and axiological re-imaginings (Fine, 2018).

While PAR cannot be defined through a specific set of practices or guidelines, key commitments in this research approach, similar to other participatory approaches, include: 1) historically minoritized communities are co-researchers, 2) disparate forms of knowing are brought into continuous contact with each other, 3) people, institutions, and practices are historicized, 4) tensions are embraced as sites for learning, and 5) practices are re-negotiated towards making social change (Osibodu et al., accepted).

The approach to knowledge production in PAR is aligned with the learning sciences, particular sociocultural theories of learning, that center attention to power, and the way expansive views of learning can facilitate collective learning and challenge the status quo (Mendoza et. al., 2018; Gutiérrez, 2008). Dominant and subordinated forms of knowing and doing are brought together to open a space for alternative knowledges and

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practices (Gutiérrez, 2008). However, this effort inevitably leads to tension between the status quo and the subordinated. In this paper, we focus on how tensions are viewed and valued, and the ways these decisions can constrain or expand new social imaginaries.

Tensions as sites for learning

Researchers who take participatory perspectives have identified several tensions common in their research. Below we examine two tensions -- practicality and performativity -- to explore what can happen when these tensions are either ignored or embraced. In the former, the unaddressed tension continued to plague the project and stifle productive conversation. In contrast, centering the tension of performativity in project activities created an opportunity for new learning and social arrangements, and fundamentally shifted the nature of the work.

Practicality

Participatory approaches easily reinforce dominant discourses and structures around learning and equity despite a commitment to including co-researchers centrally in the work. This can occur, for example, when the research is constrained by discourses around *practicality*. Discourses of practicality, as Bang and Vossoughi (2016) argue, can be "mobilized in ways that can deflate wider forms of social and pedagogical imagination, tethering the visioning and exploratory work of design to what is practicable given, at minimum, current disciplinary and political–economic structures" (p. 178). The focus on what is realistic given current educational structures and systems constrains the possibility of deeply interrogating and historicizing these structures, and ultimately, imagining new possibilities.

We explore a tension around discourses of practicality that emerged from the project described above, a failure to recognize this tension, and the narrowing of possibilities for shifting into new discourses. One aim of the PAR project was to co-construct a framework for noticing for re-humanizing mathematics that interrogated dominant ideologies of whiteness in mathematics education. The group read and discussed articles about ideologies (e.g., Louie, 2017), learning, and noticing in the context of watching videos of classroom mathematics teaching.

In this vignette, a mathematics teacher (MT), a community leader (CL), and a university scholar had a conversation over Zoom about ideologies present in noticing around the prompt: "What does it mean that our noticing practices often stem from dominant ideologies?" This prompt was embedded in a larger discussion about the nature of ideologies, noticing, and their connection to classroom practices.

The exchange opens when the university scholar points to the idea that one might articulate a commitment to anti-racist teaching but due to socialization could reproduce dominant ideologies in everyday interactions. The community leader responds by referring to the overarching question and article and describes the importance of recognizing that all noticing is necessarily "interested":

> CL: I think this is where you are going with this question, let me know. I know this article was talking about different frames of noticing and how you have to build habits. And we have to get into our inner subjectivities of even being able to notice. So, like, "Oh, I didn't notice that I thought of smartness in this way", or "I didn't realize that smartness could be exuded in this way by "these" particular types of students. Right? Which is why I think those frameworks are really powerful in thinking about noticing, and to be constant, incessant, and intentional. Because otherwise, we absolutely could end up failing to acknowledge that noticing is political. It's not neutral and we can't be color-blind towards it.

Here, the community leader reinforced the importance of noticing ideologies, such as the ones around smartness, in education. As a concrete instantiation of dominant ideology, the notion of smartness is powerful as it directly relates to mathematics learning, the labels that get organized for students, and broader systems of oppression. The mathematics teacher responds to this exchange by focusing on the importance of knowing subject matter to recognize the value of students' ideas. The teacher describes their own experience as a teacher learning enough mathematics content to be able to notice different forms of smartness.

> MT: …When I became a math teacher, I realized how much I didn't think like a mathematician and I didn't understand a lot of connections, and now that I've seen student work, I've seen different students produce different work. I've gotten better at not saying, "That's wrong, but I see what you're thinking. Talk to me more about it." I think content knowledge is also huge as we start to do that—notice what's smart.

Utterances by the teacher, while focused on expanding smartness, shifted the conversational space back to the practicalities of teachers' content knowledge, and away from race, ideology, and regularities in noticing. Content knowledge may support expansive noticing of students' mathematical activity, but it may also be coupled with colorblind or deficit discursive ideologies. Instead of diving into the tension that emerged in this exchange, however, the group moved on.

The tension between identifying anti-racist noticing ideologies and teachers talking about their current instructional practices is not unexpected since teachers are looking for ways to ground abstract discussions in concrete practices. This tension occurred regularly in the project discourse but was not identified by project participants until the project ended. We wonder what it might have meant to pause during moments like this one, and to think together why grounding discussions in existing classroom practices might dilute critical conversations. Instead, this tension became a reoccurring "stuck place" that constrained imagined possibilities for the group.

The next vignette is a contrasting case in which a tension that emerged for the group was taken up centrally into the project and inspired new activities and social arrangements.

Performativity

The second tension, performativity, refers to situations in which minoritized individuals are tacitly or explicitly expected to perform their racial, ethnic, or gender identities (Fanon, 2008). It is also a tension that occurs regularly in participatory work through racialized power dynamics that cause undue burden and racial battle fatigue to minoritized groups. As Patel (2015) writes:

> ...precisely because of the variances among and within dynamics, a closer attention and rigor should be paid to questions of coordinates and ongoing responsibilities and relations among peoples, places, and practices. This stance has a long history in many worldviews and even some research traditions, such a Participatory Action Research (PAR) approaches, but by and large is not common place in institutionally sanctioned research with the Western academy (p. 57).

Ongoing vigilance to positionalities, social arrangements, and patterns of interaction and destabilization of these is a focal point of participatory work. Yet, performativity is often mundane and ubiquitous as it is woven into the fabric of invisible racism, making it difficult to discern in moments everyday activity.

This vignette explores how the tension of performativity was experienced by project members, and steps taken by the team to examine them. The excerpt below is taken from an interview with one of the community leaders, who in response to a question about tensions they were experiencing as part of the project, mentioned that they were feeling the need to perform around race:

> I sometimes experienced it as a performance for me to have the discussions around race because it feels like it is expected. It's fine because it's something I embody and embrace, so it doesn't feel like it is a chore. But it feels performative knowing that expectation is placed on me. Since the summer, some healthy tensions have come up in that micro-moment when a question is posed like: "Who is going to bring up race, first?" I've been trying to play more of an educator, waiting eight seconds, instead of jumping in. The performative element comes in when I feel like I need to jump in right away.

Here, the community leader is naming the burden they experienced in deciding when and whether to bring a racial perspective to project interactions. They talk about the expectation that was "placed" on them by virtue of their body being in a space with whites, and the way they tried to navigate this tension by taking an educator point of view. The positioning of the community leaders, all of whom were BIPOC, as the ones to explain the system of racism and how it impacted BIPOC students was a regular feature of the conversations early in the project and was noted by the community leaders as a source of harm and fatigue. Instead of ignoring this tension, the project team decided to explore it further. The community leaders were interested in pursuing academic publications, so a self-selected group of team members (including all the community leaders) conducted a study on the tensions around performativity that emerged in the project. This group wrote a conference proposal, which was accepted and later co-presented (Authors, 2019). The group also presented the conference paper to the entire project team at a summer institute, and the topic became foundational to the group's decision-making, which was to take the burden of being vigilant about race off community leaders. This decision was represented, for example, in the group's design of a professional development (PD) for mathematics teachers on noticing. Instead of having

everyone participate in the PD, the group sought to protect the community leaders from once again having to perform with white teachers who were new to these issues. Thus, they designed the PD to be led by the primarily white members of the project team, with the community leaders serving as "outside experts", providing ongoing advice on design decisions. In this case, then, moving deeply into the tension led to new social arrangements for joint activity in ways that the group felt excited about.

Conclusions and Implications

Our goal in exploring tensions that emerged in a participatory action research project was to invite conversation about the importance and challenges of participatory epistemologies. As a foundation of the participatory paradigm, unearthing tensions is complicated, messy, and emotional work. Tensions often represent stuck places where lines of power are colliding and making waves in the social interaction. Because of this, we worry that learning scientists who desire smooth interactions and clear goals, boundaries, and outcomes will be hesitant to take up participatory perspectives. Researchers who adopt participatory approaches to research recognize that transformation only occurs when lines of power are made visible and recognize the potential of tensions to reveal these hierarchies. As we illustrate, when a tension around practicality was not explored, dominant discourses appeared to be maintained. When a tension around performativity was taken up, it appeared to prompt new imaginaries for the group's work together.

We believe that as learning scientists we are primed to take up participatory epistemologies, such as PAR, more centrally in our work, and that seeking out tensions will become an important way of pursuing equity and justice goals.

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Empirical Validation of Early Mathematics Learning Progressions

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Abstract: Learning progressions describe the development of sophistication in students' thinking about discipline-specific topics, and specify the intermediary phases of students' understanding that lead from foundational knowledge to more advanced thinking. The specificity of this developmental progression can meaningfully inform the teaching and learning process, including the design of classroom assessment resources. The purpose of this presentation is to describe the theoretical and empirical evidence used to specify and empirically validate the learning progressions for two early mathematics learning progressions focused on numeric relational reasoning and spatial reasoning. Empirical evidence was collected from teachers' accounts of students' development of sophistication and task-based interviews with students. The resulting learning progression served as the foundation for classroom assessments designed to provide teachers with actionable data to use in instructional decision making.

Learning progressions to inform mathematics classroom assessments

Learning progressions and trajectories articulate the development of students' understanding within a domain. They reflect a research-based sequence of how students move from novice to advanced thinking within a domain (Corcoran, Mogat, & Rosher, 2009). In science and mathematics education, significant advances have been made to articulate learning progressions and trajectories, respectively. Based on a comprehensive review of learning progressions and trajectories, Confrey (2018) noted that there are no substantial differences between the definitions of these theories of learning; as such, we use the term learning progressions herein.

Learning progressions describe the development of sophistication in students' thinking about discipline-specific topics. This sequential progression of understanding moves from students' foundational knowledge to more advanced thinking (Bennett, 2015). Progressing from foundational levels of understanding to advanced thinking involves a network of intermediary knowledge and skills that characterize the learning progression. By nature, these intermediary knowledge and skills portray student thinking as a progression toward targeted understanding. Some have likened these intermediary skills to stepping stones along a path or to hand and foot holds on a climbing wall. Both are useful analogies for describing the knowledge, skills, and cognitive processes that students exhibit as they progress from less to greater understanding in the domain.

Three important structural components help define a learning progression: lower boundary, upper boundary, and intermediary knowledge and skills. First, the lower boundary of the progression represents the foundational knowledge and skills that students need to engage with the intermediary knowledge and skills. These may be conceptualized as pre-requisite knowledge and skills or prior learnings that form the basis for new learning. Second, the upper boundary of the progression reflects a greater level of sophistication that is expected at the culmination of a specific phase of learning, and may be determined by curricular expectations (e.g., content standards), canonical disciplinary knowledge, or societal expectations of competence (Corcoran et al., 2009; Duschl et al., 2011). The upper boundary of one progression may represent the lower boundary of another. The lower and upper boundaries can be characterized as the entry and exit points of the learning progression, respectively, and flank the intermediary knowledge and skills. Third, and finally, the intermediary knowledge and skills can be conceptualized as the incremental progression of understanding that accumulates over time to represent the nature of knowing in a domain (Duschl et al., 2011), and include knowledge representations, cognitive processing, and the structure and organization of concepts. The intermediary knowledge and skills are not a rigid set of understandings that must be mastered before progressing; moreover, the nature of the connections between these intermediary knowledge and skills may differ for each person.

As part of a larger project, we articulated learning progressions for two early mathematics concepts, numeric relational reasoning and spatial reasoning. These learning progressions are intended to form the basis of instruction and assessment in Kindergarten through Grade 2. The purpose of this presentation is to describe the theoretical and empirical evidence used to specify and empirically validate these learning progressions. We used an iterative development process that included a thorough analysis of existing literature, input from experts in the field of early mathematics, teachers' perceptions of the developmental appropriateness of specific knowledge and skills, and cognitive interviews with children.

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Numeric relational reasoning

Numeric relational reasoning (NRR) is often defined as the ability to mentally analyze relationships between numbers or expressions using knowledge of properties of operations, decomposition, and known facts (Baroody et al., 2015; Farrington-Flint et al., 2007). Numeric relational reasoning is closely related to number sense, the ability to work with numbers flexibly (Gersten & Chard, 1999). For example, students use addition facts that they know, such as 5+5=10, to solve unknown facts, such as 6+5 (i.e., "Since 5+5 is 10 and 6 is one more than 5, 6+5 must be one more than 5+5."). Numeric relational reasoning is not a rote procedure that can be followed step by step. Instead, it requires reasoning through a "strategic" decision making process based on the relationships between numbers (Whitacre et al., 2017).

Spatial reasoning

Spatial reasoning (SR) – the ability to interact with, navigate in, and understand one's environment – is a foundational concept for early mathematics (NRC, 2009). Spatial reasoning is thought to have two primary components: spatial orientation and spatial visualization. Spatial orientation refers to the ability to picture objects or settings from different perspectives, such as mentally re-orienting one-self to see something from above or below. Spatial visualization is used when a child imagines an object and transforms it mentally. Evidence suggests that spatial reasoning skills support students' overall mathematics knowledge and specific concepts such as place value, relationships between numbers, and operations (Newcombe, 2010). Students with strong spatial skills create mental images of numbers and situations, which strengthens their problem-solving and number sense abilities. The links between spatial reasoning and mathematics are so strong that "spatial instruction will have a 'two-for-one' effect, yielding benefits in mathematics as well" (Verdine et al., 2014).

Evidence to empirically recover learning progressions

Because learning progressions are intended to inform teaching and learning, they must be carefully articulated and sufficient evidence should be collected to evaluate the accuracy of the claims being made about students' development of understanding. Ketterlin-Geller and colleagues (2013) suggested an iterative process for articulating a learning progression that included four stages:

1. Specify domain-specific cognitive processes, strategies, and knowledge using theoretical propositions about learning, literature reviews, tasks analyses, and empirical models of learning.
2. Organize cognitive processes, strategies, and knowledge based on plausible interactions identified through theoretical propositions about learning, student interviews, and analyses by domain experts.
3. Differentiate levels of expertise through evidence from student interviews, experimental research examining performance differences, and examination of item-difficulty hierarchy.
4. Instantiate cognitive processes, strategies, and knowledge in test specifications with input from expert review panels, alignment studies, student interviews, and psychometric modeling.

Throughout each stage, data should be gathered from a variety of sources in an iterative process.

In this presentation, we describe the theoretical and empirical process used to empirically validate the numeric relational reasoning and spatial reasoning learning progressions. For each learning progression, we report results from several sources. First, we report results from an extensive review by experts. Second, we described descriptive and inferential statistical analyses of survey results from teachers in grades K-2. Third, and finally, we report analyses from cognitive interview data with children in K-2 to identify themes in their reasoning skills.

Theoretical evidence

To articulate hypothesized learning progressions for both NRR and SR, we used an iterative process that included meetings with subject-matter experts, literature reviews, internal reviews, and external reviews with subject-matter experts. As introduced earlier, each learning progression includes lower and upper boundaries as well as intermediary knowledge and skills. Because of the complexity of NRR and SR, we divided each construct into subconstructs or targeted learning goals. Each targeted learning goal includes core concepts which are comprised of fine-grained knowledge and skill statements. These knowledge and skill statements are ordered from least complexity to greatest complexity and specify the grade level range within Grades K-2 at which they are most developmentally appropriate.

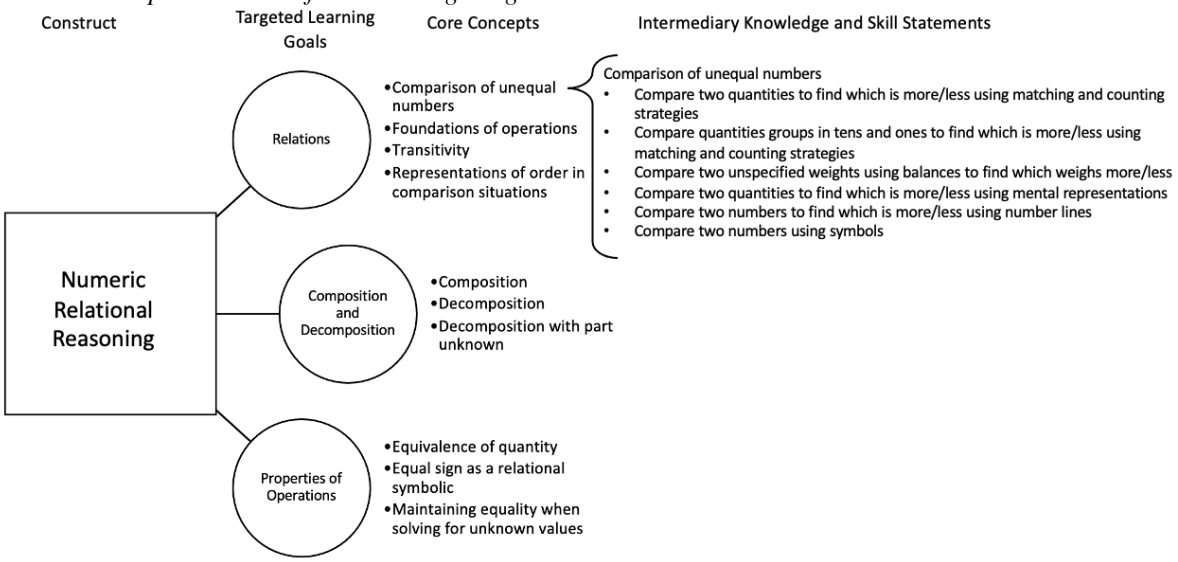
For NRR, we identified three targeted learning goals that are further divided into core concepts. For NRR, the three core concepts are (1) relations between quantities, (2) composition and decomposition of quantities, and (3) properties of operations. Each targeted learning goal is further divided into core concepts. For example, relations includes (1) comparison of unequal numbers, (2) foundations of operations, (3) transitivity, and (4)

representation of order in comparison situations. Within each core concept, multiple knowledge and skill statements that make up the intermediary phases of learning. The SR learning progressions include two targeted learning goals: (1) reasoning spatially within objects and (2) reasoning spatially between objects.

This structure is displayed for NRR in Figure 1.

Figure 1

Example Structure of the Learning Progressions



Study 1

After an initial draft of the learning progressions were articulated for both NRR and SR, we conducted cognitive interviews with children in Grades K-3. Cognitive interviews are grounded in psychological interviewing methods as a way of investigating participants' cognitive processes and understanding how participants store and structure their knowledge in long-term memory. During the interviews, participants work on tasks that are often open-ended and require multiple steps to complete. The interviewer asks in-depth questions designed to better understand the participant's thinking.

We included students in Grade 3 to test the upper boundaries of the learning progressions. For NRR, we interviewed 32 students across two timepoints for a total of 64 interviews. For SR, we interviewed 15 students across two timepoints for a total of 30 interviews. Interview protocols were strategically designed to provide (1) tasks aligned with each of the intermediary knowledge and skills in the learning progressions, (2) scaffolding questions, and (3) reasoning questions to better understand students' thinking. To collect confirming and/or disconfirming evidence, all students had an opportunity to respond to each task, regardless of the hypothesized developmental appropriateness. We examined correctness by skill statement by grade level to examine if the ordering and grade-level designations of our hypothesized learning progression could be empirically recovered. Qualitative analyses were also conducted to investigate if additional reasoning concepts were used by students that were not captured in the learning progressions.

Quantitative and qualitative analyses of cognitive interviews provided important information on students' conceptualization, students' prior knowledge to work through the content, the connection between concepts, and at what grade level students demonstrate emerging and mastery level of understanding. The results from the analyses of cognitive interviews provided us with evidence to empirically recover the NRR and SR learning progression and make some adjustments.

Study 2: Surveys with teachers

Another source of validity evidence comes from surveys administered to teachers in Grades K-2. We administered separate surveys for each learning progression. Educators are uniquely positioned within the teaching and learning process to provide meaningful input; Educators are very familiar with the grade-level curriculum and can often pinpoint areas where students tend to struggle. Moreover, teachers may be able to anticipate students' errors because of their recurrence over time and across groups of students. As such, educators may have insights into student learning that can help verify the structure of learning progressions.

Approximately 300 teachers responded to the survey on NRR, and 200 teachers responded to the survey on SR. The survey presented each of the intermediary knowledge and skills within each learning progression and

asked teachers to consider the grade level taught and respond about the developmental appropriateness of the skill, whether the skill was a focal or prerequisite skill, and how often and when they teach the skill during the school year. We investigated the alignment between our hypothesized learning progression and teachers' conceptions about the developmental appropriateness of the skill statements. Survey results yielded meaningful information to support or modify the hypothesized learning progressions for both NRR and SR.

Conclusions

In this presentation, we describe the theoretical and empirical evidence used to specify and empirically validate the learning progressions for NRR and SR. For each construct, we began by thoroughly specifying hypothesized progressions using input from subject-matter experts, literature reviews, internal reviews, and external reviews with independent experts. To evaluate the accuracy and sufficiency of the hypothesized learning progressions, we collected evidence from various sources, including cognitive interviews with children and surveys conducted with teachers. These data contributed to an iterative process in which revisions were made to the learning progression after each phase of data collection was complete. The process and resulting learning progressions will be disseminated during the presentation.

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"It Appears to Be a Free-for-All": Designing for Audience Agency in an Immersive Theatre Environment

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Abstract: While there have been a handful of learning scientists who have championed research in theatrical spaces, there is still so much more to learn from these incredibly rich learning environments. *FORTS* is an immersive theatrical production and informal learning space where participants *actively* co-create knowledge through improvisational and collaborative processes. It was developed by a team of theatrical designers in much the same way that learning scientists design learning environments—through iterative cycles of design. This qualitative case study examines what the lead designer of *FORTS* learned through engaging in its design and implementation. A narrative of the design process was constructed from an interview with the designer which discussed her goals, original design decisions, expectations, feedback, reflections, and iterative design decisions. The theme of *agency* emerged as foundational to the designer's iterative process and to her shifting understanding of the relationship between immersive theatre design and its participants.

Introduction

This past year, the *Journal of the Learning Sciences* published a special issue entitled "Learning in and through the arts" addressing the need for more extensive research in artistic disciplines. However, even though the articles promoted arts environments as "valued sites for learning" (Halverson & Sawyer, 2022, p.1) and explored key disciplinary practices and socio-cultural learning processes, none of them presented work from theatrical learning environments. While there have been a handful of learning scientists over the decades who have championed research in theatrical spaces (Sawyer, 2003; Halverson, 2010), the fact remains that there is still so much more to learn from these incredibly rich learning environments. The present paper seeks to contribute to the clear need for investigation in the arts, specifically in the discipline of theatre.

FORTS: Build Your Own Adventure! is an example of an immersive theatrical production, an increasingly popular form of theatre which breaks down the separation between audience and actors and expands the possibilities of what is considered "playing" space. Unlike more traditional types of productions in which audience members *passively* receive information from the stage, immersive shows serve as informal learning spaces where participants *actively* co-create knowledge through improvisational and collaborative processes. In *FORTS*, audience members *replace* the actors and engage with the constantly changing environment in which they are immersed.

FORTS was developed by a team of theatrical designers in much the same way that learning scientists design learning environments—through iterative cycles of design, implementation, analytic reflection, revision, and retrospective analysis (Cobb et al., 2003). Since there is considerable wisdom often captured in designed objects and activities that is never made explicit (Schon, 1988), researching designer learning can help uncover and examine that wisdom. The purpose of this case study (Stake, 1995) is to explore the learning of the lead designer of *FORTS*. Specifically, this paper asks: *What did the designer learn through engaging in the design and implementation of FORTS?* Answering this question will help us better understand the kinds of learning that happen in immersive theatrical environments and will also help us understand what designers learn when they engage in iterative design processes for both these and similar types of spaces.

Theoretical framing

Machon (2013) suggests key features of immersive theatre are the centrality of audience members, the participants' physical immersion in a sensorial world, and the prioritization of space and place. She explains there are usually either tacit or sometimes explicit "rules of engagement" which guide participation. White (2013) calls the designers who create these environments "procedural authors" who decide the extent of audience agency within an event through setting limits, or "horizons of participation," and offer suggestions to navigate interactional possibilities within those boundaries. Nibbelink (2019) considers the role of the audience in an immersive performance as one that actively and continuously joins with the "compositional forces" in the piece to construct the event itself.

Given these features of immersive theatre, this paper takes up two related questions: How do designers create the learning spaces and set the stage for audience agency? What do they learn from iterative cycles of designing such spaces? In many respects, the *FORTS* designer confronts the same challenge that learning sciences

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researchers confront when they build learning environments intended to promote students' active involvement in the construction of knowledge. That is, in an immersive theatre production, the traditional role of audience member as spectator is intentionally disrupted. Audience members are asked to become performers (Heim, 2015). For example, people may be asked to become voyeurs to a private scene between two actors, make choices about where they want to go next in a giant warehouse full of performers, or even co-create the narrative of a play as it is being performed. Regardless of how the role of audience participant is designed, "the motive is consistent: to give agency so audiences can...choose their own adventure" (Tran, 2013, p. 31). Challenges for *FORTS* designers are similar to those of learning scientists and teachers in formal learning environments: What sorts of tasks, materials, and scaffolds support active engagement on the part of students/audience members?

Methods

The bounded case (Yin, 2018) and the focus of this study is the lead Creator (C) of *FORTS.* An hour-long, semi-structured reflective interview was conducted with C. Questions focused on C's role in the design process; her goals, design choices and their rationale; problems she encountered and her solutions; changes to the design over the years; her perspective on audience member participation including specific expectations; and any final reflections. The conversation covered *FORTS*'s three-year run and four variations of *FORTS* design: an "Original" *FORTS* show designed for both children and adults to attend together; Birthday Parties for a birthday child and their guests; Toddler Takeover Days for very young children and their adults; and Adult Nights for adults only. The basic *FORTS* design is framed as a journey from an ordinary world into a magical one. The 45-minute show takes place inside a black box theatre with sofas piled with pillows and cardboard box pyramids placed throughout. Adventure Guide facilitators cued by clock chimes run the practicalities of the performance such as when and how interactive objects (crayons, sheets, clothespins, and flashlights) get introduced. Lights change from day to night and back again to day. Music and sound effects such as doorbells, dogs barking, and crickets get played over a sound system. The one element that changes for each show is who is in attendance.

Analysis. A first phase of analysis focused on identifying C's design process. This phase involved *a priori* structural coding informed by Edelson's (2002) design decision categories (design procedure, problem analysis, design solution) as a framework for initial inquiry. The transcribed interview was parsed and tagged with respect to these design decision categories. The second phase of analysis focused on further parsing C's design process using six categories that reflect different phases of the design process. **Goal statements** (n=17) were identified as C's statements regarding desired outcomes of the design. **Original design decisions** (n=28) captured the original set of decisions regarding the structure and elements of the design. **Expectation statements** (n=15) reflected how C anticipated the audience might participate and behave. **Feedback statements** (n=27) were identified as comments about audience enactment. **Designer reflections** (n=27) were the designer's comments about her observations. **Iterative design decisions** (n=27; design changes=10, no changes=17) were identified as C's decisions whether or not to make any changes to the design following specific feedback and reflection comments. In a third phase, a narrative of the design of *FORTS* was constructed from design decisions, statements, and reflections that were related in space or time in the discussion of the *FORTS* design and enactment. A final analytic phase captured shifts in C's thinking. Throughout analysis, the author contacted C with follow-up questions when necessary.

Findings

Overall, the theme of *agency* emerged as foundational to the entirety of C's design process and to her understanding of the relationship between immersive theatre design and its participants. Initially, C conceived of *FORTS* as an environment that afforded an expansive view of audience agency. However, C's iterations, in response to design problems during implementation, set greater limits on audience actions in the space. Additionally, over the course of several years, C observed consistency in how people participated in *FORTS.* As a result, she then experienced shifts in her thinking about how much control the *FORTS* design exerted over audience members' actions, recognizing ways in which the design actually served to structure participation and limit audience agency. The specifics of the evolution of C's learning about agency in the context of *FORTS* are elaborated in the remainder of the findings.

Goals, design decisions, and expectations

While C had multiple goals for the show, a foundational one and the "kernel of the question that turned into *FORTS*" was a desire to support audience agency. She initially conceptualized agency as giving people "complete" and "total control" over the space, allowing them to be fully in charge of their interactional choices. In conjunction with the design team, C made design decisions which she hoped would facilitate audience agency. These decisions included: eliminating professional performers, and instead having audience members be the actors in the space;

making fort building the show's key activity as it was assumed to have a low barrier to entry; picking objects for people to play with that would be familiar and also open-ended for different uses; establishing two "boundaries" for the space that covered all behavior: *Be Safe and Be Kind*; and determining when and how Adventure Guides would "wordlessly" and "sneakily" leave items around the space to be discovered.

With these goals in mind, C designed with the expectation that any number of possible things might happen because every performance would consist of a different group of people, each with different personalities who might engage in an endless number of potential activities. She worked hard to "release" the traditional expectation of a "good audience" in that as long as people were safe and kind in the space, they could choose to interact with the design however they wanted. Despite "going in with a theory and the trust that audiences are going to be great," C admitted that she "really had no idea" how people would participate and was open to the possibility that the *FORTS* "experiment" might fail.

Figure 1
The FORTS *environment built by audience members*

Outcomes, reflections, and revisiting design decisions

C discussed several design iterations which were instituted in response to observing how various audiences interacted with the design. These changes, in contrast to her goal of supporting audience agency, served to set limits and provide more guidance for interaction. One such example is when the designer changed the ending of *FORTS* after a first preview weekend. The initial ending "just used to end with the end of the day," C explained. The lights came up, the sound went away, and audience members were expected to leave behind or knock down what they had created and played with. C noticed how upset children got at this moment and described how hard it was to get people to leave the space. "It was just a really terrible ending," she acknowledged. She wondered how to create a sense of ending for audience members with the absence of a formal curtain call. This design problem was solved by changing the ending in numerous ways: playing a celebratory song and having an Adventure Guide lead a dance party to it; more carefully crafting the "language of leaving"; and creating a ritual of "resetting the space" which encouraged people to rebuild the initial box pyramids together before departing.

Furthermore, after reflecting upon *FORTS* over three years, C was surprised how the enactment of the design seemed to hit the "same notes every time." There were multiple instances where she mentioned how consistent the show felt and how "similar dynamics crop[ped] up." C then mentioned receiving feedback from educators who attended the show and commented on how the design seemed to guide moments of participation. These combined observations contradicted what she had originally designed for and expected to see at *FORTS.* Prior to this, C had not fully recognized the power of the show's design to structure audience actions. But her thinking shifted when she began to see how the design exerted more control over the audience than she had previously envisioned. For example, C suggested that the "very deliberate" and "very crafted" way of how Adventure Guides wordlessly introduce new elements into the space—sneakily scattering them around for participants to discover - held a "tighter structure" than she had previously thought. C also mentioned the overall "container" of the production—the "one script, one aesthetic ethos, vibe"—which may have also facilitated consistent enactment. In contrast to how C originally conceived of *FORTS* as a "total free-for-all" she now says it "feels like, looks like—it *appears* to be a free-for-all experience."

Discussion, implications, and conclusion

Throughout the design and implementation of *FORTS*, C's understanding of the relationship between design and agency shifted, both implicitly through design iterations and explicitly as she recognized how the design created

consistent enactment. The discrepancy between the conception of agency that C sought to support and the structured design decisions that she made highlights the complexity of negotiating this design tension. C's altered understanding of the relationship between audience agency and the design of *FORTS* aligns with what scholars of the immersive theatre genre also assert. Gabelmann (2019) notes that even though audience member roles are changed in this type of theatre, the agency the shift in roles creates is "often illusory." She also suggests that: "Though it seems as though the audience has the power to completely control the narrative, this is rarely the case in immersive theatre. More often than not, spectators follow a series of guidelines that covertly shape their experience of the piece" (p. 26). Many of C's design decisions acted as invisible boundaries or a "series of guidelines" for audience members to follow—the choice of items to include in the show, how they were presented, the day-to-night lighting progression, the sound of a doorbell ringing, even the name of the show—every choice helped to guide audience members to a favorable outcome in their participation at *FORTS*.

While the tension between providing structure and supporting agency has been examined by scholars in the past, the present findings provide an important reminder for continued exploration of this topic. By C's own admission, an essential goal of hers was to fully empower participants in the *FORTS* space. Thus, even a professional with years of expertise in participatory theatre *still* had much to learn about power relations among herself, her design, and the audience.

This analysis has several implications for designers who design with agency at the heart of what they do, including teachers who value student-centered classrooms and learning scientists who attend to power in their designs of learning environments. Supporting agency is an issue to be aware of not just during the conception phase of a design process, but one that is in constant negotiation throughout the entirety of the design process. Additionally, *agency* can mean different things to different people at different times. Therefore, maintaining clarity regarding the specifics of what agency means in a designed environment throughout the design process is crucial to those who value centering learners in their work. For people who design with others, it might be beneficial to explicate what agency means for the team collectively rather than assuming everyone shares the same definition. Based on a common conception of agency, designers can then identify what would count as evidence of audience agency thereby providing agreed upon evaluative criteria.

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Development of Students' Science Identities in a Biology Classroom: A Learning Community Approach

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Abstract: This paper describes the objectives, theoretical framework, design and outcomes of a research study conducted with 55 students in a Grade 11 Biology classroom in a diverse urban school in Ontario, Canada. Students worked as a learning community to explore and discuss authentic case studies and datasets, evaluate the credibility of resources, participate in scientific argumentation, and explore science-related careers. The year-long curriculum, co-designed with a teacher and guided by a theoretical model of Knowledge Community and Inquiry (KCI), engaged students in co-constructing a collective knowledge base, supported by technology environments, where students made connections across course topics, connected to real-world issues, and explored science careers. Through the Career Exploration activity, students learned about their peers' interests and became more knowledgeable about various careers; through their discussions, students were motivated to further explore their own science identities.
Keywords: learning community, collaborative learning, science identity

Objectives

A substantial research literature has addressed the benefits of a learning community approach, such as developing and advancing a shared collective knowledge base (Bereiter & Scardamalia, 2014; Slotta & Najafi, 2013) and supporting inquiry-oriented discourse (Fong & Slotta, 2018). This approach emerges from the Fostering Communities of Learners model of a community in which students use real scenarios and are supported by deep disciplinary content, and where students share expertise with their peers (Brown, 1997). In a science classroom, students are engaged with their peers in a model of a scientific community (Bielaczyc & Collins, 1999). Contributing to a shared and co-edited knowledge base, with a support of a technology environment, is fundamental for a learning community described in this paper (Fong & Slotta, 2013; Slotta & Najafi, 2018). By engaging in a model of a scientific learning community, students develop collaborative skills, create new ideas and learning opportunities for their peers (Song, et al., 2010). Through conversations during group work and participation in authentic scientific activities, students develop their science identities, including specific topic interests, and potential career directions (Thoman et al., 2007). This study examines the context of a scientific classroom learning community, and how students' interactions with peers, materials and activities can foster the development of career identity. Our main research question: "How does learning in a collaborative environment supported by the KCI Model and technology contributes to the development of students' career identities?"

Theoretical foundation

The notion of identity is described as an individual's sense of self within a group or a content, developed through interactions with others, which is evolving and can be regulated by culture and context (Leary & Tangney, 2012; Roeser et al., 2006). It has been shown that social context can improve an individual's motivation -- not only by providing support, but also contributing to an individual's interests (Thoman et al., 2007). Under the interactionist approach (Kim & Sinatra, 2018), it is the interaction between a student and the context that encourages or restricts the student's formation of science identity. Others suggest that interpersonal processes influence the self-regulation of motivation (Thoman et al., 2007). For example, if a student feels that other classmates are interested in a science subject, they may also express a higher interest – leading to the notion of an interest quorum to be established (Nazari et al., 2017). The role of conversations has also been studied as a means of gaining value about topics, where students can socially verify and build their perception of an activity as interesting and valued (Nolen, 2001). Moreover, in collaborative activities, students jointly develop their understanding of the topic and achieve shared representations of it (Clark, 1996). Talking with others about one's educational interests and receiving social recognition during these conversations have been shown to increase interest in science careers, even more significant for women than men, in particular for women with a lower science identity (Jackson et al., 2018).

Method

Our study explored how students' interactions within a classroom learning community, including authentic inquiry tasks, can impact students' science identity formation. For the development of this year-long curriculum,

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design-based research (DBR) methodology was applied: the curriculum was co-designed with a teacher of a Grade 11 Biology class consisting of three cohorts, totaling 55 students. Students worked as a class, in groups, and individually to explore case studies and datasets, evaluate the credibility of resources, participate in scientific argumentation, reflect in personal journals, and explore science-related careers. We applied the theoretical model of Knowledge Community and Inquiry (KCI), in which students construct a collective knowledge base and engage in scaffolded inquiry activities, with accessible learning outcomes (authors, 2018). Throughout the semester, students contributed their ideas to the emergent collective knowledge base and built on their previous ideas.

Through the course, students explored primary and secondary resources (i.e., scientific journal articles) concerned with the topics of the five units of the curriculum: Genetics, Biodiversity, Evolution, Animal Systems, and Plants. We also added a cross-cutting diet and nutrition theme. Guided by the KCI model, a series of inquiry activities was designed, using a variety of technology environments and materials to support students' collaborative work. Among those activities, we designed a Career Exploration activity where students collectively built knowledge about and connections amongst a wide range of science-related professions. Exploration of science careers was a focus of at least one lesson in each unit, in which students contributed to the community Career Folder (on Google Drive), collaboratively editing Google Docs and adding details to the careers posted by other students and/or adding a document with a new career. Up to six students from three cohorts could contribute to each career page. If more than six students wanted to contribute to the career, they were encouraged to create another document with the same career. Working in groups and discussing their choices, students gradually developed the Career Knowledge Base, which served as a platform for further discussions and personal exploration of potential science careers and their connections to other careers. While current study is completed, we are planning its iteration and we are also aware of the study limitations. The DBR is a complex process which includes many interconnected elements. Brown (1992) described the difficulty of conducting design experiments in situ, rather than in the controlled conditions where the designer has control over the task and other variables. When using the DBR approach, authors should provide descriptions of the contexts, theoretical framework, details of the design, and their impact on participation (Barab & Squire, 2004), included in this publication. Besides, authentic learning contexts are unique to each classroom, which is why findings of design-based studies may have a limited generalizability, but offer insights for other researchers (Fong & Slotta, 2018).

Data Sources

Data included tables, documents and personal journals created by students individually, in groups and as a class. Co-constructed tables and documents to which students contributed their responses represent a collective knowledge base built during the school year. In the Career Activity, students built a Career Knowledge Base which served as a platform for further discussions and career explorations by students. Students researched and added to the career description, made connections to other professions, explored university/college programs that would support the career, researched the level of demand for each career and the starting salary, and added interesting videos and articles. They also discussed how various careers related to each of the curricular unit. Students' answers to science identity questionnaires were also collected. The questionnaires asked three central questions: 1. What are some interesting career directions that were connected to this course, which you may not have considered before? 2.What is your current thinking about a career? Was it influenced by anything you encountered in this course, and if so, how? 3. Should teachers make a stronger emphasis on career connections within their courses? How can we help students keep thinking about their career?

Findings

Through exploring different careers and contributing to the class Career Knowledge Base, students built their understandings of various careers in science and of their own science identities. In their Career Pages (23 documents created), students identified connections to almost 100 different professions. The top three careers of interest were Neurologist (7 students contributed), Oral Surgeon (6 students), and Forensic Scientist and DNA Analyst/ Pharmaceutical Chemist (5 students per each). The maximum number of words describing a career in a collaboratively created document was 1432 (the career of Neurologist). Students connected their careers of interest to many other careers (e.g., the career of Epidemiologist was connected to 19 other careers). Some of the career connections are shown in Figure 1. Also, 60 links to various resources related to future careers were added by students. Pages on less prominent professions, such as astrobiologist, myrmecologist and genetic counsellor, were also created.

The Career Exploration activity helped students gain insights into specific career interests or discover careers of which they had not been previously aware. They also became informed about qualifications required to pursue certain careers. In the process of the analysis of students' responses to the questionnaire, several main themes were revealed (Table 1). Selected students' quotes regarding their participation in the activity are provided

in Table 2. The Career Exploration activity, including collective knowledge work and discussions about careers, was emphasized by a number of students as helping them see connections between different science fields, industry and other fields, such as business or law, and become interested in exploring various careers. Students indicated that the section where they explicated college and university pathways for each science career was very valuable. At the end of the study, some students still had questions about careers, such as about workload for certain careers, career integration and job market, changing career, and how technology will affect future jobs. Collaborating with each other as a classroom learning community, through the exploration and recognition of their peers' interests, social verification and building their perception of the activity as valued allowed students to develop their interest in the topics, which is believed to be a primary driver of science identity (Maltese & Tai, 2010).

Scientific and scholarly significance

This study demonstrates the potential of a learning community approach achieved through a collaborative student work by progressively adding to and making use of a collective knowledge base, through discussions in groups and as a class, in helping students to start developing interest to and knowledge of many science careers, and contributing to the formation of their science identities. This study contributes to the literature on the factors influencing the development of science identities and will be of interest to a broader educational community. Moving forward, we are interested in deepening our understanding of identity formation. Future work will explore the notion of Funds of Identity, and the various forms of intersections that may occur within a classroom learning community.

Figure 1

An example of career connections built by students in the Career Exploration activity

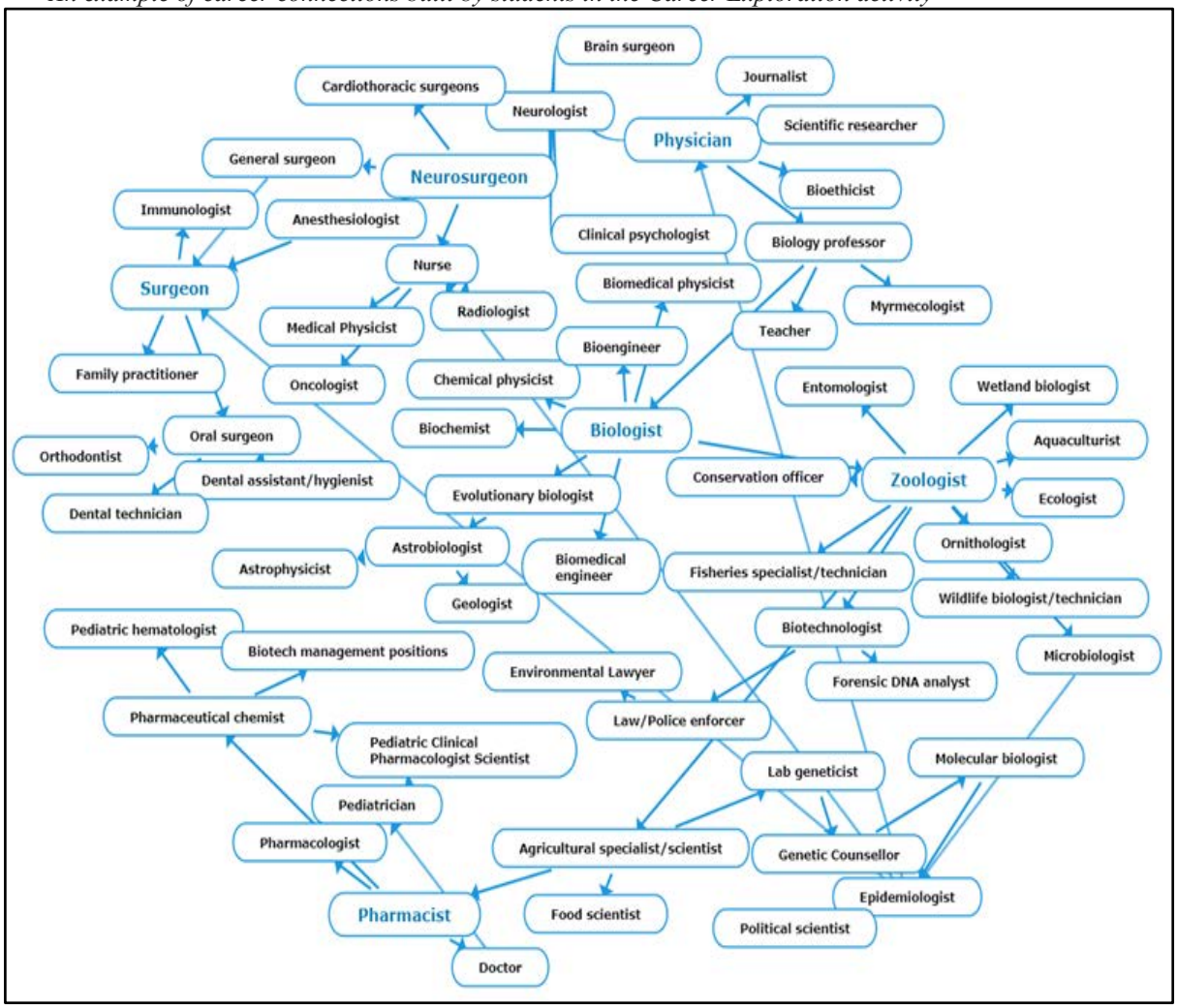

Table 1
Main themes identified in students' questionnaires

- Looking at everyone's else work gave students more insight about the career. - Students were interested in the area in general but after their participation in the activity they could narrow their interest to certain careers. - This activity has informed students about the qualifications and soft skills required for various careers. - This activity showed students many different ways how biology or other disciplines can be applied to the real world and industries. - Even if students were not interested in a science career, this activity helped them plan their future secondary education and job.

Table 2
Selected students' quotes about science career exploration activity

- Researching the different careers and looking at everyone else's work has given me some more insight. - I thought I would never venture into the STEM field. Everything looked too complicated. However, today after researching about neurology, I now realize how fascinating it is. - The ideas generated from today's class have inspired me to think about my own career path. - I wanted to get a job in the justice system, but for me the only viable option was to be a lawyer. Being a forensic DNA analyst keeps me in that field, while also being able to continue studying STEM. - It also impressed upon me the need for some planning for a future career and a strong friend network and communication skills to find new jobs and succeed in the workplace.

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Insights about Helpful Covid-19 Learning Resources from Caregivers of Elementary School Children

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Abstract: Media resources are a central component of children's learning ecologies in the U.S. However, much of the coverage of the Covid-19 pandemic came through channels for adult audiences, and the "infodemic" added to the difficulty of interpreting information from media sources. This paper analyzes learning resources collected in a diary study conducted with 109 families with elementary school aged children at the beginning of the Covid-19 pandemic. Findings show that the resources caregivers found useful in communicating with their children about the pandemic are intertwined with their life experiences and interpretation of their children's information needs.

Introduction

> When COVID first started we were listening to the news on the television nonstop. So my girls kept seeing the news and what was going on. It was challenging for them because I would give them an answer to a question and literally rules and guidelines changed within an hour on certain days. *Layla, mother of 5-year-old Maia and 8-year-old Rachel*

When Covid-19 arrived and sparked a wave of lockdowns, parents and other caregivers (e.g., grandparents, adult siblings) had to decide what they were going to tell their children, how they were going to respond to their questions about the changes in their routines, and how much to shelter their children. Media resources such as national and local news outlets, government press conferences, and social media were flooded with coverage of the pandemic. In addition, an "infodemic" of conspiracy theories, misinformation, and fake news about the coronavirus and Covid-19 erroded public trust in health officials and spread fear and feelings of hopelessness around the world (The Lancet, 2020). Access to reliable health information and the ability to apply that information is a critical component of health equity (Gonzalez et al., 2020). Since families are mediators of both children's health learning (e.g., Squires et al., 2012) and interpretation of media (e.g., Takeuchi & Stevens, 2011), unpacking how families were using media resources to learn about Covid-19 is critical to understanding how families adapted to the pandemic.

Using digital media with young children is a contentious topic, with debates about the benefits and dangers of screen time cast in moralizing language. For years experts in child health, such as the American Pediatrics Association, have encouraged caregivers to limit their children's interactions with digital media (Lemish, 2021). Yet years of research on children and media demonstrate that well-designed media can promote learning (e.g., Sesame Street) and social interaction (e.g., cooperative multiplayer online games and virtual communities), and that joint engagement with media is a productive form of collaborative learning that can arise between caregivers and children (Takeuchi & Stevens, 2011).

To understand how caregivers approached learning about the pandemic with their families, this paper examines how 109 families of elementary school children were exploring pandemic related topics and concepts through the use of social and media learning resources. In this context, "media resources" include both information media designed for adults as well as educational programming for children. Given the dynamic nature of the infosphere and the limitations of our static data collection method, this paper does not aim to analyze the content of the media learning resources, but rather document caregiver perspectives and reflections on using media to learn about the pandemic with their families.

Methods

The analysis presented in this paper considers the research question: What resources were caregivers using to learn about the pandemic, and which ones were most helpful for talking to their children about the pandemic? The data come from a larger diary study conducted with 109 families from 28 states across the U.S. over the course of two weeks in May 2020 using *dscout*, a mobile qualitative research platform (Barron et al, 2021; Pozos et al., 2022). The participants were recruited from dscout's panel. The caregivers were mostly women (67%) with

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children in public elementary schools (84%). Racially, 55% self-identified as white, 16% as Black, and 15% as Latinx, 9% as Asian, and 4% as Middle Eastern or North African.

This paper considers data from one portion of the five-part study where participants shared how they were learning about the pandemic with their children. Participants provided a snapshot of their Covid-19 learning ecologies (e.g., Barron, 2006) by responding to checklists of pandemic learning topics and sources, and providing examples of learning resources they found most helpful. The checklists were analyzed with statistics by family demographics. Given the lack of a unified response to Covid-19 and the speed at which the news cycles were occurring at the time of the study, we felt it was important to differentiate between the resources caregivers were generally accessing compared to the ones that they found to be most helpful for talking to their children about the pandemic to give us insights that could help with the design of future crisis learning materials. The examples of learning resources were cataloged, specifying the name of the source, type of source (e.g., YouTube video, CDC website, PDF, family member), the caregiver's description of the resource, and why (if explicitly stated) they chose to use that resource in particular. Types of resources were standardized and one researcher independently applied the codes to the log of resources in order to understand the frequency with which the types of resources appeared in the sample. In total, 272 examples of learning resources were given by the caregivers.

Findings

While all caregivers indicated using at least one resource, there was a lot of variation in response to the prompts with a few caregivers explaining how they try to avoid Covid-19 being the focus of their day, others describing how their children bring sources to them to talk about, and yet others who wanted to help their children understand what was happening, but were not sure how to go about doing so.

Topics and sources families used to learn about Covid-19

Overall, the topics and resources that caregivers reported using with their children to learn about Covid-19 revolved around accessing information that they needed to navigate the "new normal" of life in the pandemic. The topics that the caregivers most frequently reported their families learning about were how to protect themselves (91.7%), public health orders (88.1%), what Covid-19 is (73.4%) and how Covid-19 spreads (71.6%). About half of the caregivers indicated that they were learning about the symptoms of Covid-19 (55%), the economic impacts of the pandemic (43.1%), and the global outbreak (40%). No meaningful differences were found by family demographics.

The most frequent types of sources caregivers used to learn about the pandemic were family discussions (85.3%), television (68.8%), social media (57.8%), and the CDC website (38.5%). Approximately one-third of caregivers were consulting local government websites (35.8%), online searches (32.1%), friends (32.1%), family members (31.2%), or teachers (29.4%). Again, no meaningful differences were found by family demographics.

Media resources caregivers found most helpful

Overall, caregivers found resources that helped them keep up to date and find explanations for questions that they and their children had to be the most helpful (see Table 1). TV news providers, websites with articles about Covid-19, the CDC communications channels, popular cartoons, and family/friends were the resources most frequently listed by caregivers to meet this need. The types and topics of the questions the caregivers noted their children asking and the conversations they sparked are the subject of a separate paper (Pozos, 2022). However for the purposes of understanding this analysis, it is helpful to know that 75.2% of caregivers reported their children asking them about daily pandemic disruptions, such as why schools were closed, when they would be able to visit family and friends, how long the pandemic would last, and why the families made changes to their routines. Many caregivers were challenged to provide satisfying answers to these questions.

Table 1

Media Learning Resources Reported Most Helpful Across All Families, by Overall Frequency

Count	Resource	Reasons caregivers found the resource helpful
News Resources		
60	TV New Providers - National, local, and global cable news outlets (e.g., CNN, Fox, NBC Nightly)	Keeping up to date on outbreaks and public health orders
32	Websites (articles) - Includes newspaper websites	Keeping up to date with latest outbreaks and finding

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	(e.g., NYT, Daily Courier, Washington Post), educational providers (e.g., NewsELA), medical providers, and unspecified online articles	answers to questions; for caregivers of young children, helpful to be able to find information and then relay to their children
11	Radio / Podcast - NPR, local stations, BrainsOn!, The Daily	Providing a family-friendly way to listen to Covid-19 info in the car or around the house
10	Unspecified news media - Mentions reading or watching the news generally	Keeping up with trusted news media sources; may also be a daily practice for the caregiver
Educational/Entertainment Resources		
22	Popular cartoons / shows - BrainPop, Daniel Tiger, Sesame street, Doc McStuffins, LEGO Batman	Finding age appropriate messaging about disease spread and prevention for their children
16	YouTube videos - Includes general "YouTube Videos" such as influencer accounts, educational videos, "kid-friendly" videos for younger children	Finding explanations about how viruses spread and for learning about how others are experiencing Covid-19
5	Other videos - Videos from specific websites, not found on YouTube (*Only reported from caregivers of 5-8 year olds*)	Finding explanations and demonstrations of the importance of handwashing that the young children understand
5	Books/Print Media - PDF storybooks about Covid, public health flyers	Providing interactive conversation starters
Social Resources		
18	Family / friends - Family members who are health care workers, children sharing with each other, the participants identifying themselves as resources	Clarifying and explaining the pandemic to children in accessible language
15	Social Media - Twitter, Facebook, TikTok	Following the news and family/friends experiences
11	School communications - Emails, announcements, morning messages	Providing educational content about the virus and personal protection
6	Teachers / Doctors - Child's teachers or doctors (*Only reported from caregivers of 5-8 year olds*)	Answering questions and reassuring children. Some teachers give assignments to learn about the virus or recommend videos
Institutional Resources		
32	CDC communications - Website, Facebook posts, YouTube channel	Explaining and clarifying trustworthy info and recommendations in text & visual form
6	Governor & White House Briefings - Specifically the governors of NY, NJ, VA, KY	Keeping up with the news at a state level. Learning what other states are doing.
6	Government websites (not CDC) - State or federal websites	Accessing simplified public health information with visuals
Other		
10	Email newsletters, Scripture, local news paper, web searches, local Covid-19 taskforce, lists of links	

Discussion & conclusion

Analysis of the learning resources that caregivers reported using to learn about the pandemic with their families showed caregivers drawing on a range of national media, institutional, educational, and social resources to make sense of the rapidly changing landscape of the early pandemic. The resources that ended up being the most helpful for them to use when discussing the pandemic with their children varied by the age of the children and the caregivers' perceptions of what information was necessary and appropriate to share with the children. Unpacking how caregivers interpret their children's information needs and what role media play in them also helps us think about what caregivers really mean when they say they are taking a specific approach, such as sheltering their children. There is also more to learn about how caregivers manage their children's access to information at home, beyond just screen time, building on this and brokering research by Gonzalez et al. (2020). How and why do they mediate content? How are their perspectives manifested in their goals for their children's engagement with media?

In what ways might they be learning through negotiating access to information with their children?

Finding and interpreting information about the Covid-19 pandemic became a particularly fraught topic when this study was conducted in May 2020. Since then, more educational programming about the pandemic for children and adults has been released, while partisan divides about everything from the nature of the virus to the vaccines have grown simultaneously. The Covid-19 learning ecology continues to be complex and families' decisions about how to engage with learning resources models for their children knowledge systems and values that are embedded in community practice. Thus, the findings from this study contribute to an understanding of how families assemble learning resources in times of crisis to fulfill the information needs of both adults and children.

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Student Participation in Sociocritical Data Literacy: Shapes, Trends, and Future Directions from a Middle School Science Unit

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Abstract: Data science has increasingly integrated sociocritical theories and approaches, helping youth to not only learn data science but also relate data to their everyday and sociohistorical lives. Our project, Writing Data Stories, furthers these efforts by exploring sociocritical data literacies in a large-scale classroom enactment. We examine trends in middle school science student groups' (n=11) *data participation* and *sociocritical participation*, showing how these forms of participation ebb and flow across a 21-day unit. We then present focal group case studies to further unpack how participation shifted over time and suggest what factors contributed to these shifts. We found that data participation was affected by the tools at students' disposal, and sociocritical participation was shaped by the questions groups asked of each other and the data. These findings suggest that special attention to tools and guiding questions is critical when designing for sociocritical data literacy in middle school science contexts.

Introduction

Against the backdrop of an increasingly online and data-driven educational landscape, data science education has become an increasingly important field in its own right (Wilkerson & Polman, 2020). In order to be its most impactful and relevant to students, data science is also seeking to incorporate more critical and humanizing approaches to data (Lee et al., 2021). Writing Data Stories leverages sociocritical literacy (Gutierrez, 2008; Irgens et al., 2020) to provide rich data science learning, especially in non-dominant youth communities, through integrating scientific inquiry units into the K-12 science classroom. In these inquiry units, students are empowered to explore, visualize, and alter a dataset's contents, structure, or values using the Common Online Data Analysis Platform (CODAP) (Finzer & Damelin, 2016).

A key aspect of the project is supporting students to leverage both everyday and disciplinary genres to make sense of, contextualize, and reauthor datasets (Wilkerson & Polman, 2020). For example, in one of our classroom units, youth were supported to contrast advertising genres used to convince people to consume in the grocery stores with genres used to convince people in science, such as claims, evidence, and reasoning. Students then were invited to take their ideas a step further in exploring a cereal dataset to investigate which factors that might trigger diabetes to a more significant extent, such as sugar, fat, and cholesterol, and try to construct a convincing argument for what is the ideal cereal the school cafeteria should provide to students as their breakfast.

Theoretical Framework

Our work leverages notions of sociocritical literacy (Gutiérrez, 2008), a historicizing literacy that privileges students' sociohistorical lives to point out contradictions and tensions in the relationship between school-and-non-school-based knowledge. Other studies in data science have leveraged similar approaches that have seen success supporting students to critique and reauthor data in ways that invite new sociohistorical understandings of family, migration, and place. For instance, Kahn (2020) examined how students transformed datasets to write intergenerational family geobiographies, making new forms of data learning possible for students and families. Also, Van Wart and colleagues (2020) showed how remapping and envisioning youth's local neighborhoods troubled their relationship to normative data scripts and their relevance or hindrance to community improvement goals.

Building on these studies as well as sociocritical literacy, our study contributes a syncretic approach (Gutiérrez, 2008), which aims to reorganize the relationship between disciplinary knowledge and everyday knowledge as both valuable and needed in the process of knowledge building. We designed syncretic units spanning 21 days of in-school instruction, investigating nutrition, diabetes, and data literacy in a middle school on the west coast of the United States. At the same time, we set the goal to support youth to become agentive data practitioners (Wilkerson & Polman, 2020), primarily through their participation in data moves (Erickson et al., 2019) that inspire students to structure, calculate, filter, and transform datasets. Our preliminary findings showed how middle school students leveraged their everyday knowledge to create new forms of data literacy in the classroom while exploring the nutrition datasets on CODAP.

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Research Question

We were interested in how a syncretic design worked in the classroom context and whether youth's everyday knowledge came into a meaningful conversation to create new forms of data literacy, expanding the scientific disciplinary learning of nondominant youth. The research question is: How did youth's everyday knowledge mediate the development of meaningful conversations around data in a middle school science classroom?

Methodology

Various artifacts were collected for the qualitative data analysis, including classroom videotapes, student worksheets, student end-of-day reflections, and screen recordings of the students' Chromebook activity. A codebook was iteratively created to generate themes related to the research question, and there were six overarching subcodes under the two top-level codes, *sociocritical participation* and *data participation*. Based on their prior seating arrangement, 41 students were assigned into 11 small groups (from group A to K) and participated in this study simultaneously. Student participation has been analyzed using six subcodes to investigate how and when they engaged in the unit to develop their sociocritical data literacy across 21 days.

For the sake of space, we only elaborate on the subcodes that were most germane to our case studies. Under the code of *sociocritical participation*, syncretism is defined as using everyday and disciplinary resources to expand both everyday and disciplinary learning. Both had to be expanded to be syncretism, which we call our two criteria of syncretism. Here is a hypothetical example of student activities that would meet these two criteria of syncretism. Say for instance that students are engaged in a task naming food factors that are most important to them. If this group uses everyday ideas such as taste *and* disciplinary ideas such as sugar content on a Nutrition Facts label to choose their factors, they are expanding not only their reasoning about data but also expanding their personal connections to data that they might see in their everyday lives.

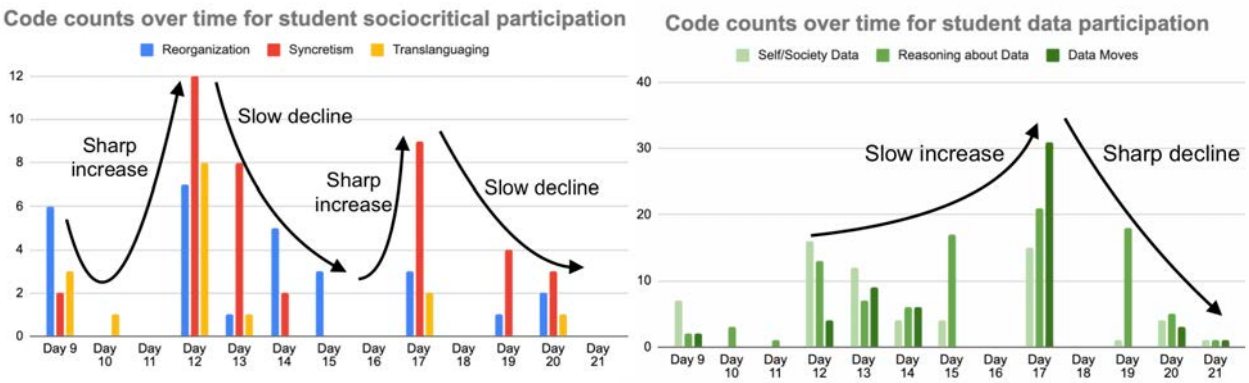
Next, two sub-codes of *data participation* need to be defined as these are examined in the cases. Reasoning about data is defined as students engaging in disciplinary data knowledge and practices already valued in the school context. For example, this code was used whenever students talked about patterns, center/trend/spread, case versus aggregate, construction of datasets. Data moves are coined as students filtering, grouping, sorting, aggregating, or otherwise transforming the data toward new purposes. For example, this code was used when students filtered out cereals on the dataset that were too high in sugar.

Findings

Figure 1 and Figure 2 present subcode counts and chronological trends in groups' *sociocritical participation* and *data participation*. Interesting trends are the spikes in all sociocritical participation in Figure 1 (Day 9, 12, and 17) and the spike in all data participation in Figure 2 (Day 17), which then experience a slow decline over the next few days.

Figure 1 and 2

Focal student groups (n=11) *sociocritical participation* and *data participation* across 21 days



Analysis of key student group cases

Next, we conducted case studies of key groups that seemed to have similar trends in participation to the overall trajectories in participation pictured in one or both the Figures. Analyzing these representative cases can illuminate the possible factors that contribute to these trends, especially those unique to the classroom context. We considered a trend robust if the pattern was present for individual group trajectories for at least two groups.

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Case 1: Syncretism decline from the Day 12 spike

Group K was one of two groups (Group J, Group K) whose participation matched the decline in syncretism from Day 12 into Day 15. Students in this group had pseudonyms Jonathan, Diana, and Yazmin. On Day 12, students were asked to discuss what nutrition factors in food were most important to them:

> Diana: We have to find two or more important facts.
> Dahlia: I think it's "fiber, sugar, and calories" (group agrees).
> Diana: Where can you find this information?
> Yazmin: The informational label. It'd be...it's on the cereal box huh!

This exchange met both the criteria for syncretism. Reasoning about data was expanded when this group demonstrated an emerging ability to pinpoint data sources in their everyday life (a cereal box that Yazmin was imagining). Personal connections to data was expanded when this group articulated which nutritional factors they were most interested in and began brainstorming where to look up this information.

On the following day, this group saw a decline in syncretism because their activities did not seem to expand reasoning about data even though they made personal connections to data. On day 13, students input foods they ate into CODAP, and group K began discussing how many calories were in each group member's favorite foods. For instance, Diana looked up the calories on her favorite snack, "Takis," and seemed shocked by how much sugar and how many calories are in it. In these moments, although students were learning more about their favorite foods using the language of nutrition facts, their reasoning about data did not seem to expand any further than entering the data into CODAP.

Case 2: Increase into Day 17 of all data participation and syncretism

Group E was one of two groups (Group E, Group J) whose participation matched the increase of data participation and syncretism leading to Day 17. Students in this group had pseudonyms Natalie, Lolita, Alex, and Bryson.

On Day 15, Group E seemed to expand their personal connections to data as related to their everyday lives, but did not necessarily expand their reasoning about data. In the following excerpt, students evaluated a cereal using both nutrition factors and their everyday experiences, creating an opening for syncretism that was not pursued by the group:

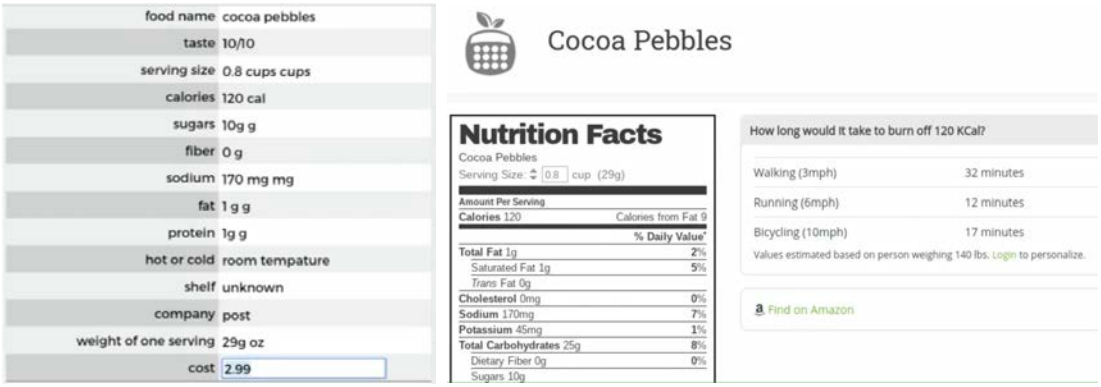
> Natalie: Oh, this one has no fat and no fiber.
> Alex: Which one?
> Natalie: Rice krispies.
> Bryson: [examining the Nutrition Facts printout] No total fat, no fiber.
> Natalie: Doesn't rice krispies taste like nothing? Like... not the bar, but the cereal?

This moment was not quite syncretism because although Natalie was beginning to make personal connections to the data with her question, the group's reasoning about data after this moment remained solely focused on comparing cereals based on nutritional factors. Thus, they did not meet the criteria for syncretism that both everyday and disciplinary participation be expanded. Had they leveraged Natalie's everyday experience to start comparing cereals based on taste and nutrition, these moments might have better aligned with syncretism.

On Day 17, Group E finally did see moments we categorized as full examples of syncretism, and they experienced a substantial increase in data moves. These data moves included adding a new case card for cocoa pebbles (Figure 3), adding new attributes to the dataset such as company, price, and taste, inputting values according to their everyday experience (Taste: 10/10), and leveraging other sources of information beyond CODAP (Google Search, NutritionX website - Figure 4) for other factors (Price, Company). We attribute the increase in data moves to the fact that Day 17 was students' first time using computers, exploring CODAP, and exploring the cereal dataset.

Using these data moves, Group E added a new cereal into the dataset and characterized it using information from both everyday and disciplinary sources. As far as everyday sources, they interviewed each other to decide that the Cocoa Pebbles was neither hot nor cold, but room temperature, that it had an excellent taste, and that the shelf was unknown. As far as disciplinary sources, they searched on Google for typical prices and searched on NutritionX.com for nutritional information (Figure 4).

Figure 3 and 4
Students added a new cereal case on CODAP and searched Cocoa Pebbles on NutritionX.com.



These moments met both the criteria for syncretism. Reasoning about data was expanded when students began to see their personal experiences as valid, inputting ideas like Taste = 10/10 into CODAP. Personal connections to data expanded when students seemed interested enough in their new attribute of cost to continue inputting costs for other cereals in the dataset.

Discussion

This work begins to suggest how sociocritical data literacy takes shape, ebbs, and flows in a middle school classroom context. For instance, Figures 1 and 2 suggest that data and sociocritical participation seem to mutually reinforce one another, such as the spike in both syncretism and data moves on Day 17. Across our focal groups, it was not surprising that data participation was affected by the presence of tools (i.e., CODAP, search engines, and the cereal dataset). However, it was interesting to see how students' sociocritical participation, namely syncretism, seemed largely to be supported or not by the questions students asked of each other and the data. For instance, in Case 1, syncretism emerged when Diana asked where sources of information could be found. Similarly, in Case 2, syncretism emerged when members of Group E interviewed each other about Cocoa Pebbles. These findings are significant because they suggest that additional attention to tools and guiding questions is needed for a syncretic approach to support sociocritical data literacy in a large-scale classroom context. A limitation in this work is that we centered syncretism, but more is needed toward *sociocritical* data literacy. Future work should support analysis of the politics of food, cultural practices, and other necessary elements supportive of nondominant youths' sociocritical literacies (Gutiérrez, 2008).

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Capturing Students' Learning Strategies in Action Using Clickstream and Eye-tracking Data

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Abstract: When interacting with open-ended environments, students are free to use different learning strategies. In this exploratory study, we focus particularly on college students (n=47) and their use of inquiry and feedback strategies as they explore a science simulation game. By capturing their behaviors through both clickstream and gaze data, we can more closely examine the effect of different strategy uses on their learning. Backwards regression analyses were used to examine students' early behaviors in the simulation and results indicate that learning outcomes can be best predicted by a combination of inquiry and feedback processing behaviors. Of particular interest: quality over quantity of inquiry was more predictive of learning; and both clickstream data of feedback *use* and eye-tracking data on *earlier stages* of feedback processing (e.g., noticing, predicted learning). These results have implications for the design of future open-ended environments that can better support student learning.

Introduction

Scenario*: Laura and Heidi are students in the same major with similar GPAs. For a class activity, they interact with an open-ended learning environment that requires inquiry skills and provides feedback. Afterwards, they complete a test to measure their knowledge. Laura receives a lower score than Heidi.* Assuming they started with the same prior knowledge, what did they do differently in the simulation that affected their learning outcomes? This study contributes to the identification of learning strategies used by students as they study a phenomenon and highlights the importance of using multiple types of measures to understand students' learning processes.

I. Learning strategies and technologies

Inquiry and simulations

Simulations offer scientifically authentic environments for students to learn about natural phenomena. In STEM fields, a boom in online simulation environments (e.g., PhET) has provided students with opportunities to put their inquiry skills into practice (Wieman et al., 2008). Here, we define scientific inquiry, broadly, as the ability to design experiments, then gather, test, and analyze evidence to reveal patterns in the data. Specifically, in the environment discussed here, we focus on the strategies of simplification and finding equivalence (Käser and Schwartz, 2020). Students' behaviors in science simulations, captured in the form of clickstreams, offer rich information about their science inquiry processes as they explore the phenomenon of interest. Going back to the example of Laura and Heidi, it may be the case that in Heidi's exploration of the system, she designed better experiments that provided more information about the model behind what she is observing in the data than Laura.

Feedback and learning technologies

The increase in accessibility of digital technologies provides a unique opportunity to capture real behaviors of students' engagement with feedback instead of using more limited measures such as self-reports. To expand our understanding, we shift from a general perspective to a study of specific, individual behaviors that students take while processing feedback; interactive, digital environments provide students with expansive opportunities to not only receive feedback, but to act on it (Segedy et al., 2013). To the best of our knowledge, there is limited work studying feedback processing (e.g., Tärning et al., 2020). Returning to the example of Laura and Heidi, it may be that Heidi scored higher because she processed the feedback in the system more thoroughly than Laura.

Different students' behaviors while interacting with a learning environment should be analyzed to better predict student learning and design the correct scaffolds to support their understanding. The study presented here uses an open-ended science environment that provides affordances for both learning strategies to be used and measured, with an end goal of understanding how these strategies might interact to support better student learning.

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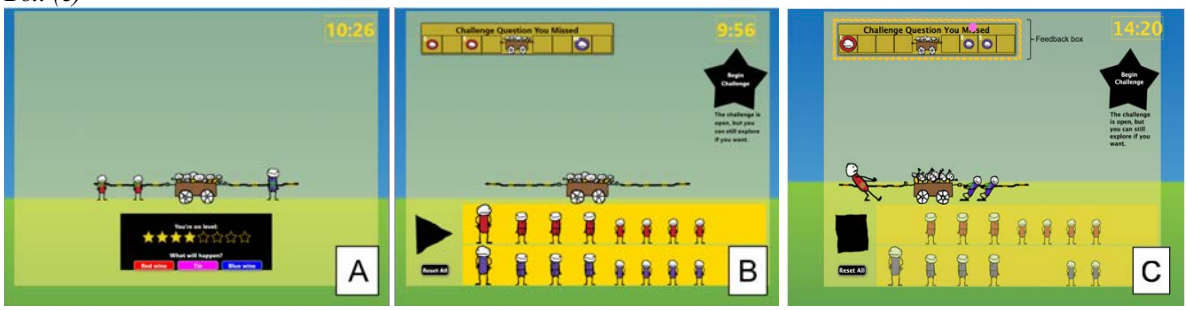
II. Pull!: An online environment for measuring learning strategies

Pull! is a physics game modeled on a PhET simulation, Forces and Motion Basics (Käser and Schwartz, 2020). Pull! is framed around a tug-of-war: teams of small, medium, and large characters on either side of a rope try to pull the other team across a center line. The object is to answer a series of eight questions in a Challenge mode and predict whether a given setup will go left, right, or end in a tie. In the simplified physics of the game, the winning side simply depends on the total "weight" of each team's characters; position does not affect the outcome. To succeed in the game, learners must understand the ratios between the characters. If learners miss a question in Challenge mode, they are sent to an Explore Room, where they have the opportunity (if they wish) to test any number of setups to learn about the simulation environment (see Figure 1). Questions progress in difficulty: three easy (e.g., a small character on either side), two medium level (e.g., a medium vs. 2 small), and three hard (e.g., 2 small, 1 large vs. 3 small, 1 medium); learners never see the same problem twice.

Figure 1

Pull! Screenshots Include an Example Medium-level Challenge (a), the Explore Room (b) and AOI Feedback Box (c)



The Explore Room is designed to provide feedback, as well as allow open-ended inquiry; upon entering the room, a player sees the question she missed in the top left corner as feedback and has unlimited choices to test setups among the provided characters by placing characters on the rope and pressing <play> to start the simulation. Some setups provide less information about the system, e.g., have identical characters on each side or have so many characters on each side that it would be difficult to discern relationships. Other setups are more informative, e.g., a medium vs. 2 small characters yields a tie. We hypothesize that certain behaviors in the Explore Room will predict better learning as measured by a posttest. It might be the case that more informative setups yield better learning, where more informative means students test setups which use principles of good inquiry, e.g., simplification. Another possibility is that feedback uptake yields better learning, where uptake is defined as students testing the same set-up as provided in the feedback box. In some cases, these factors will overlap, i.e., the feedback displayed shows an informative setup that is beneficial to students' learning.

Methods

Participants and Procedures

Community college students (n = 62) consented for the study and were compensated with a 0.5 class credit. Fifteen students with low-quality eye-tracking data or incomplete measures were removed, resulting in a final n = 47. Study procedures were approved by the Stanford Institutional Review Board. The study was conducted in 30-minute individual sessions, consisting of four stages: i) eye-tracking calibration, ii) interaction with the simulation, iii) learning measures, and iv) a debrief where experimenters provided a summary and answered questions.

Measures

For this study, we used several sources of data. The first two sources of data are measures of student behaviors while playing the game: 1) clickstreams extracted from students' interactions with Pull! and 2) gaze data extracted from the eye-tracking. The third source of data is the posttest administered immediately after students played the game and include two types of learning measures. More detailed information is provided below.

1. Clickstream data

All setups (experiments) run in the Explore Room were logged by the system, then characterized in two different ways. First, setups were categorized based on their simplicity and informativeness for discerning the ratio between character types. This included identifying tests that isolate one of the characters' sizes (one-sided), as well as tests

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that result in a tie (and thus are highly informative). Second, setups were categorized based on whether they likely resulted from feedback uptake or independent inquiry. They were classified as feedback uptake if after missing a question in Challenge mode, students test a setup with the same characters and same positions as the missed question (Exact Feedback) or the same characters in different positions (Inexact Feedback). Setups were classified as independent, self-driven inquiry behaviors if they were not related to the feedback. Metrics included the total number of setups tested, as well as counts of setups categorized by both informativeness and source (independent inquiry of feedback) as described above. Additionally, we coded for whether a player explicitly tested whether position had an effect by varying, in two consecutive tests, only the position of one (or more) characters.

2. Gaze data and feedback noticing

We used a screen-based eye-tracker (Tobii Pro Nano) to record students' eye movements as they played the game. Gaze data was cleaned using a smoothing algorithm (Hessels et al., 2016), then mapped onto the game coordinates and logged as a series of game events. For the purposes of this study, a question of particular interest was how the visual inspection of feedback affected student learning. Fixations were computed in the pre-defined area of interest (AOI), the feedback box in the top left corner of the Explore Room (see Figure 1C). The maximum time students spent looking at this AOI was calculated each time they entered the explore room.

3. Learning measures

Two types of learning measures were used in the posttest. 1) A performance measure focused on quantitative understanding of the ratio structure governing the system. It displayed a setup of characters on the left side of the screen. Students chose whether or not each of ten possible configurations on the right-hand side would result in a tie with the given left-hand configuration. Students received one point for every correct response and lost one point for each incorrect response. The maximum score was 10 and the minimum was -10. 2) In an open-ended response measure, students responded to the following statement: *Explain to someone what are the rules of the game you just played.* This prompt was included to measure how learners chose to verbally describe what they understood as important from the game and served as a measure of more nascent understanding of the system. Student responses were transcribed and coded using the following levels: 1=Qualitative response, 2=Mentioned arithmetic without including values, 3=Included general values, and 4=Included specific-detailed values.

Results

Overview of game play and learning measures

Individual students played until they either beat the game or timed out after 15 minutes. The average game play time was 8.8min (SD=4.4min). Most players beat the game (85%), with an average of 9.55 (SD= 8.35) Challenge attempts. The average on the learning measures was 5.23 (SD=4.22) on the performance measure and 2.72 (SD=1.31) on the open-ended response item.

Which student behaviors in the online environment predict their learning?

We present exploratory analyses to determine which behavioral measures among students' clickstream and eye-gaze data best predict their learning as measured by the posttest. Due to space restrictions, we present only those analyses that: 1) used a dependent learning measure, Z-Post score, that is the sum of the z-scores of the posttest measures described above; 2) looked at behaviors early in the game, examining data up to the first five Challenge attempts to equalize for game play length across students and 3) focused specifically on behaviors after missing medium difficulty questions (levels 4 and 5) as these are the levels that require basic understanding of the underlying rules of the system. And thus, best captured the learning strategies that students were utilizing.

The behavioral measures described in the measures section, in addition to the number of medium difficulty questions missed, were entered as independent variables into a backwards regression model (SPSS v. 27, default criterion: probability of F-to-remove >=.100) to predict students' learning performance. The final model achieved ($F_{(4,42)} = 6.46$, $p = .000$; R-squared = .38) indicated that the Z-post score could be predicted by four variables: two feedback-related variables (Number of one-sided tests that reflected exact feedback setups and Maximum gaze time spent on feedback in a single Explore room visit; standardized **β**'s = .40 and .26 respectively) and two inquiry-related variables (Number of informative, self-driven one-sided tests and Check position score, a variable indicating if learners tested for position; standardized **β**'s = .24 and .22 respectively). Interestingly, neither the number of medium level questions missed within the first 5 challenge room attempts, nor the number of total tests conducted during subsequent exploration remained in the model, indicating that it is not the quantity but the quality of experiments that lead to better learning outcomes.

Figure 2
Scatterplot of One-Sided Tests Driven by Feedback vs. Independent Inquiry by Z-Combo Posttest Score (Note, points jittered up to .4 above whole number value)

We further examined students' use of one-sided tests (see Figure 2). Students with the lowest Z-post scores were least likely to test setups that were one sided (and thus highly informative) within their first five Explore room visits. Of students who engaged in one-sided tests, most focused on *either* feedback driven setups *or* independent inquiry tests. Only a handful (8.5%) conducted *both*. Together, these results suggest that both learning strategies, using feedback and conducting independent inquiry, can lead to better learning, but that students do not naturally use both, at least in the context of this learning environment.

Interestingly, among those students who did *not* explicitly engage in any feedback-related tests, there was still a correlation between time spent looking at feedback (maximum feedback gaze time) and the combined Z-post score, $r(38) = .36$, $p = .03$) indicating that *noticing* feedback (and likely decoding and making sense of it) may be a productive learning strategy, even if it is not directly *acted upon*.

Discussion and Conclusion

We examined students' use of feedback and inquiry strategies in a simulation-based, open-ended learning environment called Pull! Both clickstream and eye-tracking data were used to capture students' learning pathways as they explored the phenomenon of net forces. Results indicate that both feedback and inquiry-based strategies may lead to better learning, but that students may not naturally employ both. Notably, the feedback strategies include both active *use* of feedback, as well as earlier stages in processing, such as noticing and decoding. This has implications for the design of future learning environments and the affordances that could be built into these learning technologies to scaffold students such as Laura and Heidi. For example, the technology could draw students' attention to feedback features or help them employ inquiry strategies, like simplifying or isolating variables, that lead to more informative experimental outcomes.

The analyses presented here are exploratory and have some limitations, including the relatively small sample size and a deliberately constrained problem space. Future research and analyses will examine how affective variables may influence students' use of learning strategies and incorporate findings into improving Pull! and other new learning environments with more complex science content.

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Designing Learning Supports for Online Teaching Assistants

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Abstract: It is important in this changing world of technologies and careers for students to learn how to learn. Formal education can provide the opportunity to develop lifelong learning skills that are necessary to cultivate positive learning habits and new mindsets. For learners to build these skills, they must be embedded in their courses, making it necessary for instructors and teaching assistants to prepare content, resources, and knowledge to cultivate these skills. Building the capacity of teaching assistants gives them the means to support learners as well as helps them to become better learners too. This paper describes design and implementation of a training module for teaching assistants and the design decisions made to address the needs of the university and its students. This design work uses the Concerns Based Adoption Model to guide the design decisions and development of the formal training.

Introduction

In education it is important to focus on assisting learners to learn how to learn (Barron & Darling-Hammond, 2008) and build not just content knowledge but 21st century skills. These skills will help learners navigate formal learning opportunities as well as the demands of changing technologies, information, jobs, and social interactions with others throughout their life and careers. It is vital for learners to recognize the need for lifelong learning and the ability to re-skill and update competencies (Mawas & Muntean, 2018). Promoting knowledge retention and the transfer of knowledge and skills to new subjects, contexts, and problems are two important goals in education (Mayer, 2002). Formal education should prepare learners with the skills and desire to be lifelong learners so they can be flexible and successful as new expectations arise in whatever they do.

Within formal education, learners typically interact with content, instructors, teaching assistants, and peers (Moore, 1989). These interactions provide a means for learners to increase in their content knowledge. Fostering lifelong learning and 21st century skills in online courses is important in education today as more classes are online, and technologies and job expectations change. These skills cultivate new mindsets and learning habits that are essential for the future of society (Fischer, 2000). To foster these skills, they must be taught in the course (Saavedra & Opfer, 2012). Instructors and teaching assistants need to be prepared to teach these skills and provide resources related to them for learners. Providing training and support for instructors and teaching assistants is very important for student success. Building the capacity of teaching assistants gives them the means to support learners as well as helps them to become better learners too (Shannon et al., 1998). This design case describes the process and decisions in developing the Teaching Assistant Module (TAM) for online teaching assistants to support learners.

Context

This design case is part of a larger Research-Practice Partnership (Penuel & Gallagher, 2017) with administrators, design professionals, and educational researchers at a large, private university in the western United States. Since one of the main aims of this university is to foster lifelong learning skills, this work focuses on building these skills as well as learner readiness in online courses. This involves multiple people and design, including instructional designers, teaching assistants (TAs), instructors, resources, well designed courses, and preparation and training for people who implement the courses. This paper focuses on the teaching assistants.

The TAM was designed to help solve a number of problems identified by the university's online administrators. The most pressing problems arose from rapid growth with limited staff. When the university's online department began in the fall of 2012, the program had an enrollment of 316 students in 2 sections. By fall 2020 online enrollment had increased to 26,134 students in 426 sections. With the increase in students came a correlating increase in hiring TAs, which grew over 300% from 2017 to 2020. In addition to the rapid growth, another influencing factor was limited personnel resources. By mid 2019 the full-time staff to TA ratio was more than 1:200, making it difficult to provide individualized support.

Previous TA training was primarily focused on employment policies and procedures, with some learning management system (LMS) training. To begin the design of the new training, the existing online training resources

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were assessed for how necessary or pertinent the information was moving forward, with the majority of the materials being removed and not used. The need to improve TA interventions led us to focus on a new training course that could teach both student success strategies and pedagogical principles in the hopes to improve teaching assistant effectiveness.

Theoretical framework

The Concerns-Based Adoption Model (CBAM; Anderson, 1997) provides the theoretical framework for the design and implementation of the TAM. The CBAM functions under the premise that the adoption of new programs and initiatives are much more than materials and resources. Assessment of successful implementation must also address the attitudes and beliefs of all who will be involved and how they will respond to the changes. The CBAM consists of three diagnostic components: Stages of Concerns, Levels of Use, and Innovation Configure Map. These three stages function together to gauge effective implementation. With the design of the TAM, we were initially focused on the early informational, personal, and management steps of the Stages of Concern. The undergraduate student TAs wanted to know more about the module, how it would affect them personally, and how they would manage their time in learning and applying what they were learning.

Research methodology and design process

This partnership uses design-based research (McKenney & Reeves, 2018) to iteratively tackle problems of practice faced in online learning. As an exploratory study, we used surveys and reflections to capture the experiences, perceptions, and attitudes of the TAs related to the TAM and their classes. Data was collected over three semesters and analyzed so iterative improvements in the design, development, and implementation process could be made. This work is guided by the following research question: How effective is the TAM in building knowledge and capacity for TAs?

Participants

The primary participants in this work are TAs for online courses at the university. From fall 2020 through fall 2021, 1,455 TAs assisted with online courses. During the semester a TA works, we enroll them in the TAM as part of their job and then invite them to participate in the research activities. Data for the research is collected each semester using a pre/post surveys and a short survey to assess a specific unit in the TAM.

Design

With rapid TA growth and limited resources, we recognized a need to provide TAs with a more comprehensive learning opportunity that could be done completely asynchronously online and double as a resource and reference manual. The overarching goal of this new training module was to provide TAs with instruction on how to fulfill their job duties, how to connect with their students online and help them in their efforts to become better online and lifelong learners, student success strategies, and pedagogical principles in the hopes to improve teaching assistant effectiveness.

The TAM was created through a collaborative design process with stakeholders, designers, and researchers. The first unit focused on improving knowledge of the Canvas LMS. The LMS used in online courses was different from the LMS used in in-person sections, so LMS proficiency was an important goal in this first unit. The goal of this unit is for TAs to know Canvas and to be the main source of support to their students who are new to the LMS. This unit is to be completed before the semester begins. Unit 1 aligns with the first and second stages of concern in CBAM, *informational* and *personal*. They are learning about the LMS and becoming comfortable with it, while building their confidence with the technology.

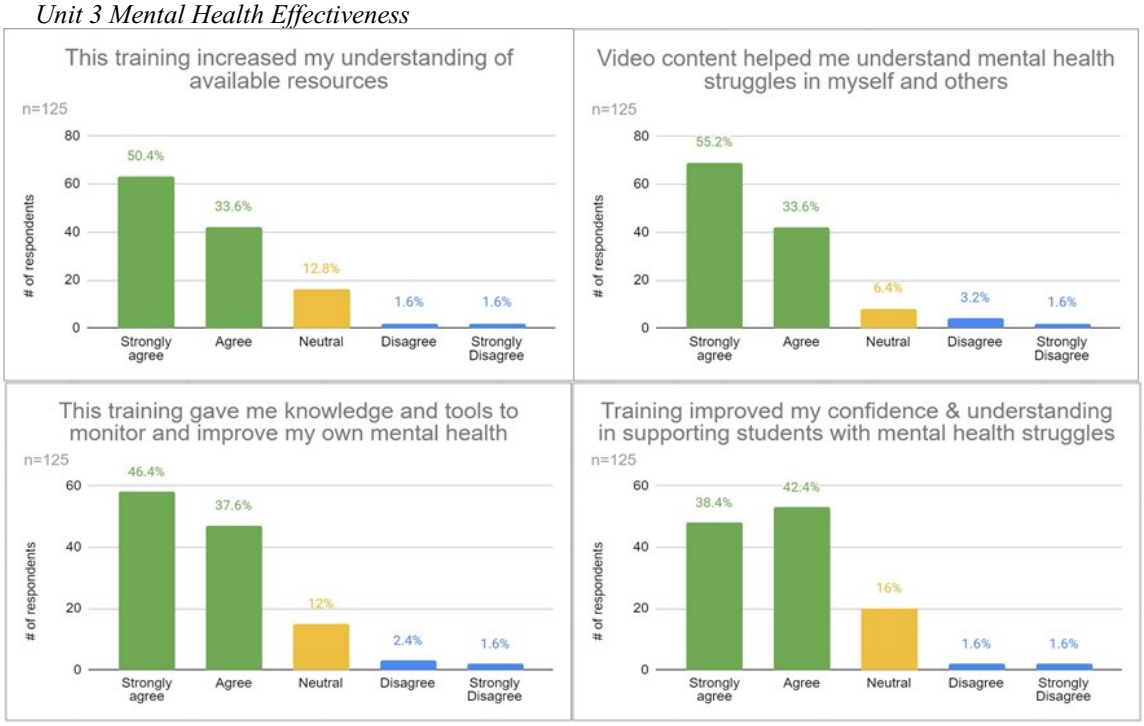
Unit 2 was created to help TAs connect with their students. Designed to be completed in the first few weeks of the semester, the unit focuses on providing timely feedback to students, creating a community of belonging through inclusion and safety, using course analytics to support online students and accommodating various needs of students. The major objectives of unit 2 included helping TAs to see *the why* of what they are doing; to act as students' success mentors and have the skills to improve student learning. This unit teaches them how to identify struggling students using data analytics and provides ways to offer support and encouragement. Teaching assistants are usually chosen because of their academic performance, but we did not want to make the assumption that they possessed any knowledge of or experience with utilizing effective learning strategies. So, this unit pushed for information as well as how what they learn might affect them and their student's learning opportunities.

The goal of Unit 3 was to provide personal growth and professional development opportunities for the TAs with the hope that the outcomes and benefits would be passed to the students they interact with. To navigate

this, we chose to provide several options to help TAs recognize their own strengths (and weaknesses) and learn how to improve on them. In line with the CBAM model, we hoped that these training sessions would help TAs to experience the importance of the material that we covered. Once they had a meaningful experience themselves, they could turn to their students, recognize their needs and help them. We acted under the assumption that if we could help TAs to become more capable and conscious students themselves, there would be some benefit that would trickle down to the students they are responsible for. In Unit 3 we ask TAs to choose their own adventure with the following topics: Happiness Advantage Bookclub, Growth Mindset, Mental Health, Active Learning, Critical Writing, Gallup CliftonStrengths, and Belonging. The format of this unit allows TAs to self-direct their training material to meet individualized growth while still maintaining training effectiveness. This design also allows returning TAs to have continued meaningful learning when they return in multiple semesters. The Unit 3 training has been the most well received unit. The most popular training chosen by TAs has been the mental health module. Working with professionals within the campus counseling center we created this unit to educate the TAs about the importance of mental health within the learning process. Survey data to evaluate this unit reports promising results about the effectiveness of the materials and movement in the right directions toward our learning outcomes for this unit (see Figure 1). TAs also have the option to earn a microcredential for each of the topics in Unit 3

Figure 1

Unit 3 Mental Health Effectiveness



One more problem addressed in our training was the lack of transfer of knowledge from one semester to another. Student positions have a high turnover rate. TAs interact with a course at a different level than instructors and can provide valuable insight into course design improvements as well as assignment management and support. We value the knowledge and experience the TAs gain and have seen it often go unnoticed. We created unit 4 to capture what was learned every semester to shorten the learning curve for the next TA. This final unit is essential to helping the online department maintain and improve their courses as TAs learn how to communicate and collaborate with the designers regarding issues in the course so that the university's online education can continuously improve. This wasn't part of the design when unit 1 was started, but it became apparent that a need for refocusing, as CBAM states, was needed each semester. At the end of this unit, the TAs complete a post-semester reflection survey similar to the pre-semester survey they take and aims to measure student learning through the semester and training effectiveness. The TAs are given the opportunity to write down how they have individually improved as both a learner and a TA and how they hope to continue to improve.

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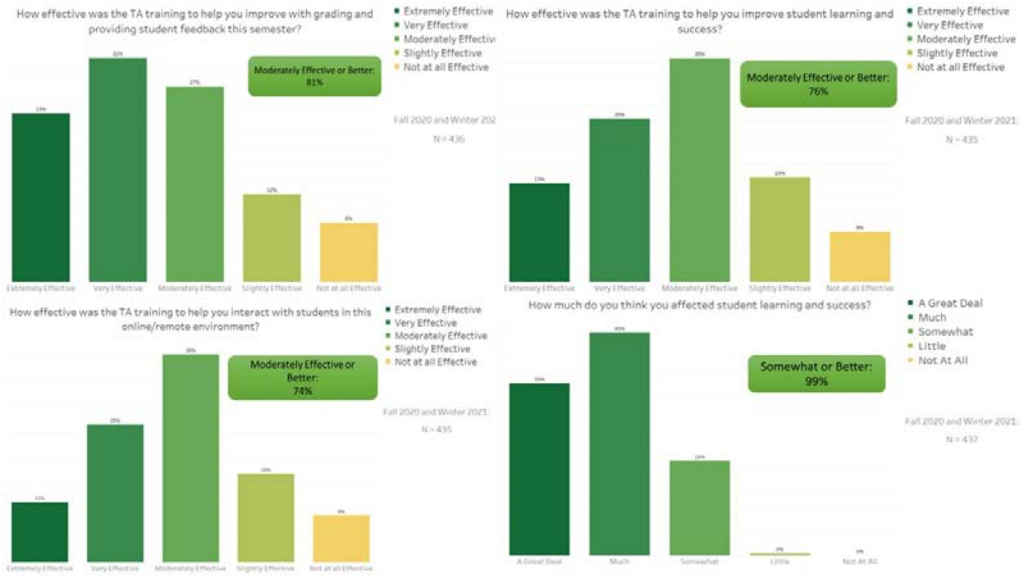
Results and discussion

Using the results from the pre/post survey to answer our research question, we are optimistic as we see evidence of the training's effectiveness. Figure 2 reports on four questions from the surveys reporting that the TAs find the TAM effective in helping them with grading and feedback, improving student success, interacting with students, and their perceptions of affecting student learning and success. 81% of respondents reported that the TAM was moderately effective or better at helping them improve grading and providing student feedback. 76% reported that the training was moderately effective or better at improving student learning and success, and 74% reported being moderately effective or better at interacting with students in an online/remote environment. When we asked teaching assistants how much do you think you affected student learning and success, 35% reported a great deal, 45% much and 19% self-reported having somewhat of an effect on student learning.

Figure 2

Training Effectiveness



Implications

At this university there is a lack of campus standard training for teaching assistants. Many entities outside of the online department have expressed an interest in creating something that would work for all TAs. It is the online department's goal to improve peer teaching and support across disciplines by creating a version of the teacher assistant training that could be easily customizable to meet a department's needs. With data supporting the effectiveness of the TAM, this service could be beneficial for other departments.

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Beyond Belief: Disinformation Strategies and Collective Knowledge Building Led by Jair Bolsonaro in Brazil

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Abstract: The creation and distribution of disputable information is currently widespread and significant in the political debate. Explanations of this phenomenon usually imply that leaders exploit fragilities of their followers, such as lack of education or plain lack of understanding of the facts. We explore a competing interpretation: using a constructivist lens and building on scholarly work in the learning sciences, we investigate cognitive processes at play in political engagement that goes beyond "blind" belief in leaders. We conjecture that those leaders might be employing efficient learning strategies that legitimize their actions and inspire loyalty.

Introduction

The crafting and distribution of alternative versions of facts is particularly relevant to present-day political discourse. In this paper, we focus on this trend as it manifests in strategies employed by Brazilian President Jair Bolsonaro, who–in one of many similarities to Donald Trump–had allegedly made 2,700 false or distorted statements in 1,000 days in office (Freitas et al., 2021). A widely held belief about Bolsonaro and Trump is that their constituencies follow them "blindly" without understanding of the real contents of their messages, and that a "better educational system" would eventually enlighten these followers. Here, we investigate a competing explanation: *audiences' belief in these leaders is not necessarily blind; instead, these leaders and their followers work in tandem to build their own robust theories on the backs of flimsy assumptions and facts–but the resulting theories are strong and internally coherent.* Research in information science has found evidence of similar mechanisms at play among alt-right groups (Zuckerman, 2019; Lewis & Marwick, 2017; boyd, 2018).

We hypothesize that there are sophisticated cognitive mechanisms at play that go beyond blind belief in a leader, and that these mechanisms are powerful enough to justify the creation of strong theories that guide political behavior. Our investigation focuses on ways in which Bolsonaro employs sophisticated activators to engage his audience in an *active and collective knowledge construction process*, which results in the audience's feeling that they are creating their own knowledge. Thus, rather than telling followers what to believe, Mr. Bolsonaro might be (consciously or not) applying efficient teaching strategies.

This paper builds on our previous work (e.g., Russo & Blikstein, 2022; Russo et al., 2021) to explore potential contributions of the learning sciences to our understandings of how political leaders influence the construction of his or her followers' political knowledge. Despite bordering on conspiracism, that political knowledge might sound like robust, solid theories to those who own them. We draw on a classic constructivist perspective and on work from the information sciences to analyze video data containing informal conversations carried out by Mr. Bolsonaro and citizens (similar to Trump's "chopper talks"). With that, we hope to offer a contribution to the learning sciences in the form of new hypotheses to explain modern-day knowledge construction in contexts that affect people's everyday lives.

Theoretical framework

Constructivists propose that learners build their own knowledge in interaction with the world, and that individuals assimilate new information according to preexisting mental schemes (Ackermann, 2001). diSessa (1993) advanced constructivist theories with the Knowledge in Pieces" framework, an explanation to how "experience feeds into knowledge." He claims that children's intuitions about the workings of the world can be used to advance their understandings of science and, more specifically, physics. Those intuitions, diSessa argues, form phenomenological primitives ("p-prims"), mental structures that offer possible explanations to observed phenomena. As p-prims develop, they come to form more complex mental structures named "coordination classes" (diSessa and Sherin, 1998). These structures support individuals in their process of making inferences from observable phenomena, sometimes even getting in the way of knowledge supported by evidence. We transfer that concept from physics to political science to formulate our hypothesis that political knowledge built upon a learner's prior "pieces" would be much more solid than that formed by the unidirectional ready-made messages on which political leaders traditionally rely.

This transfer to the social sciences is not novel. Philip (2011) proposed the "ideology in pieces" (IiP) framework, employed originally to study notions of race and racial justice in schools and teaching. Part of the IiP

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framework is the notion of "naturalized axioms," the parallel of p-prims in the context of the social sciences. The researcher posited that individuals' observations about phenomena in society and politics are heavily contingent on historical and social contexts. In other words, naturalized axioms are described as elements of common sense that people employ as they make sense of the social world. For example, Philip (2011) identified that, to explain why some students are unsuccessful, teachers might use naturalized axioms like "kids would rather play than work." Like p-prims, the IiP framework implies, *naturalized axioms also form coordination classes*. One crucial difference from coordination classes formed by p-prims, however, is that there is no universally agreed-upon meaning of commonsense elements like "blame, responsibility, or fault," but they acquire socially shared denotations for specific groups, depending on the sociohistorical contexts. That is, although coordination classes are originally highly dependent on observable phenomena, the ideology in pieces framework ascertains a slightly different nature to it, now compatible with phenomena pertaining to the social world. These concepts become important when we investigate constructivist theory-building as a cognitive device that citizens employ to understand politics and society.

Data collection and analysis

Mr. Bolsonaro regularly confers with citizens and journalists from highly partisan media outlets. We initially watched 50 video recordings of those conversations (total length: 12 hours) that were published on YouTube between April 30th and July 26th, 2021. We then reduced the sample to pieces whose content included proper dialogues and that contained references to emergent, controversial topics (much of the initial sample resembled fan-idol encounters that are not relevant to the present analysis.) This filter left us with six recordings (total length: 1:18:50). Some of the selected clips had been edited after the original publication to exclude explicit disputable claims about authorities in the federal government, but we accessed the original versions using the Internet Archive Wayback Machine. Our analysis is based on those original recordings. After transcribing the videos, we employed grounded theory (Charmaz, 2006), developed initial codes over multiple cycles of discussion between the authors, and elaborated an analysis framework that draws on the concepts of coordination classes and naturalized axioms. Next, we assigned quotes and dialogue excerpts (N=78) to 3 naturalized axioms that form a larger coordination class and to groups of assumptions that compose those axioms. We then classified the quotes according to the kinds of activators employed in each one. Finally, we ranked the recurrence of activators across naturalized axioms.

Results

After extensive analysis and coding of the dataset, we converged on three main strategies that function as "activators" in Mr. Bolsonaro's utterances (Table 1). It is intriguing that these strategies are akin to many of the productive teaching strategies found in the education literature.

Table 1: *Activators, their frequencies, descriptions and examples*

Type of activator	Freq.	Description	Examples
Schemata	74 (94%)	A mental "template" to guide the learners (in this case, the citizens) in their interpretation of current facts	*"the individual is always in conflict with the collective" "all left-leaning governments are dictatorships."*
"Socratic" dialogue/ rhetorical questions	27 (34%)	In an interactive manner, the followers reach conclusions through strategically positioned questions. In this case, the speaker does not answer, but suggests ideas through subtle questioning, a process that leads followers to feel that they are actively building knowledge	*see dialogue example below*
Contrasting case	13 (16%)	Comparison between two or more contexts. In this case, the comparisons are usually between contexts that are known to the listener and ones of which they have but stereotypical mental images	*"Electronic ballots are only used in Brazil and Bangladesh; paper ballots are used everywhere else in the world, including Japan and the United States. Guess who is wrong?"*

Note: there is overlap between types of activators. Therefore, the sum of percentages is greater than 100.

Example Socratic dialogue:

Bolsonaro:	Have you heard of a hacker who is in jail?
Follower:	Yes, I saw that video.
Bolsonaro:	And why is he in jail?
Follower:	Because he invaded the SEC (Supreme Electoral Court)'s system.
Bolsonaro:	But didn't Barroso (head of the SEC say that the Court's system is inviolable?
Follower:	Yes, he did.
Bolsonaro:	But why is he in jail, then, if he didn't commit a crime? The evidence is clear!

Table 2. *Co-occurrence of activators and naturalized axioms*

Activator	Naturalized axiom		
	Hidden forces act against Brazil's development	There are ways to fight those forces	The Left can ruin Brazil
Schemata	28	10	29
"Socratic" dialogue/rhetorical question	15	2	12
Contrasting cases	3	0	10

A coordination class and its naturalized axioms

Our analysis identified one coordination class that pervades a significant part of Mr. Bolsonaro's speech: *"Bolsonaro is the best resource we have to avoid Brazil's downfall and the rise of communism."* Although this coordination class might sound like an acceptable political stance, a closer look at its underpinnings reveals that this "truth" is constantly reiterated and justified by naturalized axioms, taken-for-granted assumptions that, at the very least, resemble conspiracy theories. For example, one of the naturalized axioms is founded on the belief that there are *secret*, non-patriotic forces hindering the president's efforts to lead Brazil to greater development. The trio of excerpts below, stated by Mr. Bolsonaro, shows an example of naturalized axioms in practice: (1) a supposed conspiracy (*a hidden force*) against his plans to implement a so-called "verifiable ballot" (an alternative term to print voting system), (2) how this supposed plan has been devised by leftist leaders (*the Left can ruin Brazil*), and (3) the successful implementation of that plan would mean his defeat in the elections (*one way to fight the hidden forces* is to implement electronic ballots):

> *Excerpt 1:* Why, after Justice Barroso visited the House and spoke with party leaders, did these leaders replace their parties' representatives in the verifiable ballot committee, so that the print voting system sank? Why? Elections that are not clean, that are not transparent, <u>are not elections</u>. What we want is to avoid problems in 2022. Will we have elections? We will (have) clean elections. (2021, July 22)
> *Excerpt 2:* The people who took Lula (former president, leftist) out of jail and made him eligible again are the same people who will secretly count the votes inside the SEC. I'm not insulting Justice Barroso, I'm showing the truth! (2021, July 19)
> *Excerpt 3:* We have, for example, a Supreme Court Justice against transparency in the elections [...] As the old adage, the leftist adage goes: *the ones who count votes are the ones who win the elections.* This is what we have under way for next elections. (2021, July 20)

Bolsonaro's theory building starts with few assumptions, and progresses to making the final claim that there is a movement in course to "steal" the elections. *But he does not simply tell it to followers, instead, he takes them for a complex "theory-building ride."* First, there is the suggestion that Justice Barroso is violating the Constitution and deviating from his proper legal role by lobbying against the verifiable ballot bill. Second, the president implies that the "verifiable ballot" is the only way to ensure "clean" elections (second excerpt) and that the current electronic voting system is corrupted (elections that do not happen accordingly to his formula <u>are not elections</u>). Third, he adds that freeing former President Lula was another piece of this elaborate puzzle to steal the election–which he is helping people uncover. He concludes by associating Barroso with a "a leftist affair" in the elections. In our analysis, we found other examples that imply these types of nefarious associations between congresspeople, mainstream media, and the Justice system.

Conclusion and discussion

Our data show that Mr. Bolsonaro employs powerful cognitive strategies similar to those studied in the learning sciences, guiding his followers through an apparently efficient knowledge building process. Instead of simply stating that "elections will be stolen," Bolsonaro makes available a complex set of facts and assumptions that most likely will lead to his desired outcome. Thus rather than statements, he offers "templates" that support people in their understanding of current political affairs, and engage in Socratic dialogue with followers, techniques that are employed to "activate" a coordination class (that borders on conspiracy theories) and ensures loyalty among a consistently significant number of voters in Brazil.

Ironically, these strategies are frequently recommended by scholars in the learning sciences as mechanisms to enhance learning in classrooms. The fact a populist leader is engaging in collective knowledge building with followers using these advanced educational strategies offers a counterintuitive explanation of how they can convince followers about flawed theories to legitimize their controversial (and disastrous) programs. One implication of this preliminary research is that our development as citizens possibly requires a deeper understanding of mechanisms employed by contemporary political discourse that borders, feeds, and taps into conspiracism. Additionally, this complexifies the apparently simple idea that if people have access to more years of schooling, we will be successful in fighting disinformation. *Rather, our educational systems might have to do more than the "instructionist" business as usual,* and help learners strengthen their metacognitive skills, engage in deep cycles of inquiry throughout their school life, and become more aware of situations in which processes of critical thinking and theorizing about political affairs are being manipulated to advance harmful theories. As educators and researchers, it is our role to investigate how to avoid irresponsible exploitation of human's powerful capacity to build robust theories and make sense of complex phenomena even with faulty building blocks.

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International Society of the Learning Sciences

"Do I need to know what I am doing if I am the teacher?" Developing teachers' debugging pedagogies with physical computing

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Abstract. This paper presents findings from a study of middle school science teachers' professional learning activities designed to support the development of their debugging pedagogies. In two iterations of a professional learning activity, teachers worked to find bugs planted by facilitators in physical computing systems they were learning to integrate into their middle school science classrooms. We examine how teachers navigated the tension between developing their own troubleshooting skills versus supporting students' skills in resolving inconsistencies between what they expect of the DaSH and what it actually does. We conclude with implications for the design of PL activities for supporting teachers' debugging pedagogies.

Introduction

There is a concomitant need for designing instructional approaches and tools that integrate computational and data practices into middle school science. As part of a multi-year research practice partnership, our team iteratively co-designed a sensor-based physical computing system, the Data Sensor Hub (DaSH), and accompanying curricular units. The DaSH integrates low-cost programmable sensor technologies to support students in a range of computational activities with data (Gendreau Chakarov, et al., 2021). In the accompanying units, students encounter problems with the DaSH, or bugs, and need to troubleshoot, or debug. For moments of material resistance (Manz, 2015) when the DaSH is not operating as students expect, teachers require pedagogical skills to help students resolve their observed issues and develop their own debugging approaches for future work.

This paper explores how teachers, most of whom do not feel comfortable programming themselves, develop pedagogies to support students to expand their debugging skills. We examine how teachers navigated the tension between developing their own debugging skills and supporting students' learning by analyzing two iterations of a professional learning (PL) activity. In the activity teachers worked collaboratively to find bugs planted by facilitators that commonly occurred in prior classroom implementations. Analyses were guided by the following research questions: RQ1) How did teachers approach debugging in two iterations of the PL activities? RQ2) To what extent did the PL activities foster teachers' evolving debugging pedagogies?

Conceptual Framework: Learning to teach debugging as a situated inquiry

We characterize debugging a physical computing system like the DaSH as a situated inquiry, which "cannot be reduced to pre-specified plans or generalizable procedures" (Flood, et al., 2018; p.1405). Bugs are interactionally produced through a public recognition of an inconsistency between a working expectation of the DaSH and the DaSH's output. Debugging, therefore, requires constructing an expectation, interpreting the DaSH's output, identifying the inconsistencies between the two, and taking action with the system. Debuggers construct expectations of the DaSH by layering inscriptions (Latour, 1986) of the physical system and representations of the environment it interacts with. Inscriptions are physical representations (e.g. charts, graphs, labels) of a process (or physical phenomenon) that social actors use and remake to communicate developing knowledge and associations. The computer program is an inscription of the DaSH's operation while wiring diagrams are inscriptions of the physical setup of a working DaSH. Facilitating students learning to debug as a situated inquiry requires that teachers have flexible knowledge of the physical computing system as well as pedagogical practices. These include teaching moves of modeling and supporting thinking strategies, questioning agendas, and reflecting on applied strategies (DeLeima, et a., 2019).

Methods, Data Sources and Analysis

Teachers in two school districts participated in ongoing PL activities toward implementing instructional units in which students ask questions about environmental phenomena and use the DaSH to measure and visualize data to

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investigate them. The DaSH is a physical computing system consisting of a micro:bit (microcontroller), a gator:bit, and several physical environment sensors which can be programmed using a block-based programming language to collect and display data using sound, an array of LEDs on the micro:bit, and a row of five LEDs on the gator:bit.

This study examines two iterations of a PL activity where teachers worked together to find bugs that students commonly encountered (columns 2 and 3 in Table 1). In the PL, participating teachers worked in groups to find and fix systems with planted bugs (building on Fields et al., 2021) and discussed how to support students. This builds on a "student hat – teacher hat" approach where teachers experience an activity as students would and then consider the teacher perspective.

Analysis centers on a group from both iterations: Episode A involved three participants (Brett, David, and Grace) from Iteration 1. Episode B involved two participants, Aaron and Chris from Iteration 2. Both groups were given the same planted bugs. The activity was designed for participants using the soil moisture sensor to get the DaSH to display a smiley face when the moisture level was ***high***, and an 'X' when the level was ***low.*** Participants were given a DaSH with two bugs: the wrong program was downloaded onto the micro:bit and the correct program listed the soil moisture sensor's connection to the gator:bit on the wrong PIN.

Table 1.
Overview of debugging PL from two iterations and a proposed third iteration detailed in Conclusion

PL Objectives	Participants practice, observe, and discuss how to facilitate debugging moments that students encounter with the DaSH during the Sensor Immersion Unit.		
	PL Iteration I	**PL Iteration II**	**Future PL Iteration III**
PL method, teacher role	Teacher & student hat	Student hat	*Round 1:* Student hat *Round 2:* Both, mostly teacher hat
PL method, participation	Participants rotate through roles as teacher and students pair programming (driver & navigator)	Participants debug together, no official pair programming roles	*Round 1:* Pair programming *Round 2:* Pair in teacher hat supporting the third
PL group size	Groups of three	Groups of two	*Round 1:* Groups of two *Round 2:* Groups of three
Post PL reflection	Whole group discussion focused on debugging with students	Brief whole group discussion that mainly highlighted what bugs people encountered.	*Round 1:* Reflect on debugging strategies *Round 2:* Reflect on debugging pedagogy
Timing	30 minutes of debugging 20 minutes of discussion	20 minutes of debugging 10 minutes of discussion	*Round 1:* 30 minutes *Round 2:* 60 minutes
Directions provided to participants	Teacher hat: One participant in role of teacher Student hat: driver and navigator pair programming	Given expectation for how program should work, told to fix the bugs	*Round 1:* Given notes about the program's expected behavior, told to fix bugs *Round 2:* Help teach debugging skills
Context provided	Participants were told planted bugs mirrored bugs students have encountered	Bugs were explicitly linked to specific lessons in the Sensor Immersion Unit	Bugs explicitly linked to specific lessons in the Sensor Immersion Unit
Challenges of debugging activity	Participants were confused about how those in teacher hat could help. Three minutes in, facilitators explained bugs to those in teacher hat	Because of time constraints, participants did not have the chance to move into teacher hat or adequately reflect on debugging pedagogy.	TBD: activity planned but not yet implemented

Table 1 shows PL activity structure in each iteration. After the first, researchers recognized that combining teacher and student roles created a complexity that would be better placed after all participants could participate as a student (see Episode A below). Researchers also found that providing participants with a written expectation of what the program was supposed to do (referred to as "Expectation" below) would create direction for debugging activities. Additional shifts were also required due to time constraints for PL in District 2.

We used two qualitative methods of analysis to address our research questions: interaction analysis (IA; Jordan & Henderson, 1995) and a grounded approach with inductive coding. To address RQ1, we analyzed video of teachers' debugging tracing the trajectories of inscriptions of the environment, the DaSH, and other resources. We selected a few episodes to view, following the inscriptions teachers developed, used, and rejected to uncover their approaches to debugging. To address RQ2, we used an inductive coding scheme on the PL activity, whole group discussions, and supplementary data (interviews and surveys) to trace the representations of the role of the teacher. Focusing on where these representations unfolded, and where they did not, we developed a view of how the PL activities supported teachers in developing debugging pedagogies, which we address in the discussion.

Analysis

Episode A: Iteration 1 (Grace, David, Brett)

In 30-minutes, Grace, David, and Brett they got the DaSH to perform almost as expected by debugging as a group. At the start, Brett organized them into prescribed roles appointing David the navigator, Grace the teacher (which she initially balked at), and himself the driver. Thereafter, Brett was the only one to physically interact with the DaSH or change the program, limiting Grace and David's access to related and important inscriptions. Brett's interactions consolidated his access to the DaSH and therefore his role as the driver. David's moves supplanted

his navigator role as a support for Brett's investigation by, for example, offering the wiring diagram as a useful inscription. When approached by the facilitator to show her the planted bugs, Grace shared: "*Do I have to know what I'm doing to be the teacher?"* After hearing what the bugs were, she showed a new confidence, saying "*I know the answer.*" Knowing "the answer" dramatically shifted Grace's contributions. Before, she was tentative. Afterwards, she asked Brett to clarify his actions and gave encouragement like "you're on the right track."

In this first iteration of the PL debugging activity, the concurrent need to develop participants' roles (teacher/student and driver/navigator) had a determining impact on how the three teachers approached debugging. They positioned debugging as a distributed process where the driver has access to the DaSH and all possible inscriptions, the navigator offers next steps and resources, and the teacher (who knows what the issues are) clarifies and encourages. Brett's regular narration of his actions (e.g., "I can look through the code) and his thinking (e.g., "there's nothing on P10… so there's a problem") developed a representation of the process for his collaborators. Yet, Grace and David's access to important inscriptions were limited.

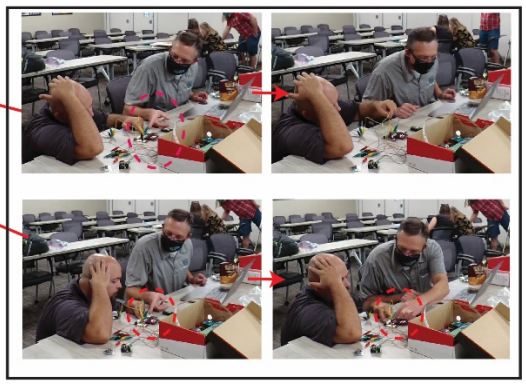
Episode B: Iteration 2 (Chris and Aaron)

In the second iteration of the debugging activity, Chris and Aaron worked without specific roles assigned and were given a written description of what the DaSH should do (*Expectation* below). In under ten minutes, they successfully got the DaSH's output to match the written Expectation. They initially took up distinct approaches to their collaboration: Chris narrated what he saw in the programming as compared to their Expectation and Aaron moved close to the DaSH and examined the physical setup. Collaboratively examining both parts of the system, Chris and Aaron determined the mismatch between the program's Pin and the Pin the sensor was connected to (Figure 3). They changed the program and downloaded the new program.

Figure 3

Transcript with screenshots of Chris and Aaron's production of a bug.

[10] Aaron: Whats::: It's supposed to be on Pin 10=
[11] Chris: =Hold it.
Umm::: According -- it say's get moisture on pin ten in moisture using power pin zero. ((leans to DaSH)). We're using power pin zero ((points to gator:bit)). And:: ((looks back to the computer)) moisture on pin ten, I don't know.
[12] Aaron: Is there a pin ten^. It just looks like one.
[13] Chris: I know there's a pin twelve ((points to micro:bit)). Pin two. Pin eight.
[14] Aaron: Sixteen, five eleven.
[15] Chris: So let's change it to different pin. And it looks like it's pin, one.



The excerpt in Figure 3 exemplifies the complex collaboration between Chris and Aaron. With Chris at the computer and Aaron at the physical setup, they layered inscriptions of the program, the Expectation, and the physical DaSH's wiring, finding the bug through joint work. For example, Chris' turn towards the setup in line 13 joined Aaron's location of the Pin (gesture during line 11) before he suggested they change the program to match the wiring (line 15). Their talk and gestures developed the association between inscriptions of the program and the physical setup to identify the issue. Generally, Chris and Aaron approached debugging as a collaborative, embodied process of collective noticing and decision making. While their emergent roles were somewhat static, they both had access to different inscriptions that, together, made clear what the issue was and what action to take to fix it. This experience has the possibility of developing pedagogies for both Aaron and Chris that support students building the embodied, and collaborative, skills of debugging such a physical computing system.

Discussion

Grace's question in Episode A ("do I need to know anything to be the teacher?") and her gained confidence once later knowing what the planted bugs were ("you're on the right track") highlights a key tension in learning to support debugging: teachers cannot know every issue that will arise and therefore need a different kind of confidence in supporting their students. DeLiema et al.'s (2019) teaching moves for supporting students each imply needing to know inquiry strategies, rather than the source of the issue. Offering teachers opportunities to work on authentic bugs created space for new teachers to develop inquiry strategies that they can model, prompt, and reflect on with their students. These strategies included different approaches to coordinating inscriptions of

the program and wired system (physical system and wiring diagram) and changing the conditions of the system to test. Strategies emerged differently due to differences in PL activity structures. Neither iteration adequately offered teachers opportunities to consider the in-the-moment moves that supporting debugging requires.

In Episode A, the group was asked to model teachers and students doing pair programming. This created varied opportunities for Grace, David, and Brett to experience debugging. Changes in the PL activity for the second iteration led to participants engaging in a more collaborative way with the DaSH, as shown by Chris and Aaron's embodied joint work of uncovering the bug (Figure 3). Post activity reflections confirmed this change: participants' discussion in District 1 revolved around strategies and resources (e.g. programming tutorials, wiring diagrams) they might use to help their students debug. Due to time constraints, discussion in District 2 included participants sharing what bug they found and how. Reflection surveys showed participants found great value in the activity. Yet, they had little time to translate their experience to an evolving debugging pedagogy.

Teachers indicated in surveys and interviews that they want more experience working with the system to gain relevant knowledge and practices. Supporting teachers requires a balance of helping them feel experienced with the technology and prepared to support students' developing situated inquiry skills even when a student comes to them with an issue they have never seen. In both PL iterations, the activity and facilitation foregrounded the importance of finding the bugs, rather than explicitly understanding the strategies participating teachers employed. The first iteration offered some room for participants to consider teacher moves but much less ability to develop their own strategies. The second iteration offered ample opportunity for Chris and Aaron to develop strategies for debugging but offered little experience considering how to engage with students' strategies. Our proposed third iteration (Table 1) offers teachers debugging experience and time to consider pedagogies.

Conclusions and implications: Planning a third iteration

Teaching debugging necessitates finding comfort in not knowing the answer. Professional learning experiences about debugging need to balance supporting teachers in developing debugging experiences and skills with the pedagogical dimension of supporting students to become independent and collaborative debuggers. Both dimensions are important and professional learning experiences should be explicit about which they address and when. Our third iteration addresses the need to support teachers knowing *the strategies* for students to take in-the-moment, not the source of the problem. Teachers need experiences engaging with practicing debugging to develop their own "perception and action" (Flood et al., 2018) so they have relevant experiences with embodied collaboration, noticing inscriptions and making flexible decisions, which is structured in Round 1 (Iteration III). Teachers can then leverage their experiences as they model, rehearse, and reflect on debugging pedagogies that support students developing debugging strategies and mindsets (Round 2), rather than giving them "the answer."

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Caste and Queerness in Hindu India: Examining how Human-More Than Human Relations Shape Learning Spaces

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Abstract: In the aftermath of the Section 377 judgement that decriminalized homosexuality in India, the positioning of Hinduism as historically welcoming and accepting of queerness has swiftly pervaded the Indian landscape. While a useful shift in the public sphere, the intersectional axes of caste, gender, and sexuality within everyday learning spaces is still fraught. In this paper, I examine how the cultural practices of caste-privileged and straight Indian teachers were privileged and shaped learning spaces. Drawing on Indigenous, queer feminist and feminist new materialist theories, the intra-action analysis methods developed in this study trace *how* dominant communities' ways of knowing become inscribed into the meaning that everyday objects in school spaces take on, making invisible, queer ways of knowing and being. This work offers an approach to examining precolonial histories that shape learning spaces in India towards fighting against the rise in Hindu nationalism.

Despite the Right to Education Act (Article 21-A) and state-wide reservation policies that require schools enroll students regardless of their caste and gender, intersectional forms of discrimination persist within schools in India. Briefly, rooted in the Hindu religion, the caste system divides human beings into four *varnas*– Brahmins, Kshatriya, Vaisya, and Sudras. These 'Savarnas' (with caste) are an inherited identity, distinguished in part by the level of purity their being is assumed to embody, with Brahmin cis-males considered the 'most pure' (Upadhyay, 2020). Those outside the caste system (e.g., the Dalit community) are considered 'Avarna' (without caste) and therefore 'impure' and 'untouchable' (Upadhyay, 2020). For centuries, Savarna communities have mobilized Brahminical ideologies around purity to enact horrific violence against Dalit communities, while simultaneously working to institutionalize caste, gender, and sexuality-based discrimination into India's sociopolitical, economic, and cultural spheres (Upadhyay, 2020).

Building on research that examines how Brahminical heteronormative ways of being are privileged and asserted as normative in India's sociopolitical and cultural spheres (Subramaniam, 2019), I examined human-MTH relations that shaped learning spaces. Specifically, I looked at how the cultural practices of Savarna and straight teachers at New School (NS) were positioned as normative (Hand et. al., 2012) and traced how this shaped learning spaces in ways that further oppressed marginalized communities. "Both caste and queerness are about who we can and cannot touch, intimately, privately, and publicly" (Chatterjee, 2018). As such, I recognize these forms of discrimination as a material practice whereby the MTH is deeply implicated in *how* Brahminical ideologies are (re)produced. I ask: *How do human-MTH relations contribute to positioning Brahminical and heterosexual ways of being as normative in school spaces?* Through the analysis I highlight the need for reform in everyday material-discursive practices within Indian schools as one way to fight against the rise in caste and sexuality-based discrimination.

Caste and Queerness at New School: The site of this study

NS was established eleven years ago as part of a township for families moving into the rapidly gentrifying rural area in South India, 2 hours from the closest city. At the time of this study, a large portion of the school identified as middle class families and Savarna castes, with none of the teachers openly identifying as queer. Barfi and Princess were teachers at NS who taught high school finance and psychology respectively. Barfi grew up a in middle class Tamil Brahmin family and did not face significant barriers in accessing an education. Her life was shaped through 'typical' expectations off middle class Tamil Brahmin women – prioritizing a marriage arranged by her family and only then pursuing a career. In contrast, Princess belonged to a Christian and caste-oppressed community from the North-East of India. The product of a matriarchal culture where women were very powerful and respected, being unmarried at 28 years of age (and therefore outside the gendered, heterosexual and Savarna expectations of women) was not an issue for Princess and her family. With Tamil and Brahmin ancestry, my positioning at NS was contextually dependent; I was an outsider to the school community and the country. However, my family's Brahmin lineage positioned me as an insider relative to knowledge of Tamil and Brahmin beliefs and practices. As a (then) unmarried 33-year-old who presented as female, Princess and I bonded through our desire to pursue a career over marriage. At the same time, I understood many of Barfi's cultural practices, having grown up within Brahmin communities in Tamil Nadu and Canada. I also learned to navigate the complexities of being a queer and genderqueer person within my family and the broader Brahmin community,

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"out of line" (Ahmed, 2006, p. 88) with the expectations of a cis-heterosexual Brahmin woman. At the time of the episodes analyzed, I was out as 'lesbian' to Princess and Barfi and as not out as genderqueer.

Theorizing Human-More Than Human Relations

Building on work that recognizes discrimination as a material, spatial and relational practice (Ahmed, 2006), I draw on theory that brings to the fore relations between (and within) humans and the MTH as the unit of analysis. Learning from Indigenous scholars (Bang & Marin, 2015), I build on practices rooted within India that decenter humans as an a priori individual unit and recognize the MTH as an active participant in interactions. Humans and the MTH world are not separated by an a priori static boundary. Instead, boundaries between entities are produced by enactments of power through material-discursive intra-actions. Here, I follow Barad's (2007) use of 'intra' versus 'inter' to recognize that humans and the MTH world do not 'inter'-act across a predetermined boundary. Instead, boundaries between entities emerge through power charged boundary making enactments when matter 'intra-acts' with(in) the world (Barad, 2007). Furthermore, meaning-making emerges through intra-actions within a world of non-static human-MTH phenomena, shaped through boundary-making enactments which are informed by human-MTH relations. In this way, recognizing knowledge creation as the process of engaging in intra-actions illuminates the human-MTH relations that "shape the contours of space" (Ahmed, 2006, p. 3), and the power charged boundary enactments that determine which human-MTH phenomena are allowed within proximity. As I illustrate through the data analysis, repeated power-charged boundary enactments shaped by human-MTH relations (re)produced Brahmin and heterosexual ways of being as normative in the space, what Ahmed (2006) describes as the product of repetition within the vertical and horizontal normative axes. I examined human-MTH relations that took "shape as the 'background'" (p. 88), whereby to deviate from the vertical and horizontal axes of "conventional genealogy" (p. 83) was to bring other human-MTH phenomena closer, "those that would not be allowed 'near' by straight [and Brahmin] ways of orientating" (p. 92) in the world (Ahmed, 2006). In the narrative that follows, I illustrate how Brahminical framings of heterosexuality emerged through human-MTH relations and arranged human-MTH phenomena with the goal of positioning Savarna ways of being as normative by resisting deviant 'acts' (Ahmed, 2006) that attempted to bring queer human-MTH relations and phenomena closer.

Documenting and Analyzing Human-Material Relations and Phenomena

Over six months, I engaged with field observations (Childers, 2013) both inside and outside of classroom spaces, and one structured intra-view (for this study) with each participant (Kuntz & Presnall, 2012). When conducting the structured intra-views, I built on Bang (2020), Marin's (2020), and Kuntz & Presnall's (2012) work to recognize the material world as part of co-constructing meaning-making. Building on micro-analytic interaction analysis (Jordan & Henderson, 1995) methods, 'intra-action' analysis (Krishnamoorthy et. al., 2021) revealed the ways in which different human-MTH phenomena – or intra-actants – intra-acted with each other. I paid close attention to audio recordings of moment-to-moment unfolding intra-actions by examining how human-MTH boundaries emerged through material-discursive practices. Then, I traced the consequences those boundaries had for knowledge creation – particularly whose ways of being were privileged within the ongoing activity. In the analysis, I paid attention to footing (Goffman, 1981) – the alignment of intra-actants with each other – to examine the different speaker roles (i.e., 'animator', 'author' and 'principal') that each intra-actant assumed, towards positioning certain ways of knowing as normative. Examining production formats contributed to identifying cultural frames emergent through the intra-action that allowed only particular types of human-MTH relations to shape the phenomena that emerged. The specific episode presented illustrates a 'hot spot' (Jordan & Henderson, 1995) in the data; a good example of how heterosexual Savarna ways of knowing were positioned as normative.

"I Just Wanted a Cool Nose Ring": Caste and Queerness at Snack time

This episode began when I entered the staff room during the morning snack break. Princess, Barfi, and a few other teachers were at their respective cubicles. I walked past Princess's cubicle and stood, leaning against a cubicle in the middle. Barfi was sitting in her chair by the wall and commented to me, "Look this is your, this nosepin is your grandmom's?"

In this moment, the nosepin emerged in the intra-action as a bounded material delineated as separate from my body and the surrounding matter through Barfi's utterance. I initially hesitated and explained that the nosepin was owned by "M.S Subbalakshmi" (M.S.) whom I authored as a "Carnatic singer", a "really old" and "dead" figure. Barfi and Princess's quick raised pitched overlapping utterances ["ha?", "why?", "you…how?] indicated surprise and shock at the nosepin-M.S. phenomenon that emerged through my utterance. Their reactions revealed a shift in alignment between the teachers and me, suggesting my utterance was a failure to provide the expected response that yes, the nosepin belonged to my grandmother. The intra-action, which began as a

seemingly casual question to me transformed into an unexpected and surprising material-discursive event through this intra-actional break. Princess further probed, specifically asking how *I/my body* came to be in relation with the nosepin-M.S. phenomenon. In response to Princess, I built on my previous utterance to repair (Schegloff, 1997) the shift in footing caused by the intra-actional break and authored the nosepin-M.S. phenomenon as "fake" and a "back up". Barfi didn't accept my efforts to position my relation with the nosepin as less significant through my authoring it as fake; which I authored to maintain the current footing amongst the other intra-actants. Instead, she continued to express her surprise with the nosepin-M.S. phenomenon. In a second attempt at repair, I then positioned myself as "not knowing the gravity" of this event and authored a story in which it was sensible that the teachers and I would not have a shared understanding about the importance of the nosepin-M.S. phenomenon.

The story I authored involved characters from my biological family whose connection with the story character M.S. and practices of material inheritance explained my relation with the nosepin-M.S. phenomenon. In the story, my aunt character – who did not have children – inherited and was wearing my great grand-mother's nosepin, and my siblings did not have their noses pierced so my aunt offered me the one she had received from M.S. In the story space-time, set in M.S.'s house, my aunt was drawn to M.S.'s nosepin and asked for it. M.S. rejected my aunt's bid for the nosepin entangled with her (M.S.'s) face but offered what M.S. authored as not the "real one". The nosepin offered to my aunt was positioned as fake because M.S. wore it when her "real one (was) getting cleaned". Here, I built on the repair initiated earlier to position 'fakeness' as determined by *when* the M.S. character was entangled with the nosepin she gave my aunt.

While listening to the story, Barfi did not challenge and therefore seemingly accepted the logic of inheritance and the history of human-MTH relationships that allowed me to be relation with the nosepin-M.S. phenomenon, revealing a taken-as-shared recognition of the straight vertical axis (Ahmed, 2006) that frames heterosexual genealogical inheritance within this context. Furthermore, Barfi did not challenge that the aunt character in the story space-time might be at the M.S. character's house and in a position to ask for an object of material significance (to the teachers in this context) from her. This is significant because the sociocultural and historic relations required to accept this story - specifically that the relationship between my aunt and M.S. might have existed and been intimate enough to allow my aunt to ask for and receive a nosepin reveals an acceptance of me (and my aunt) as someone with ancestral and current access to the largely Brahmin Carnatic music community.

A few minutes later, I then offered a bid to nuance how *I* was in relation with the Brahmin community through the nosepin-M.S. phenomenon by offering, "um. But I wear it because…". This attempt was not taken up by Barfi, who in overlapping Tamil utterances, continued to discuss the design of the nosepin with other teachers in the space. Then, a teacher who had just walked in paused when she heard the intra-action. She shifted her gaze, her eyes widened, and she reached over to my body and performed a movement in Tamil, referred to as '*otthikardhu*'. The act is often performed by touching the "eye or lip gently, after touching […] a revered or beautiful object" (Oxford University Press, 2009). This moment framed the MTH as sacred or that which was to be revered, further resisting my bids to shape *my* relation with the phenomenon. Once again, I attempted to refigure the nosepin-M.S. phenomenon as just "a really cool nose ring", but instead Barfi authored me at a "different level of respect now". That is, I was to be respected at a "different level" now that the sedimented framing of the nosepin-M.S.-Rishi phenomenon was aligned with a Brahmin-Carnatic music sociocultural and historic meaning. Importantly through the intra-action, my multiple bids to repair the intra-actional break initially and then contribute to meaning-making around *my* relation with the Brahmin community and the nosepin-M.S-Rishi phenomenon were ignored by the other intra-actants when not aligned with(in) this framing. My higher level of respect was emergent through and contingent on my position as a genealogical descendent and member of a specific Brahmin and Carnatic music community, and my entanglement with an object symbolic of those relations.

Heterosexuality, Brahminism and the Nosepin-M.S.-Rishi Phenomenon

Key to this analysis is that as a queer and genderqueer person, the ability to inherit valued materials and be a ratified member within the Brahmin community was also contingent on my gender and sexuality as invisible. Caste is inherited but only through the male lineage. As a queer, genderqueer, and (at the time) unmarried person, I was technically still considered a Brahmin with my membership in the community only accepted when hiding my queerness. Through the episode, the vertical axis of genealogical inheritance (i.e., inheriting from my aunt and M.S.) produced the nosepin-M.S. phenomenon as a heterosexual object "personalized as […] my background or as that which allow(ed) me to" (Ahmed, 2006, p. 88) be considered a human at 'one different level of respect now'. The sedimented framing of the nosepin-M.S.-Rishi phenomenon and the consequences of respect only held true when imposing Savarna heterosexuality as the background. As a queer and genderqueer person who is "out of line" (Ahmed, 2006, p. 92) with(in) the heterosexual Brahmin and Carnatic music community, my bids were evidence of my attempts to bring "other objects closer, those that would not be allowed 'near' by straight ways of orientating the body" (Ahmed, 2006, p. 92). In this episode, the heterosexual Savarna 'background' (Ahmed, 2006)

emerged through human-MTH relations that sedimented the nosepin-M.S.- Rishi phenomenon as a sacred material to be revered and me, as a human to be respected at 'another level', while silencing the queer 'slanted' frames.

In the aftermath of the Section 377 judgement that decriminalized homosexuality in India, the positioning of Hinduism as historically welcoming and accepting of queerness has swiftly pervaded the Indian landscape (Upadhyay, 2020). At the same time, this acceptance exists alongside caveats that consider queerness as "a 'psychological case' and queer relations (as) 'not compatible with nature'" (Sethi, 2018, as cited in Upadhyay, 2020, p. 472). Therefore, while a useful shift in the public sphere, the ways in which caste, gender, and sexuality intra-act within everyday learning spaces is still fraught. In this episode, the nosepin drew Barfi's attention the day I arrived at NS and did so once again when it entered the staff room the day of this episode. My Brahmin biological ancestry emerged through the nosepin's intra-actions and shaped the permitted human-MTH phenomena brought into proximity in the staff room space. Drawing on Kondaiah et. al., this episode illustrated that even though "no one talked about caste there […] everything gave (it) away" (2017, p. 75). In this case, my Brahmin biological ancestry emerged through the nosepin's intra-actions and shaped the permitted human-MTH phenomena brought into proximity in the staff room space.

Dalit feminists have long argued that the intersections of caste, gender, sexuality, and class cannot be ignored when working towards dismantling Hindu supremacy in India (Pawar & Moon, 2008). This paper builds on their work by illustrating that resisting the power of Hindu majoritarianism in education requires more nuanced analysis of how our learning spaces are shaped with/through human-MTH relations. I argue that resisting the power of Hindu majoritarianism in education requires more nuanced analysis of how our learning spaces are shaped with/through human-MTH relations by challenging Brahminical heteronormative framings of human-MTH phenomena that privilege Brahminical ways of knowing.

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Museum-Led Design of Student-Centered K-12 Learning: Where Informal Perspectives Meet Formal Requirements

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Abstract: Many museums create educational content for K-12 students and classrooms, bringing informal learning opportunities to formal educational contexts. The design considerations prioritized by these teams and the assumptions that influence these priorities impact the final product they create. In this paper, we describe how a museum-based design team created a learning module for use in K-12 classrooms. We report our analysis of five design team meetings and five individual semi-structured interviews, spaced strategically throughout the design process. We share what design considerations the team prioritized over time and highlight how team members verbalized assumptions about student-centered learning.

Introduction

Museum education departments are charged with carrying out the educational mission of museums, which often involves the design of activities, and materials for K-12 students and teachers. These learning experiences leverage museum collections and informal learning pedagogies while supporting and/or meeting educational standards (Feinstein et al., 2013; Garcia, 2012; IMLS, 1996; Kisiel, 2014; Kristinsdóttir, 2017).

For interdisciplinary teams of educators, curators, and researchers developing learning experiences, their design processes incorporate explicit and implicit assumptions and values about K-12 student learning (Garcia, 2012; Kisiel, 2014). However, these values and assumptions are not always visible, and different interpretations of the same concept may exist within the same team, especially with varying expertise on an interdisciplinary design team. Creating greater transparency into these design processes, and especially assumptions about student-centered learning, can help design team members to understand how they communicate and prioritize design considerations when making decisions that impact students and teachers.

To better understand how the assumptions of design teams influence the development of K-12 learning experiences, we examined how a museum-based design team developed a new inquiry investigation. Our goal was to identify the team's key design considerations and changing prioritizations based on analysis of meetings and semi-structured interviews. We also aimed to identify assumptions about student-centered learning based on team members' language about situating themselves in the minds of students.

We used values-led participatory design (Iversen et al., 2012) to identify the underlying values and assumptions that drove prioritization of design considerations and justifications. In examining how power is distributed among stakeholders, values-led participatory design specifically attends to stakeholders' values and their influence on the design process. In this study, we examined how individual design team members revealed their values and assumptions about science learning during meetings and interviews, with specific attention to the design considerations in play; the prioritization of different considerations over time; and the language used to communicate how team members situated themselves within the mind of a student. While the team under study did not actively invite students and teachers as co-designers, we found this lens helpful as a way to identify the values present and how those are shaping the design of the learning experience.

Methods

The design team at a museum in the American West has collaborated for approximately four years and consists of eight members. All team members agreed to take part in this study. The team's design efforts focus on an initiative about developing inquiry-based investigations for K-12 students and teachers that support engagement with NGSS science and engineering practices, especially gathering and analyzing data. Students receive guidance from museum scientists as they gather data and analyze data from digitized museum specimens, models, and simulations. Together, the activities incorporated into these investigations are designed to mimic the work of scientists at the museum as "authentic" science learning experiences.

The first author is an established member of the team and obtained consent to record team meetings over Zoom. She also conducted semi-structured interviews with one team member each week on a rotating basis. Interviews lasted an average of 20 minutes and included questions about how they felt the meeting went, what ideas stood out to them, and how decisions made during the meeting would impact the product and eventual users.

From video recordings of team meetings and interviews, we used informed grounded theory to develop a coding scheme that identified design considerations across meetings (see Table 1 below) as an extended design

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process (Derry et al., 2010). We selected five meetings and five interviews at regular intervals between May – November 2021 for binary coding of design considerations (i.e., discussed or not), then calculated the total frequency of codes across meetings and interviews. We created a CORDTRA diagram to show how prioritization of design considerations changed over time. Last, we identified quotes from team members that reflected their perspectives on student-centered K-12 learning as shared during meetings and interviews. These quotes illustrate how team members situated themselves in the mind of a student, and thus may indicate underlying assumptions and values about student-centered learning.

Table 1
Coding Scheme for Design Considerations Emphasized by Museum Design Team Members

Code	Description	Example
Student interest	Considerations about how to motivate and measure student interest.	"What makes it really fun and highly engaging?"
Student prior knowledge	Questions or statements about what students already know about the topic of the investigation.	"It feels like there are a set of questions that we could ask that would help us glean interest level, misconceptions, potential scaffolds that are necessary."
Student reasoning	Considering students' scientific and/or mechanistic reasoning processes while brainstorming and planning learning tasks.	"What would that allow [students] to conclude?"
Relevance to students	Looking for ways to integrate and highlight connections between a topic or activity and students' lives.	"Create some personal connection to it. You know, you need energy to survive, how do you get it?"
Authentic data and methods	Emphasizing the value of authentic science data, practices, and research method in the design process and in learning activities.	"What we are making is authentic. Whatever we ask students to do will be well-reasoned and authentic."
Alignment to NGSS	Alignment to Next Generation Science Standards (NGSS) and related state education standards.	"Science teachers are married to their core, to the NGSS standards…If you stray too far from that, they won't see the connection."
Constraints on scope/scale	Mentions of the ways that project resources and requirements constrain design.	"We're still negotiating where the [investigation] data is coming from."

Findings

Our findings are presented as three components: design considerations; temporal analysis; and student-centered perspectives. Table 2 reports the frequency of each design consideration across meetings and interviews. We found that "authentic data and methods" were mentioned most often (80% of meetings, 60% of interviews) by team members. "Student reasoning" was another frequently occurring design consideration (80% of meetings, 40% of interviews), as well as "alignment to NGSS" (60% of meetings, 40% of interviews). These considerations seem to be high priority to the design team. We also noted that several design considerations were mentioned in meetings or interviews, but not both. For example, "student prior knowledge" is discussed in 40% of meetings but no interviews, and "constraints on scope/scale" are discussed in 40% of interviews but no meetings.

The CORDTRA diagram (Hmelo-Silver et al., 2009) in Figure 1 below shows emergent design considerations in meetings and interviews over time. Overall, more design considerations are present in later meetings and interviews, with all design considerations appearing in the most recent two meetings and interviews. "Authentic data and methods" frequently occurred at each stage in the design process, both for meetings and interviews. "Student reasoning," another high-priority design consideration, appeared consistently in meetings. Though "alignment to NGSS" emerged as high priority, its discussion was late and inconsistent across meetings. We also examined how less frequently mentioned design considerations were discussed over time. "Student interest" was discussed in the May, July, and August meetings, but then was not discussed until the November interview. An earlier focus on "student interest" may have been replaced with greater emphasis on "alignment to NGSS" as the team decided on a topic and progressed toward active design of the investigations. "Student prior knowledge" was discussed during September and October meetings. "Relevance to students" was discussed in August and September meetings but did not occur otherwise. "Constraints on scope/scale" were discussed only in interviews for October and November.

Table 2
Frequency of Binary Codes Discussed During Meetings and Interviews

Code	Meeting Frequency	Interview Frequency	Total Frequency
Student interest	3	1	4
Student prior knowledge	2	0	2
Student reasoning	4	2	6
Relevance to students	2	0	2
Authentic data and methods	4	3	7
Alignment to NGSS	3	2	5
Constraints on scope/scale	0	2	2

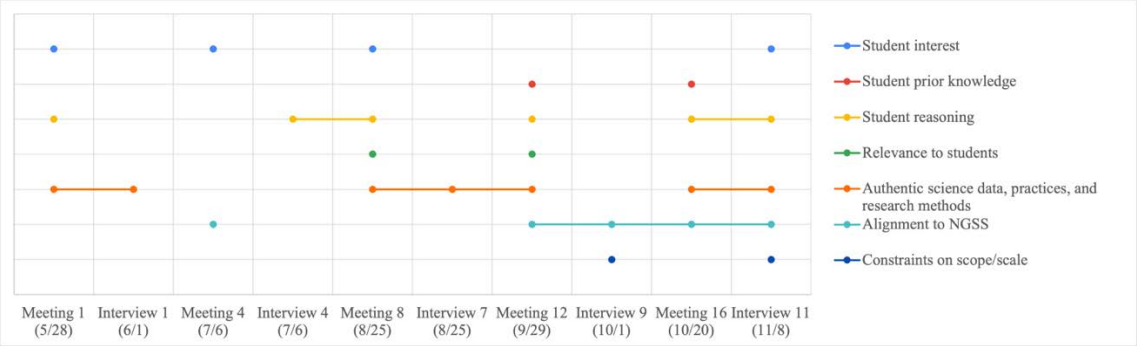

Figure 1
CORDTRA Diagram: Design Considerations Over Time

In analyzing team meetings and interviews, we noticed that design team members used specific language to indicate that they were taking on a student-centered perspective in their design considerations based on their assumptions of students' academic needs. The first two quotes below show how team members imagined each other or themselves as middle school students. The third quote illustrates how team members made assumptions about students' prior experiences with the investigation topic. The fourth quote shows how team members projected their understanding about students' capabilities regarding a given topic.

> Can you pretend like I'm a middle schooler actually? (Meeting 16, 12:33)
>
> As a student, I might look at that and be like, "Oh, that matters…" (Meeting 16, 1:33)
>
> I think students are used to thinking of tree rings for growth. But I don't know that they've ever really thought too much about the age, climate, related sort of health and, you know, robustness of the tree. (Meeting 16, 27:12)
>
> When I think about what a student could possibly walk away with… (Meeting 16, 29:08)

In these meetings, team members referenced what they think students feel, want, and need based on their range of personal and professional experiences. In turn, team members used these experiences to guide their interpretation of scientific information and the construction of learning tasks for students. These assumptions and interpretations ultimately impacted discussions of design considerations and decisions about design elements.

Discussion & Conclusion

Museum design teams are uniquely positioned to contribute to K-12 learning spaces by designing learning experiences that incorporate informal institutional assets. This study aimed to investigate a museum-based interdisciplinary design team's identification and prioritization of design considerations discussed during team meetings and individual interviews when creating inquiry-based investigations. We also noted language that indicated how team members situated themselves in the student role as a way to express and justify design decisions. In our analysis of selected meetings and interviews, we found that the team most frequently prioritized "authentic data and methods," followed by "alignment to NGSS" and "student reasoning." These design considerations became a greater focus of discussion later in the design process.

The emphasis on "authentic data and methods" and the "alignment to NGSS " throughout the design process illustrate two key goals of both formal and informal science education: authentic experiences and

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baselines for science understanding. Prior literature notes the importance of considering formal education contexts and assets when planning successful cross-over experiences between formal and informal learning environments (Garcia, 2012; Kisiel, 2014). The inclusion of NGSS alignment as a goal results from experience working with and designing for K-12 teachers and students. Meanwhile, "authentic data and methods" draws upon the team's experiences as informal educators and unique strengths of the museum's collections and scientists. The emphasis on both authenticity and educational standards in team meetings and interviews illustrates how the team considers both formal and informal learning assumptions and requirements. This finding highlights museums' role as spaces that blur the lines between formal and informal education settings (Kisiel, 2014; Kristinsdóttir, 2017).

As an interdisciplinary team, different team members have different experiences with both formal and informal education settings and likely hold different assumptions related to teaching, learning, and design. These assumptions became apparent in team meetings and individual interviews. For example, "authentic data and methods," "alignment to NGSS," and "student reasoning" appeared frequently throughout meetings and interviews, indicating that these are important design considerations for the whole team. In contrast, "constraints on scope/scale" appeared in two interviews, indicating that this design consideration may be more salient for some team members than others. The differences in assumptions held by team members mean that the common goal of designing student-centered experiences may be interpreted and acted on in a variety of ways, ultimately impacting the final product and its users (e.g., K-12 students and teachers). These findings have implications for other design teams situated in environments that span informal and formal learning. Future analysis of team data will use discourse analysis of negotiated meanings and their relationship to assumptions used to guide design decisions.

While this museum design team's approach does not explicitly incorporate participatory design, it does connect stakeholders representing different values, experiences, power dynamics, and goals to collaboratively create a product (Bang & Vossoughi, 2016; Kristinsdóttir, 2017). This attempt to democratize the design process is characteristic of participatory design projects and, in this way, the project resembles some of the challenges and opportunities that come from participatory design approaches. The lens of values-led participatory design highlights whose ideas are being heard, and whose are not, and draws on the ways values are being represented and influence the design process and products in ways that will ultimately impact the users.

In conclusion, this study provided insights into the design considerations prioritized by a museum design team and the ways that underlying assumptions about student-centered learning were expressed throughout different points in the design process. These insights serve as a first step toward deeper analysis of team members' discourse that shapes how design considerations are introduced, negotiated, and implemented. We plan to investigate how design considerations that appear to be the same on the surface (e.g., "alignment to NGSS") can be interpreted and applied differently based on the experiences and assumptions of individual team members. Understanding the underlying assumptions about and negotiation of design considerations can show a path for moving more intentionally towards shared consensus that benefits the design team members and eventual users.

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Comparative analysis of the rule-based and machine learning approach for assessing student reflections

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Abstract: This study describes Natural Language Processing (NLP) and rule-based algorithms used to assess the students' written reflection quality. We used the CourseMIRROR application to gather student reflections from 120 engineering students and converted the reflections into an equivalent quality score using human coders and algorithms. We used Cohen's kappa statistics to explore the agreement between the algorithm's reflection quality and the human coding. The results revealed a strong agreement between the NLP algorithm and human coding. Furthermore, we used Spearman correlation statistics to evaluate the relationship between the predicted quality scores and the human coding. The results showed a strong correlation between reflection quality evaluated by the NLP algorithm and human coders. Overall results revealed that the NLP algorithm embedded in the CourseMIRROR application is a good fit for assessing students' reflections and can be used to guide them during the reflection writing process.

Keywords: Reflection quality, scaffolding, mobile application, learning environment, reflection specificity, NLP algorithms, rule-based algorithm

Introduction

Fostering reflective thinking is an important instructional practice (e.g., Bannert, 2006; Stark & Krause, 2009). It involves students in a meaning-making process that helps them make connections between their prior knowledge and learning experiences, deliberately systematizing their thinking with an attitude of valuing themselves and others in a community (Dewey, 1933). Studies have shown that the reflection writing practice can promote students' engagement (Menekse et al., 2020), help them identify their misconceptions (Tawde et al., 2017), and improve their learning outcomes (Miller & Jensen, 2016). Fan et al. (2015) developed a mobile application (i.e., CourseMIRROR) that gathers students' reflections by prompting them to reflect on their experiences after each lecture throughout the semester to facilitate the integration of reflective practices in the classroom. Also, it provides real-time feedback by assessing the reflection quality during the reflection writing process and guiding users towards writing specific rather than generic reflections. Here, the reflection quality indicates the extent to which the reflection is relevant to the reflection prompt and the course.

This study describes two quality prediction algorithms (based on Natural Language Processing (NLP) and a rule-based approach) that can be used to improve the application's ability to evaluate the students' reflection quality. For the study, we collected students' reflections using the CourseMIRROR application and converted the reflections into the equivalent reflection quality scores coded by two human coders. Then, we explored whether the reflection quality assessed by the NLP algorithm and the rule-based algorithm is similar to the reflection evaluation conducted by human coders. Specifically, this study is guided by the following research question: how does the reflection quality assessed by two quality prediction algorithms relate to human coding?

Related work

Based on the reflection literature, the commonly used method to evaluate reflection writing is through content analysis (Ullmann, 2019). A typical content analysis process includes 1) reading students' reflections, 2) manually labeling them with self-described categories, and 3) converting these categories into quality scores of the reflection. Furthermore, the focus of prior studies using content analysis was to identify the level of reflection quality (i.e., shallow or deep reflection) by analyzing students' reflection journals and essays (Kovanović et al., 2018). Hence, researchers are exploring ways to automate this reflection process and facilitate the adoption of reflective practice.

Researchers are utilizing computational advancements to design automatic text analytics for assessing the students' reflection texts among the ongoing efforts. According to Ullmann (2019), these text analytics are being designed by broadly using three approaches, i.e., dictionary-based approach (find the occurrence of predefined words in the text), rule-based approach (using the rule to get better inference from the text), and the machine learning (ML) approach (using ML algorithms). Based on the previous approaches, this study utilized two algorithms 1) Rule-based algorithm where the expert has defined the pre-set pattern and their associated

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weightage, and 2) NLP algorithm trained on different educational reflection sets. Further, this study investigated the relative efficacy of these algorithms in the reflection quality.

Participants and dataset

We recruited 120 first-year engineering (FYE) students enrolled in a required engineering course from a large midwestern university located in the United States for the study. The topics covered in the course were introductory computer programming concepts, development of mathematical models, data visualization, and designing solutions for engineering problems. Of the participants, 83% were male students, and 17% were female students. Also, 61.7% were White, 21.7% were International Students, and 16.6% were People of Color (POC). Furthermore, the dataset used for this study consists of 3452 individual reflections from 28 lectures.

Instrument

We used CourseMIRROR educational application to collect students' reflections. This application prompts students with two open-ended questions to reflect on the confusing or interesting concepts at the end of each lecture. Additionally, it uses Natural Language Processing (NLP) algorithms to create students' reflections summaries by combining the reflections based on common themes (Luo et al., 2015). For the study, students voluntarily participated and submitted 3452 reflections (i.e.,1726 reflections for each question) in 28 lectures throughout the semester. Furthermore, these reflections were analyzed by two human coders based on a rubric (Heo et al., 2018; Menekse et al., 2011) and then assigned a quality score. We calculated the agreement between the two raters, and they showed good agreement, as κ (MP) = .617 and κ (POI) = .652 (Altman, 1990).

Reflectivity quality models

Following are the two approaches used to design the quality prediction algorithms that are used to assess the reflection quality:

Machine learning approach

In this approach, we utilize recent SOTA models in NLP to automatically produce a quality score. Our work uses a basic model consisting of a feature generation module followed by a classification module for score generation. In order to generate features, we used a transformer-based bidirectional deep contextual language model to automatically generate features. The module operates on the raw input text and automatically converts the text into numerical features. We used DistilBERT (Sanh et al., 2019) model for feature generation. The model is a distilled version of the original BERT (Devlin et al., 2018) transformer-based encoder. DistilBERT reduces the number of parameters to around 60% of the original BERT (110M to 66M). This, in turn, allows the model to be faster and more suited to real-time quality prediction. We used a logistic regression classifier for the classification module that operates on the generated features and produces a score of 1, 2, 3, or 4. We only train the logistic regression classification module and keep the DistilBERT parameters fixed. This can reduce the load required for training the model and similarly allows us to easily fine-tune the model with new samples acquired through time.

Rule-based approach

In this approach, a team of educational researchers defined a set of patterns and their associated weightage to score the reflection quality. Based on these rules, we designed an algorithm used to predict the reflection quality. Table 1 describes the few rules and their associated score used to design this algorithm:

Table 1
Rules with associated weightage used for rule-based algorithm

Number	Pattern	Quality Score
1	"how|what|when|where|which"	0.25
2	Keywords (extracted from the syllabus, and learning objective of the class)	1
3	"compare|comparison|difference|differentiating|determining|determination |relationship|relation|between"	0.29

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6	"^pretty clear|straightforward"	-0.6
7	"^everything|^nothing|^none|^nope|^null|^no$|^no\\s"	-0.6
10	“understood everything”	-0.6
11	"I|explanation|example"	-0.3
12	"this lecture|the lecture|all|completely"	-0.3

To evaluate the reflection quality, this algorithm parses the students’ reflections and uses regexes to count the occurrence of each pattern in the string. After that, it calculates the reflection quality by rounding off the sum of the associated weightage of each pattern based on their occurrence. Furthermore, we modify the predicted quality score to either 1 or 4, if the values go less than score 1 or more than score 4, respectively. This way, the range of the quality score is between 1 to 4 points.

Results

We divided the reflection into two sets: 1) reflections discussing the interesting aspects of the lecture and 2) reflections discussing the confusing aspects of the lecture. For the remaining paper, we will refer to the first set of reflections as “Reflections 1.0” and the second as “Reflections 2.0,” respectively. Then, we converted the reflections into the equivalent quality scores evaluated by NLP and rule-based algorithms. The quality scores range from 1 to 4 points, where a score of 1 indicates poor relevancy, and a score of 4 indicates high relevancy with the course/question. For analysis, we calculated Cohen’s kappa to evaluate the agreement between the human, NLP, and rule-based algorithm’s reflection quality scores. The result of the analysis is shown in table 2:

Table 2
Cohen’s κ co-efficient among the reflection quality scores

	Reflections 1.0			Reflection 2.0		
	1	2	3	1	2	3
1. Human coding	-	-	-	-	-	-
2. Rule-based algorithm	0.042	-	-	0.068	-	-
3. NLP algorithm	0.775	0.033	-	0.773	0.067	-

As shown in the table, it is quite evident that the NLP algorithm has a strong agreement while evaluating the reflection of both reflection sets (i.e., κ (NLP) = .775 and κ (NLP) = .773) with human coding. The rule-based algorithm has close to no agreement (i.e., κ (NLP) = .042 and κ (NLP) = .0.068) for both reflection sets with human coding. We conducted the Spearman Correlation statistics to further enhance our analysis to explore the correlation between reflection quality evaluated by the quality prediction algorithms and the human coders. The result of the analysis is shown in Table 3:

Table 3
Spearman correlation among the reflection quality scores

	Reflections 1.0			Reflection 2.0		
	1	2	3	1	2	3
1. Human coding	-	-	-	-	-	-
2. Rule-based algorithm	0.479**	-	-	0.435**	-	-

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3. NLP algorithm	0.837**	0.496**	-	0.859**	0.485**	-

**Correlation is significant at the 0.01 level (2-tailed).

The results showed that the correlation between the rating evaluated by the NLP algorithm and the human rating has a strong correlation for both sets (i.e., r = 0.837, 0.8359), with each having 1752 reflections. Even though the correlation between reflection quality scores evaluated by the rule-based algorithm has a strong relationship (i.e., r = 0.479, 0.435; N = 1752) with human coding, it is much lower than the NLP algorithm.

Conclusion

The current study has described two approaches that can be used to evaluate the students' reflection quality. One approach used the expert's defined pattern, and the other used the NLP algorithm to evaluate the reflection quality. This study investigated the performance of both approaches in terms of their ability to produce similar results to the human coders. Our results showed that the NLP algorithm based on the DistilRoBERTa and DistilBERT with SVM is a promising model to evaluate the reflection quality.

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International Society of the Learning Sciences

"Love Struggle, Love Self, *regardless**:" Arts Organization Leader's Use of Socio-historical Analytic Artifacts in Their Determinations of Successful Teaching Artists

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Abstract: Black artists fill the (art)world with images, objects, sounds, and experiences that disrupt sociopsychological functions shaped by anti-Black racism (Fanon, 1952; Wynter, 1999, 2005; Gikandi, 2011). Learning in and through the arts has been a major vehicle for animating Black communities' resistance to dehumanizing experiences across space and time. Out-of-school time arts organizations serve as fugitive learning ecologies where creative risks can be taken up and celebrated as material and embodied forms of resistance. This paper details the ways three Black women-identifying out-of-school time arts organization (BW-OSTA) leaders use social analytic artifacts (Vossoughi, 2014) derived from an historical art exemplar to determine what makes a successful teaching artist. Using a socio-historical approach to re-mediation (Cole & Griffin, 1983) and risk (Lee, 2009), this paper tethers the politics and ethics of an exemplary Black artist to the determinations of successful teaching made by three contemporary BW-OSTA leaders.

Key terms: Learning in and through the arts, risk, resistance, socio-historical, social analytic artifacts, re-mediation, successful teaching

Introduction

As Sylvia Wynter (2005) stated, the invention of "Man" in modern humanism was made possible by ontological and epistemic violence that rendered Black people antihuman (p.128-129). Black arts and Black aesthetic movements have long served as interruptions to this violence, as the material, ideological and sonic creations provided opportunities to create habits of mind within but not of the structuring violence of enslavement and its afterlife. Acts of risk-taking and resistance to anti-Black violence that occur through learning in and through the arts can be seen in the New Negro Movement This generation of formal artists includes the life and works of Miss Augusta Savage, a sculptress, teaching artist, and community-based organizational leader. Her story is of vital importance for demonstrating the way Black artists have used the means of cultural production to engage the symbolic material of daily life to recreate self-representations without rearticulating dominant relations (Gaztambide-Fernández, 2013, p. 227) and the risks involved in those pursuits. Miss Savage's everyday applications of symbolic creativity to symbolic materials and resources throughout her life shaped her political and ethical commitments in important ways. As James Baldwin and Frantz Fanon have stated, "the purpose of an education is to learn how to live" (Baldwin, 1963) and "in the world through which I travel, I am endlessly creating myself" (Fanon, 1952/2008, p. 179). As Augusta moved through the (art)world, she recreated herself to meet the needs of her community.

Arts Organization Leader, Miss Augusta Savage

Miss Augusta Savage began sculpting animal figurine "friends" using red clay in her backyard at an early age. Born to a family of 14 children and two working parents, her father discouraged her artistic skill, believing it was sinful and refusing to acknowledge the practice as a form of psychic refuge for the introverted young girl. As a result of her mother's encouragement, Miss Savage moved from Florida to New York where she trained professionally and met, during the New Negro Movement, many of the greatest race scholars, artists, and activist in history. As an employee of the Federal Arts Program (FAP), an effort under the Works Progress Administration (WPA) to boost morale after the Great Depression (Lance, 1982), she was a fierce and demanding advocate for young people's artistic development and gainful employment for professional artists. After teaching some formal and community-based arts courses, Miss Savage opened the Savage Studio for Arts & Crafts in 1932, became the first director of the Harlem Community Arts Center in 1937, and opened the Salon of Contemporary Art, the first gallery in America devoted to the exhibition and sale of the works of black artists, in 1939 (Hayes, Buick, Cook, & Savage, 2018). Her accomplishments allowed for the Harlem community to have free and work-as-you-go art classes, student teaching experiences, gainful employment in the arts, and opportunities to exhibit and sell artwork in an all-Black gallery (U.S. National Park Service).

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At the height of her success, Miss Savage fell on hard times. The Salon for Contemporary Negro Art closed within three months of its opening due to a lack of artists, collectors, and a dedicated audience who could contribute to the consistent creation, sale, and growing discourse of art by Negro artists. The paranoia of the emerging era of McCarthyism positioned Savage under a great deal of scrutiny for her activities with young people. As Sharif Bey highlights in his 2017 article, Augusta was seen as a nuisance to a great deal of WPA administrators for advocating for Black artists to have more gainful employment opportunities under the FAP. She also helped establish the Vanguard Club, a youth arts and activism guild that was supported by well-known communists (Bey, 2017). With hesitant support from the government, the Harlem Community Arts Center and with federal funding for the arts slowly being reallocated to war efforts, Augusta's professional and personal investments seemed to disappear from the public view.

Her latest piece was created in 1959, three years before she passed, while living in Saugerties, NY. While in Saugerties, Augusta purchased and renovated a home with a farm and art studio that met her basic needs. The contours of her life, seemingly coming full circle are too uncanny to be by accident. From a small girl imagining a life amongst the animals to a now 53-year-old woman with her own farm, income, and space to work on whatever art she pleases, Miss Savage continued to blossom in her own self-determination to create the life she imagined as a child. She continued to teach and create art for 15 years. She was diagnosed with cancer at age 69 and passed away in the following year on March 30th (Hayes, et al., 2018).

Theoretical framework

Learning risk & resilience in and through the arts

In my use of a socio-historical approach to re-mediation, I position the thinking of each BW-OSTA leader deep "into the past to trace the basics of [racial] literacy all the way back to the beginning" (Cole & Griffin, 1983,p. 69), mapping the moments of consequential learning within and across temporal, social, and spatial scales of action (Gutiérrez, Engeström, Sannino, 2016, p.278) during slavery and its afterlife. The life of Miss Augusta Savage is full of acts of refusal, fugitivity, and escape- important habits of mind, or social analytical artifacts (Vossoughi, 2014) that necessitate a cultural-ecological framework of risk that locates consequential learning in and through the arts in the everyday practices of Black survival.

Learning to live while constantly (re)creating yourself is an expansive notion of learning through everyday activity. In the life and works of Miss Savage, we see the ways that learning in and through the arts is a consequence of dynamic, adaptive processes linked to issues of identity (Lee, 2009, p.78). In both the telling of Miss Savage's story and the survival of her artwork, the many modes of risk and resilience present in her psychosocial resources for arts-based praxis can be discursively situated as a precursor to those of contemporary teaching artists. Using the cultural-ecological framework for learning and development, I view Miss Savage and her creative praxes as ideological resources or habits of mind. In arts-based organizations, whose daily work continues to be fraught with refusals to anti-Black racism and celebrations of creative risk-taking and resilience, young people, teaching artists and organizational leaders continue to make sense of and respond to the on-going and emergent ways they experience historical inequality (Lee, 2009, p. 78). These responses are access points to knowledge pathways that reduce cognitive labor and provide support for learners to persist (Lee, 2009, p. 86).

These arts-based knowledge pathways are funds of knowledge (Gonzalez, Moll, Tenery, Rivera, Rendon, Gonzales, & Amanti, 1995) that have developed over and across time and are historical examples of expansive learning and boundary crossing (Engeström & Sannino, 2010, p. 13). Black people have learned and continue to learn about the antagonistic relationship between Blackness and humanity. I use a socio-historical approach to re-mediation and risk to demonstrate the ways BW-OSTA leaders in this study are accessing psychosocial resources from the past and locating their determinations of successful teaching artists in opportunities for creative risk-taking, escape, and refusal of anti-Black inquiries and methods. In the next section, we review our methods for analyzing these resource and knowledge pathways.

Methods

The conditions of the historical moment call attention to the ways those methods have been culturally produced in crisis. Data for this study was collected through Zoom interview due to the COVID-19 social distancing and travel restrictions. We use critical visual discourse analysis to analyze each BW-OSTA leaders' sensemaking in their mission statements and interview data, alongside analysis of their activities during the interview context. Analyzing the visual alongside the textual re-mediates the discursive practices of Miss Savage into the methodology for data analysis.

Through web content and audio-visual recordings of interviews, we used normative-evaluative reconstructions (Carspecken, 1996) to conduct a critical discourse analysis using web content and Zoom interview data. Through several rounds of low and high level concept and value coding followed by meaning field mapping,

we determined each leader's conception of "success," "successful teaching," and/or "successful teaching artists" to understand what politics and ethics shape their thinking. Depending on one's proximity to power and their positionality within arts organizations, organizational values held by leaders are shaped by the politics and ethics they have about "success."

Findings

In her focus group interview "R" names that she is very intentional about preserving the rich artistic history of Detroit, particularly their Motown legacy and names that successful teaching artists know of this history and reclaim it through their arts practices. She connects these ideas to the young people of the city by stating that a part of the vision of success is to retain them through their "neighborhood growth strategy," which includes promotion and celebration of "what we have in Detroit." These practices bespeak Miss Savage's efforts to maintain art, crafting, and gallery space for Black artists and enthusiasts in Harlem. Similar to Miss Savage, "R" created pathways to art space and community membership as a means for young people to risk reinvesting in an art identity as citizens of Detroit.

"J" states that her organization's mission is to "eradicate racism and its damaging effects." In her organization Teaching Artists (TAs) need to be cultural matches and understand the endemic nature of racism to work towards that mission. The idea of teachers needing to be cultural matches is a long-held belief (Clark & Brown, 1986; Carter, Karani, Jackson, Jackson, Lucas, Neckerman, Podolny, Pollock, Tyson, 2003) of Black educational spaces. It helps teaching artists navigate anti-Blackness and racism in ways that reach the young people they serve and reduce the risk of additional institutional and interpersonal harm. Considering the many intersectional identities young people have, TAs need the cultural capital to creatively negotiate ideological and institutional constructs of power. J's ideas about successful teaching artists operate alongside a history of cultural repertoires of practice (Gutiérrez & Rogoff, 2003) that protect youth who are multiply minoritized. This is a belief held by Miss Savage who supported the efforts of black youth group The Vanguard, who was supported and advised by known communists, despite the threat of McCarthyism. Miss Savage was very much aware of the risk of being willing to assist but knew of the importance of young people being able to speak their mind and receive the political education they desired to protect their mind, bodies, and spirits.

"S's" organization unabashedly mirrors the spirit of the owner, herself. The organization's mission is interesting in that it intends to "interpret and mirror culture and community, investigate race, gender, and personal identity in relations to *post*-Blackness" or this idea that Blackness itself is an identity that can be transgressed. The erasure of Blackness would mean that all systems dependent on race (i.e., humanism, capitalism) would cease to exist as we know them. By shaping an arts organization around trans-ontological ideas like a post-black world, TA success is identified in the embodiment of these ideas. TAs uplift the times where S's essence shines through in both their teaching and the youth's learning and engagement. In a similar, albeit humble manner, this form of embodiment relates to one of Miss Savage's most infamous quotes: "I have created nothing really beautiful, nothing really lasting, but if I can inspire one of these youngsters to develop the talent I know they possess, then my monument will be in their work" (Hayes et al., 2018). These curiosities towards post-Blackness in "S" & Miss Savage demonstrates a desire to transcend the oppressive reach of racial discrimination and embrace the cultural-historical methods that work towards achieving that.

Conclusion

This paper positions the historical activities of Augusta Savage in relationship with the political and ethical commitment BW-OSTA leaders make in their determinations of who is considered a successful teaching artist. Following Carol Lee's (2009) ecological model of multiple pathways for access to psychosocial resources, these political and ethical commitments serve as pathways that inform the ways leaders view successful teaching. As is a part of the long history of Black arts and Black aesthetic movements, the preservation of city history, cultural representation at multiple levels of engagement, and understanding the individual body and collective creative space as locations for embodied risk and resistance are important mediating artifacts for successful teaching in contemporary art organizations.

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International Society of the Learning Sciences

Moments of Pedagogical Feedback with Explanations: Interactional Foundations for Supporting Educational Dignity

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Abstract: This paper explores pedagogical design processes of educational dignity by analyzing data across three learning contexts and configurations–a facilitator and student in a museum-based tinkering environment, a professional choreographer and dancers in their dance studio, and two students in a high school history class–to show how moments of feedback with explanations can contribute to the process of coordination in joint activity, invite meaningful participation, and support educational dignity. In particular, we present three case studies to illustrate two primary findings: (1) through moments of feedback with explanations, participants invited one another to embody forms of meaningful participation, and (2) these invitations to engage in meaningful participation created a collective, educationally dignifying conceptual space in which activity was continued forward. These findings offer developing insights into the *how* and *towards what ends* of designing for educationally dignifying learning environments, contributing to discussions on the revisioning of equitable education systems.

Continuing the Reimagining of Equitable Education Systems

In the U.S., we are experiencing a public contestation around the design of education contexts sparked in part by the pandemic and growing racial justice movements. Nasir, Bang, and Yoshikawa (2021) reflected on this moment as "a once-in-a-generation opportunity to make real progress toward a system of education that truly serves all students, providing the kinds of teaching and learning that enrich lives, spur innovations, and reflect a deep and abiding commitment to equity" (p. 54). As more districts move back to in-person schooling, we have the opportunity–and responsibility–to continue this reimagining by offering empirical analysis on the potential cultivation of equitable education systems in the 21st century.

We heed this call by exploring the pedagogical design processes of educational dignity; "educational dignity is the multifaceted sense of a person's value generated via substantive intra- and inter-personal learning experiences that recognize and cultivate one's mind, humanity, and potential" (Espinoza et al., 2020, pg. 326). Understanding educational dignity as an interactional and discursive achievement, we offer data across three learning contexts to demonstrate one way meaningful participation and educational dignity unfold and move activity–or learning–forward. Specifically, we attune to moments of feedback with explanations, which reflect moments of one person sharing their perspective, ideas, questions, or concerns on another's participation/activity using forms of narrative, descriptions, and definition. We argue that moments of feedback with explanations can contribute to processes of intersubjectivity in joint activity and serve as indicia of educational dignity. This finding offers developing insights into the *how* and *towards what ends* of designing for educationally just and dignifying learning environments, offering empirical examples that expand current and future discussions on the revisioning of equitable education systems.

Literature Review

As more research incorporates the needed political interrogation of the ways sociopolitical systems shape and reinforce oppressive hierarchies, we continue beyond this interrogation by asking what systems or values *should* guide the design and joint activity in learning environments. For those committed to the creation of equitable and just education, researchers have explored the different aspects of research that must be reconsidered: from the design of the research collaboration (Bang & Vossoughi, 2016), the organization of social structures (Gutiérrez, 2008), to the ways of seeing learning as interrelated social and conceptual processes (Vossoughi et al., 2020); the cultivation of equitable education requires a multifaceted, multimodal, multi-epistemological integration. Across these different categories, we see a consistent theme: social interaction. What is the role of social interaction in pedagogically uplifting and sustaining educational dignity?

Espinoza and colleagues (2020) provide a detailed framework for seeing educational dignity as social accomplishment mediated by meaningful participation. Dignity itself is not something that can be created or destroyed, everyone has dignity; rather, the goal is to design dignity-affirming learning environments that uplift and feed students' dignities. The emphasis on social interaction in the experience of educational dignity has been explored through axiological innovations (Bang et al., 2016), epistemic heterogeneity (Warren et al., 2020),

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embodied pathways (Vossoughi et al., 2020), and pedagogical improvisation (Jackson, 2021a). Across these works and others, researchers continually evidence educational dignity as an ethical process supported through the moment-to-moment interactions. As the Learning Sciences continues to build a diverse pool of empirical evidence on what educational dignity looks like in practice, in this paper we aim to contribute with new examples that additionally address *towards what ends* (Philip, Bang, & Jackson, 2018) these dignity affirming pedagogies work. The participants providing feedback across our three empirical examples not only provide feedback interactionally, responding to other participants in situ, but pedagogically structure their explanations in dignity-affirming ways. Surfacing the interactional structure of this pedagogical move across contexts and configurations is essential for continuing to cultivate equitable educational spaces.

Methodological Approach

This paper explores the following research questions: what did moments of feedback look like across three different settings organized around values of educational dignity? How did these experiences with feedback contribute to –if at all–the fostering of educational dignity? To answer these questions, we explore three different learning contexts drawn from each authors' individual research projects: between a facilitator and high school student in a museum-based tinkering environment (Author 1), a choreographer and dancers in a professional dance company (Author 2), and tablemates in a high school US history class (Author 3).

Although each data set was collected around different questions of learning and development, we took similar approaches in the development of data sources, which included developing field notes, video-recording participants' activities, and conducting interviews that foregrounded documenting interaction from a sociocultural perspective of learning (Gutiérrez & Rogoff, 2003; Lave & Wenger, 1991). Having the benefit of similar data sources, we aimed to answer our research question by drawing on Matusov's (1996) participatory notion of intersubjectivity as a process of coordination among participants in joint activity. With joint activity as the unit of analysis, we traced activity directions by dividing the video data into activity directions, and transcribing verbal and nonverbal actions, such as gestures, to explore the ways the participants structured the interactions (Erickson, 1992). Then, we analyzed how the qualities of feedback with explanations contributed to the process of coordination between participants to progress activity. We also analyzed how explanations served as indicia of meaningful participation and educational dignity in joint activity using micro-ethnographic analysis (Erickson, 1992). To this end, we looked beyond the binary of adult-centered and child-centered models of pedagogy and explored joint activity as a pedagogical practice where all participants involved were seen as active co-participants (Vossoughi et al., 2021a). Since intersubjectivity, meaningful participation, and educational dignity are distinct interactional achievements, our findings suggest that moving joint activity forward does not automatically imply that participants' contributions are taken seriously or that their full personhood is seen and considered. Similarly, affirming learners' dignity does not necessarily entail moving joint activity forward. Thus, our empirical contributions help reveal how these three notions can come together when participants in joint activity offer feedback to move activity towards more meaningful and just ends.

Findings

We present three case studies to illustrate two primary findings: (1) through moments of feedback with explanations, participants invited one another to embody forms of meaningful participation and (2) these invitations to engage in meaningful participation created a collective, educationally dignifying conceptual space in which activity was continued forward. The potential for pedagogical action to shape dignifying learning processes is an argument made by previous scholars (Vosoughi et al., 2020); through these findings, we offer both an extended view of what one pedagogical practice–feedback with explanations– mediated forms of educational dignity across different social configurations and organizations of learning. Furthermore, by offering examples from different data sets, we highlight the potential for this practice to further activity and extend the learning of not just the individual, but the collective experiencing of (and contributing to) educational dignity.

The first case study draws from a 16-week ethnographic study of a museum-based tinkering program for high school students called the FabYouth program (Echevarria, 2021). During an interaction between Gerard (facilitator) and Darrius (student), Gerard crafted an explanation that invited Darrius to think and learn about troubleshooting, the flow of electrical energy, the manipulation of the flow of electrical energy, the terminology of short-circuiting, and the cause of short-circuiting. I found that Gerard, the facilitator, provided feedback with explanations that contributed to the process of coordination in joint activity, invited meaningful participation, and supported educational dignity. Feedback went beyond correct or incorrect evaluations and included explanations with learning as the endpoint. Therefore, explanations were directed towards understanding the roots of unintended outcomes. As a result, Gerard provided feedback with explanations in a way that affirmed students' potentials by creating openings for students to learn and iterate to work through activities.

The second case study takes us to a professional contemporary dance company, focusing on a 3-week period from a larger two-year ethnographic study (Vogelstein, 2022). During this time, Rebecca's position changed from peer-dancer to leader-choreographer and she shared how she approached developing choreography in pedagogical ways, drawing on her own experiences as a dancer to create dignity-affirming experiences for the dancers. Rebecca saw being transparent, or providing feedback paired with explanation, as caring for her dancers and intentionally giving them "what she feels like she needs from choreographers" (Field Note, 12/14/17). I found that Rebecca communicated changes to developing choreography typically not tied to dancers' abilities, but rather because of the experimental approach to creating choreography. Thus, when being transparent and providing feedback with explanations, dancers did not have to locate the reason for changes in any particular dancer. Instead, they focused their energy on the process of creation and fine-tuning as a group. Rebecca's feedback also invited multiplicity in dancers' interpretations of feedback, further demonstrating the co-creation of choreography.

Finally, the third case study is a moment between two students, Bolaji and Sarah, in which feedback and explanation encouraged new forms of collective, dignifying participation in a US history class. Drawing on a year-long ethnographic study (Jackson, 2021b), I found that during discussions, Sarah became a primary source of knowledge and validation to Bolaji by way of feedback and explanation. Sarah's explanation created the conditions for supporting Bolaji's educational dignity by reinforcing and continuing his meaningful participation in the developing collective inquiry when he quietly asked a question. Because Sarah made this pedagogical move towards her peer, she ensured Bolaji was still jointly-coordinated in thinking, allowing for both of their participation in the large-class discussion to continue. Therefore, Bolaji was able to not only receive a detailed explanation for his question but also have further validated in his positioning as a meaningful participant alongside Sarah in the class' collective thinking, demonstrating how engaging feedback and explanation functioned to create and extend educationally dignified activity.

Discussion and Conclusion

Feedback with explanations invited participants to embody forms of meaningful participation characterized by agency through positioning (Davis et al., 2020) and moved activity forward. In the first case study, Gerard offered feedback that positioned Darrius as a learner by affirming that Darrius was prepared for conceptual engagement with the circuit with proper support. Gerard did this by accompanying his feedback with an explanation that took the shape of storytelling and personification of electrical energy. As a result, Darrius was invited to engage with the feedback to understand the roots of unintended outcomes. In addition, although Darrius did not ask for an explanation, Gerard provided one. In doing so, Gerard showed Darrius that his wondering was important and affirmed Darrius' potential to learn the concept of short-circuiting and circuit design, when it was not necessary to move the activity forward in that moment but would be generative in the future for Darrius.

In the second case study, Rebecca positioned the dancers as co-participants, exploring the unknown of the final choreography through a process of experimentation and multiplicity of interpretations that opened up creative possibilities. Rebecca also carefully crafted her feedback to communicate that revisions to choreography were not critiques of dancers' abilities, but rather a part of the process to create a larger cohesive creation together. This is important because using dancers' artistic choices and ideas in a piece of choreography can feel exploitative when dancers are positioned as needing to be good enough to fit a choreographer's vision rather than contributing to the co-development of a shared inquiry.

In the third case study, Sarah's explanation answered Bolaji's question by first exploring shared knowledge and then providing a summary of a lecture. As a result, Sarah positioned Bolaji as having the answer to his own question, and then she provided Bolaji with a summary of a lecture to further support his memory, thinking, and participation in whole-class discussions. Together, all three cases show how the explanations that accompanied feedback worked to support participants by way of positioning to invite meaningful participation that invoked participants' agency and affirmed their dignity as valid and generative members of these respective learning communities. Feedback with explanations also invited participants to engage meaningfully, creating a collective, educationally dignifying conceptual space (Espinoza et al., 2020) in which activity is continued forward (Matusov, 1996). These three cases illustrate how feedback with explanations can serve as moments to shift activity in immediate ways, but can also serve as reference points in the future, suggesting that feedback not only drives activity, but it can also serve as a seed for continued learning (Gutiérrez & Rogoff, 2003; Lave & Wenger, 1991).

We are pedagogically inspired by the humanizing ends these instances of feedback with explanations move towards in their respective learning ecologies and we are excited at the new theoretical and pedagogical questions they raise. In particular we are interested in the new relations that these forms of feedback with explanations can support (Vossoughi et al., 2021b) in terms of the interwoven nature of intersubjectivity and ethical relations between participants and the domain, such as how Gerard positioned Darrius as a learner while

positioning himself as someone who Darrius could wonder with and seek support to learn more about circuitry. We are also interested in the motivation for when moments of feedback are paired with explanations in moments of joint activity because our three case studies illustrate times when participants supported one another without being asked to go into such depth. For example, Darrius did not ask for an explanation and neither did Rebecca's dancers. While Bolaji did ask a question, it was indirectly asked, and Sarah decided to answer his question pedagogically. However, she could have given Bolaji a one-sentence answer that would have omitted the kinds of positionings that her original explanation provided, or even positioned Bolaji in negative ways. Ultimately, we are inspired to continue to learn from and with our research collaborators and embark on new efforts to support the engagement of meaningful and dignity-affirming participation interwoven in pedagogical moments of feedback with explanations.

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Tuning Perceptions and Inferences to See a Graph in a New Way

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Abstract: This work examines the representational and social features of a computational modeling activity to understand the role they play in helping a student make sense of a simulation graph. Specifically, it examines shifts in the student's thinking as she reflects on the output of a computational model of thermal equilibration, which she has built. By analyzing the student's trajectory through the lens of Coordination Class theory, the paper illuminates how she comes to see the simulation graph in a more sophisticated way through her interactions with the technology and the interviewer. The paper shows how these features of the computational modeling activity support her transition from seeing oscillations of temperature about the mean as a visual effect caused by the computer screen, to understanding that oscillation amplitudes are related to microscopic fluctuations in temperature, which decrease as the number of particles in the system increases.

Introduction

Today, many scientists use computational models to represent and make sense of scientific phenomena. Science education research has investigated student engagement in computational modeling. Some research programs have focused on the design of environments that make the construction of computational models more accessible to younger learners and studied how these environments support learning (Bain, Anton, Horn & Wilensky, 2020). The present paper focuses on student learning in a block-based modeling environment, seeking to characterize, at a fine grain-size, how exploring a computational model of thermal equilibration helps one student find new meaning in a graph of temperatures.

Theoretical foundations

This study is informed by the Knowledge in Pieces (KiP) perspective, which views an individual's knowledge as a complex system of many different kinds of elements and structures (diSessa, 1993). One structure discussed in the KiP literature is a *coordination class* (diSessa & Sherin, 1998). Coordination classes are used to obtain measurable information about the world and are composed of both perceptual and inferential components. The perceptual component consists of *readout strategies*, which the individual uses to *extract* data from the world. The inferential component consists of an *inferential ne*t, which the individual uses to decide what data to extract, and to *draw inferences* from the extracted data. For example, suppose an individual wants to determine which of two objects is being pulled toward Earth with greater force: a bowling ball in their left hand, or a marble in their right. In this situation, the individual draws on their readout strategies to perceive the relative weights of each object. They draw on their inferential net to determine that the bowling ball feels heavier, and therefore must be experiencing a greater Earthward gravitational force. The individual's readout strategies are related to their sense of touch and their inferential net includes ideas about heaviness and force. This paper analyzes the development of one student's understanding of a graph through the lens of Coordination Class theory. Though the theory was originally developed to understand how individuals obtain information about measurable quantities (such as force or speed), a number of studies have borrowed the theoretical machinery to make sense of how individuals see other kinds of information in the world. This work uses readout strategies and inferential nets to characterize shifts in the focal student's extractions and inferences, which allow her to understand a graph of thermal equilibration in a new, more sophisticated way.

Methods

This paper analyzes data from a larger study focused on students' engagement in theory building through computational modeling. To lower the threshold for participation, our team designed block-based computational modeling microworlds using NetTango (Horn, Baker, & Wilensky, 2020), an interface to NetLogo (Wilensky, 1999). The present study seeks to characterize, at a fine grain-size, how theory building through computational modeling supports learning and asks the question: *How do the representational and social features of a computational modeling activity help a student make sense of a graph in terms of the law of large numbers?*
To address this question, we analyze one student's explorations in a NetTango microworld during a 1.5-hour interview. Data were collected in three forms: video, screen capture, and audio recording. The present report focuses on data from an interview with a student we call Sage (13 years old) who explored the *Thermal Equilibration* modeling microworld, pictured below (Figure 1). The screenshot shows a model that has been built

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and initialized. The black box is the *world*, which depicts the activity of the agents (green and purple particles) that are programmed to behave according to the rules specified by the model. To the left of the world are parameters the user can adjust to prescribe initial numbers and speeds for green and purple particles. When the user presses the *setup* button, the world populates with particles that match these parameters. When they press *go*, the particles begin to behave according to the *act* procedure, which the user defines with blocks in the field to the far right. Just to the right of the world is a graph, which shows the temperature or average energy for the groups of green and purple particles over time. It is important to note that the graph shows quantities the model can calculate, which could never be measured in reality, as the particles mix over time. The student is asked to imagine that the particles constitute green and purple gasses at different temperatures, which are mixed together in a container, and to model the situation where the two gasses arrive at the same temperature

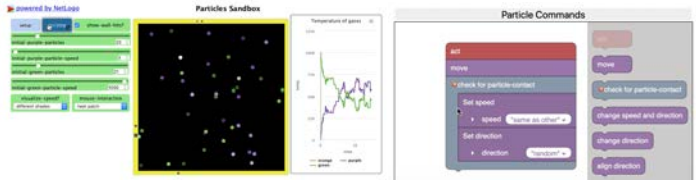

Figure 1. Screenshots of the *Thermal Equilibration* modeling microworld.

An audio recording of the interview with Sage was transcribed. Both screen capture (with audio recording) and transcript were analyzed to look for evidence of learning. A shift in Sage's thinking was identified during an activity toward the end of the session, where she attempted to make sense of the graph produced by her thermal equilibration model. A Knowledge Analysis (diSessa, Sherin, & Levin, 2016) was conducted to understand the smaller steps through which her thinking was refined. The data were analyzed using constructs from Coordination Class theory (readout strategies and inferential net) to understand how her extractions and inferences were refined, leading her to see a graph of thermal equilibration in a more sophisticated way. Her trajectory was divided into five episodes, which were analyzed to identify how her extractions and inferences, which determined what she could see in the graph, changed in relation to her interaction with the technology and the interviewer.

Findings and Discussion

Episode 1: Noticing the behavior of the graph

Sage had been tinkering with parameter settings and her model produced a plot (Figure 2, right) that resembled a graph she had drawn earlier to illustrate hot and cold liquids equilibrating over time (Figure 2, left). The episode opened with Sage commenting on the similarity between the NetTango plot and her graph.

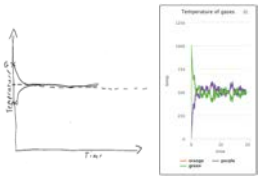

Figure 2. The plot on the left was drawn by Sage, the one on the right was produced by the microworld.

Sage: It's sort of looking like that graph [points at her drawing]. Well now it's like inverted. Well it's like correcting itself. So, I think eventually it will get to align or, well no, maybe.
Int.: What do you think is causing it to go...
Sage: Because I, I don't know. Every time I'm like, "Oh look, it's going smooth." They just like, just like straight up. It's like, um, it, they're like swapping each time.

In this episode, Sage extracts information from the graph. She first notices that it has the same global shape as the graph she sketched. As time goes on, she notices that the curves overshoot the mean and appear to swap places. Her extractions, which move from global shape to a finer-grained detail, are dictated by her readout strategies as well as her inferential net, which dictates what of the available information appears to her to be relevant to making sense of the graph. The particular readout strategies and inferential net she brings to her initial observation arise spontaneously in response to the activity. Sage's extraction of the fluctuation about the mean was afforded by the

modeling environment, which plotted the separate temperatures of the two gasses, despite their having mixed. In reality, such a graph, and therefore such an extraction, would be impossible.

Episode 2: Focusing on the aggregate-level behavior

Hoping to capitalize on the problem Sage has stumbled upon, the interviewer asks her to explain the phenomenon.

Sage: Maybe it's being set to random and then they're going the inverse of each other. So, if one is slowing down, then the other one is speeding up. Then the average will always be the same.
Int.: What is the average…? Temperature is going to be the measure of the average speeds…
Sage: So, the temperature. For green, the speed, it looks like it's centering like right around 500, which is good 'cause that's the middle. So, it should be just a little bit of both. So, it's like if, if the 500 was zero then it would be 500 and negative 500, then it would be like the inverse.

In this episode, Sage extracts more detailed information about the plot, observing that the oscillation of the curves is symmetric. She also draws an inference from the symmetric oscillations, determining that they represent the particle speeds going faster and slower in a mirrored way. The interviewer asks her about the temperature, or average speed of the particles. In response, Sage extracts quantitative information of the mean value about which the two curves oscillate. She infers that this value is sensible, given the values of the two particle groups she started with. She further extracts that the curves are oscillating about the mean value by the same amount. Importantly, Sage is extracting information and drawing inferences in response to the interviewer's questions.

Episode 3: Focusing on an agent-level mechanism

The interviewer asks Sage to explain the "jagged" nature of the curves.

Sage: Well, at the beginning I thought it was because this just happens over a long time. It was just pixels and if you zoomed out, it wouldn't be jagged, and it was just 'cause of the computer screen. But now that it's going up and down, I think that it's just because, if one bounces into a wall and gets a little bit slower, then the other one just has to get a little bit faster.

The interviewer's question prompts Sage to share two inferences. The first concerns her initial thinking, which was that when a graph exhibits oscillation it is an effect of the computer visualization. The second concerns her new thinking, which is that the phenomenon is real, and is caused by particles speeding up and slowing down. It appears the interviewer's question has activated these two inferential nets, which Sage uses to make sense of the phenomenon. Sage's extractions and inferences appear to occur in response to the interviewer's questions.

Episode 4: Comparing systems with different particle numbers

The interviewer is interested in helping Sage see that the amplitude of the oscillations decreases as the number of particles in the system increases. Towards this, she asks Sage to compare different numbers of particles.

Int.: So, it's really jagged around 500. Let's see if you raise the number of particles, if it's the same. Do you think you'll get the same jagged line around 500, but up 250 or down 250?
Sage: Um, uh, maybe, I think. Yeah. [increases each group of particles to 50].
Int.: Well it's definitely going fast towards 500. And then it's a little bit slow and then it's doing the thing you saw, which is a little bit of this dance around the 500.
Sage: Yeah. But it's a lot closer now. Like, like it's not going up.
Int.: Okay. What about if you made the particles even more -
Sage: Um, go to like a hundred [slides each group of particles to 100]. Um, I think maybe it will be, it might get all the way flat, but it might just be very close.

The interviewer's suggestion to compare the model with different numbers of particles leads Sage to run the two different models and observe the difference in amplitude heights. She extracts the amplitude information. She then uses her inferential net to compare the two different heights and establish that the one with more particles has the smaller amplitude. This prompts her to predict that 100 should flatten the amplitudes to zero, or close to zero. Here, as in the previous episodes, Sage's extractions and inferences appear to be influenced in important ways by her interactions with the interviewer. They are also afforded by the modeling environment, which allows her to run the simulation with different numbers of particles and compare the amplitudes of the temperature fluctuations. Sage appears to have recognized a relationship relevant to understanding the law of large numbers: the larger the number of particles in the system, the less any single particle will influence the average.

Episode 5: Connecting agent and aggregate levels

The interviewer asks Sage what happens to the curve as she adds particles.

Sage: Um, it's still not like quite a curve. As the number of particles increase, as the sample size increases, then the actions of one particle don't affect the big total as much.
Int.: That is such a cool thing to have said. What do you mean by that?
Sage: So, if you're doing a study like this, if you just had me, it wouldn't really be like a full and complete study because I am not the same as every person and if you have like a hundred people it will be way more accurate because a hundred people is closer to the diversity of knowledge that our population has than one person. And if you had every seventh and eighth grader do it, it would be a hundred percent accurate because everyone was represented.

Sage uses her readout strategies to extract the shape of the curve and describes it as not perfectly smooth. She activates her inferential net and offers an explanation for why increasing the number of particles smooths out the curve. Her inferential net includes information about sample size and how a sample more closely characterizes a population as it gets closer to the size of the population. Much of her thinking is left unarticulated, however, it appears that she has activated prior knowledge related to the law of large numbers, in that she understands the distance of deviations from the mean increases for smaller samples, since individuals within the population have a greater weight within the average. Her activation of this knowledge appears to be in response to her inference about the relationship between a large number of particles and a lower amplitude of fluctuation, as compared to a small number of particles and a higher amplitude of fluctuation about the mean. She drew this inference as a result of comparing simulation runs with different particle numbers, which she did at the request of the interviewer.

Summary and Conclusion

The interviewer asked Sage why the curve was jagged. Sage shifted from thinking it was an effect that would resolve itself (Ep. 1), to describing what was happening at the aggregate level (Ep. 2), to describing what was happening at the agent level (Ep. 3). The interviewer then asked Sage to compare different numbers of particles (Ep. 4). This caused Sage to infer the relationship: the more particles, the lower the amplitude of fluctuation. The interviewer then asked Sage what she noticed about the relationship between particle number and curve (Ep.5). Sage offered an analogy to explain her understanding, drawing on ideas that suggest intuitive resources for understanding the law of large numbers. This sequence illustrates Sage's trajectory from having an incorrect explanation for the graph, to a somewhat scientifically sophisticated explanation. The mediating influence of the technology and interviewer appear significant. The technology allowed her to see invisible fluctuations in average speed and the average temperatures of groups of particles that mixed together as soon as the simulation began. Though Sage initiated the discussion, the interviewer continued to focus her attention on the details of the curve, asking her what might be causing the fluctuations about the mean, and finally, how increasing the number of particles influenced the size of the fluctuations. Some of her questions activated Sage's readout strategies and allowed her to extract new information, while others activated Sage's inferential net, which she used to explain what might be causing the fluctuations and why increasing the number of particles decreased the size of the fluctuations. The interviewer's questions played a role in changing the composition of Sage's readout strategies and inferential net, which she used to make sense of the graph. Shifts in activation of the perceptual and inferential components of her knowledge system helped her make sense of the graph in a new and more sophisticated way.

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What does 'Computer Science Education for All' Look Like in a Korean Middle School: an Ethnographic Case Study on an Informatics Teacher's Local Contentious Practice

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Abstract: Along with the worldwide emphasis on computer science (CS) education for all, *informatics,* one of the CS subjects in Korean middle school education, has been expanded from the elective to the compulsory since 2018 to offer CS learning opportunities for all students. This study seeks to document how CS for all agenda is enacted in a local school context by exploring an ethnographic case of one informatics teacher. Using the construct of local contentious practice as a conceptual framework, I examine the teacher's actions and interactions for and related to teaching informatics in the particular school context where larger sociocultural assumptions and narratives about CS teaching and learning operate. Through a reflexive thematic analysis of the ethnographic case data, I identify three patterns of local contentious practice enacted by the informatics teacher and with the teacher's school community. Implications for future research and practice toward CS for all is discussed.

Major Issues and Purpose of Study

Young people are and will be living in a fast-evolving world operated by computing systems and applications grounded in computer science (CS) knowledge and practices (ACM & IEEE, 2020). It is crucial for young people to have sufficient and sustained opportunities to learn CS, which will help empower themselves as wise and ethical producers, consumers, and problem-solvers of computing-based applications, systems, and information. In this regard, many countries across the globe, including South Korea (Korea, hereafter), have utilized their public education systems as access points toward the goal of CS for all students (Hubwieser et al., 2015). CS for all is urgently required to work against injustice exacerbated by racial, gender, economic, cultural, and regional disparities in access to quality CS learning opportunities, and computing-informed lives and career pathways (e.g., Computer Science Teacher Association, 2020).

Since 2018, informatics, one of the CS subjects in Korea, has been expanded from the elective to the compulsory according to the national curricula policy revision to serve the goal of CS for all. Korean middle schools now provide their students with either one or two credits of informatics courses across three academic years. This policy shift is considered a meaningful step forward, given that CS subjects have long been offered as electives (e.g., informatics until 2018), or as parts of other subjects like technology or domestic science.

However, to better work toward CS for all, there is still much to be addressed in terms of policy and its implementation at local districts and schools. Utmost concern is inequity due to insufficient learning hours assigned to CS subjects. Most CS subjects at primary and high-school levels remain electives or as parts of other subjects, which hinders extensive and sustained learning opportunities across different grade levels (Kim, 2021). Although middle school informatics has shifted to be a compulsory subject, it only takes up one or two credits of a total 99 credits earned across three middle school years. One of other significant concerns is how schools maintain CS teacher workforce. In the case of middle schools, 77% of informatics teachers majored in CS-related disciplines while 23% are non CS-majors or minors (Korean Association of Informatics Teachers, 2021). Moreover, 49% of teachers who majored in CS-related disciplines circulate two or more schools to teach informatics while 51% work full-time at one specific school teaching other subjects in addition to informatics. In the situations like these, parents who believe the importance of CS for their children's future look for out-of-school private CS learning programs, particularly when they are affluent enough to afford the additional expenses.

Whether students can have sufficient CS learning experience is, therefore, highly contingent to and disparate by local communities, schools, and families students live in. It is the disparities that can contribute to perpetuating educational injustice. Furthermore, these are not only the issues within Korea. Similar injustice issues have been reported across the globe (e.g., Goode et al., 2020). Sustainable and concerted efforts to eradicate such issues and transform policy and implementation is in dire need to actualize equitable CS education and to use CS as a means toward justice, not as a sources of perpetuating injustice.

Despite the issues in policy shift and implementations of CS, there exists a dearth of research, particularly in Korean context, investigating how such issues may operate in and around informatics classrooms. Moreover, ethnographic understanding of what CS for all looks like is surprisingly underdeveloped. If the purpose of CS for all is to offer equitable learning experiences, how the policy-level shift has impacted students' learning via their teachers' practices in local school contexts should be investigated in ethnographic and case-specific details.

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As an attempt to address the need for investigation, therefore, this study explores an ethnographic case of one Korean middle school informatics teacher, Mr. G. Particularly in this study, I attend to Mr. G's actions and interactions *for and related to* teaching informatics in the particular context of his school. By actions and interactions *for* teaching informatics, I refer to those Mr. G directly aimed at teaching students the informatics subject. In comparison, the *related to* teaching informatics means those shaping and situating his teaching. I frame such actions and interactions with the construct, local contentious practice, which explains on-going formation of the sociohistorical self in the encounter with institutional narratives (Holland & Lave, 2001). By using this construct, I sought to articulate how CS for all policy agenda has shaped (and been contextualized in) local school implementations as Mr. G's case illustrates. The following research question guides this study: *Which patterns of local contentious practice do Mr. G's actions and interactions for and related to teaching informatics reveal?*

Conceptual framework

I utilize local contentious practice as the conceptual framework to analyze and articulate the ethnographic case of Mr. G, focusing on his actions and interactions for and related to teaching informatics in a Korean middle school context. Local contentious practice calls attention to two histories: history-in-person and history-in-institutionalized-struggles. History-in-person, as a personal narrative of self-making, takes shape via interactional practices with others in local spaces. By history-in-institutionalized-struggles, Holland and Lave (2001) refer to institutional narratives grounded in historicized and trans-local structures, which provide resources for people's actions and interactions and leave traces in their formation of history in person; as such, I call this history as historicized institutional narratives in this paper.

Local contentious practice takes shape via interactions between people and tensions that arise from people's different positions in historicized institutional narratives. Viewing teaching and learning through the perspective of local contentious practice helps to understand different forms of interactions shaped by multiple actors at different positions of power in their local learning institutions. In their institutional learning spaces (e.g., a school classroom, a teacher staff meeting, school events), multiple actors (e.g., students, teachers, principal) and non-human constituents (e.g., spatial structures, disciplinary knowledge, school-national curriculum) interact within historicized institutional narratives and dynamic networks of power.

Local contentious practice can be a means of transformation as people create and recreate their history-in-person as well as the historicized institutional narratives (Calabrese Barton et al., 2020). In this regard, examining local contentious practice in educational institutions such as schools can help to identify sources and processes of disruption and transformation brought to bear on the institutions. As such, I attend to identifying Mr. G's local contentious practice, and describing how his practice may have brought about disruption and transformation of his school community's assumptions, discourse, and practices around CS teaching and learning.

Methodological approach

I answer the research question, by undertaking an ethnographic case study that utilizes a reflexive thematic analysis. Taking an ethnographic case study approach allowed me to 'be with' participants—i.e., Mr. G, his colleague teachers, and his students in real world contexts. Conducting a reflexive thematic analysis allowed me to focus on how the construct of local contentious practice is enacted and contextualized in the specific case.

Ethnographic Case Study

Ethnographic case study method examines events and individuals real time within a bounded system situated in larger cultural and historical contexts (e.g., Angers & Machtmes, 2005). This method is appropriate for this study seeking to answer the research question by examining Mr. G's practices for and related to teaching informatics (inward attention) and the multi-scalar contexts in which the practices are shaped (outward attention).

Positionality To this study, I bring my positionality, which I would call my history-in-person as a researcher who seeks to work toward equity in and through CS and STEM education, and as a former teacher who once taught informatics in Korean classrooms.

Context This case took place between January and September 2021 in a middle school within a low-income neighborhood in one of the Korean metropolitan cities. A total of 220 students (76 6th, 73 7th, 71 8th graders) and 26 adult members (21 teachers, 1 principal, 1 vice principal, and 3 administrative) constitute this school community. Since 2018, this school has been designated as one of Innovation Schools aimed at educational transformation in economically disadvantaged communities. Regarding informatics subject, this school offers 2 credits of informatics, 1 for 6th and 1 for 7th graders.

Participants The case teacher is Mr. G, with 20 years' experience teaching informatics at four Korean public middle schools, including the one in the study. Seven additional participants were recruited through snowballing sampling: Mr. G's colleague teachers (Mr. D and Ms. P) and 5 students (three 6th, and two 7th graders).

Data Generation & Analysis

I generated data, including individual and group interviews, instructional and curricular documents, students' learning artifacts, and the researcher fieldnotes. I analyzed the data by using a reflexive thematic analysis. This analysis method facilitated me to find meanings from data through concurrent dialogue and contextualization of theory-based coding framework (Braun & Clarke, 2019). I took three analysis phases.

Open coding. Interview transcripts were major data for open coding. The unit of analysis was an instance the interviewees pointed out as important for and related to informatics teaching and learning; the instance was either interactional (involving different actors) or reflective (involving individuals' reflections on systems and practices). Each unit is coded in an exploratory manner as I first read transcripts through chronologically, and then triangulated the coded instances with other data. As codifying interactional or reflective instances, I also assigned sub-codes to the components constituting each instance—e.g., individuals, actions, spaces, and tasks.

Construct-informed coding. For this phase, I first established a coding framework drawing on the construct of local contentious practice, and iteratively refined both the coding framework and the codes and sub-codes. The coding framework involved concepts used to describe the construct, such as actors, relationships, interactions, tensions, community, institution, history-in-person, historicized institutional narratives.

Identifying patterns of local contentious practice. In this phase, I figured out relations among different codes and sub-codes refined in the second phase, from which I identified three patterns of local contentious practice as the main themes of Mr. G's actions and interactions for and related to teaching informatics in his school context. Instances described in the first analysis phase offer illustrations of how each pattern manifests.

4. Findings

Drawing on the reflexive thematic analysis of Mr. G's ethnographic case, three patterns of local contentious practice were identified from his actions and interactions for and related to teaching informatics in his classrooms and across his school community. The patterns are:

1. Creating a dialogic space that engaged colleague teachers in questioning the normalized practice of treating informatics teachers as school technicians;
2. Facilitating an agentic learning space where students engaged with academically challenging but achievable computing tasks, which disrupted the school-wide deficit view on their students as low-achieving;
3. Co-designing with colleague teachers the inter-subjects learning projects in which students utilized and integrated knowledge and skills across informatics and other subjects.

For this proposal, I briefly unpack how the *first pattern* manifested, and which histories (i.e., Mr. G's history-in-person and the historicized institutional narratives shared by the school community) operated.

The first pattern manifested through sociopolitical actions he took in his school community of colleague teachers and principal. By sociopolitical, I refer to how he called his colleagues' attention to long-held narrative that reduced the legitimacy of informatics teachers and informatics. For example, during the third teacher-staff meeting he had since he joined the school, he made a presentation, through which he highlighted and questioned how informatics teachers are easily treated in schools more as schools' 'tech person,' than colleague teachers. He decided to make the presentation after the first teacher-staff meeting, in which he as a newcomer found that he was already assigned to take in charge of the school's digital device-related administrative work. He recalled:

> There was no option to me. Managing digital devices, wireless connections, and remote class system, a big deal after pandemic, were all my tasks. One teacher told me, 'informatics teachers are experts.' Yes, *we* may know more. Also, I don't hate such tasks necessarily, but they are thrown to *us* because *we* are viewed as school tech guys than teachers. Some tasks are what every teacher should know. Some others are what can be cared at a higher level. Upsetting.. I experience this whenever moving to a new school.

This statement indicates two histories encountered. His *history-of-person* as an informatics teacher, shaped through two decades of similar experiences, critically recognized power dynamics that positioned informatics teachers as individuals who would deal with other school members' technical issues. This history-in-person is not just about him;. As he put 'we' and 'us,' the similar history-in-person is shared by other informatics teachers. This similarity explains *historicized institutional narratives*. One of the institutional narratives is that, as Mr. G's colleague said, informatics teachers are 'experts' about computers and devices. However, such a narrative worked to reduce, not legitimize, the presence of informatics teachers. The tasks these teachers were expected to do as 'experts' were far from enacting CS for all. As Mr. G noted, it was not that informatics teachers always refuse to take technical tasks. However, he pointed out the tenacity of the reduced view on informatics teachers, the view that can be extended to how informatics as a subject can is. Mr. G continued to recall the presentation:

> When I was a beginner teacher, I just did what was assigned to me, but now being in this game for about twenty years, I have something to say. This school is Innovation School, I thought. If so, the conversation should take place. They may not know what informatics teachers do and why informatics matter.

Although the historicized narratives about informatics teachers and informatics prevailed in the school, Mr. G held up a hope that he could create a dialogic space with his colleague teachers, because the school as one of Innovation Schools had tried to establish culture that allowed democratic and often contentious conversations among different school community members. After his presentation in which he put together questions about normalized assumptions on informatics teachers and suggestions about different task loads, the atmosphere apparently went full with tension, according to Mr. G's reflection. However, some teachers put themselves into Mr. G's and other 'minor-subject' teachers' positions. Some teachers acknowledged that they actually had not thought about the normalized discourse highlighted by Mr. G. As they conversed on, they examined critically the tasks given to teachers and the underlying rationales. As a result, some of the tasks assigned to Mr. G were shared with other teachers and staff. Instead, he took the lead in the interdisciplinary learning project, the project idea other subject teachers hoped to launch but hesitated as they did not know how to realize the idea.

This pattern of local contentious practice, describing how he sought to reclaim his presence as an informatics teacher, is closely related to other two patterns. The second pattern describes how he used informatics to disrupt school-wide deficit view on their students, by engaging students in computing projects (e.g., ENTRY, Korean educational programming language platform, and international BEBRAS challenges for computational thinking), and held school events in which students taught programming other subject teachers. The last pattern shows how some other subject teachers (such as Mr. D and Ms. P who participated in this study) joined disrupting between-subjects boundaries and sought to co-design with Mr. G interdisciplinary learning objects.

Discussion, Implication, and Significance

Findings of this study about Mr. G's local contentious practice show how one teacher can bring about exposure and disruption of a school's historicized narrative, drawing on one's history-in-person that has become struggles and pathways toward CS for all. Utilizing ethnographic case study methods with a reflexive thematic analysis enabled me to gain the place-based empirical evidence of and insights from local implementation of policy, undergirded and contested by larger historicized institutional narratives about CS teaching and learning. Although the findings highlight a promising case of teachers and school communities working as change agents, the ultimate source of struggles such as course offerings and teacher supply were left unresolved. Ultimately, concerted efforts should be garnered both from policy and research panes. The CS for all agenda should result from concerted policy revision and systemic support for schools and teachers, for example, about how to resolve inter-subjects tensions of course distribution and budget concerns of increasing CS teacher workforce. Meanwhile, research should support teachers from in-service and pre-service informatics and CS teachers to other subject teachers seeking for integration with informatics and CS subjects, by providing opportunities of professional development and research-practice-partnership. Some of such opportunities should also support teachers to recognize and readily respond to power structure that may hinder CS for all; as Mr. G's case exemplifies. Findings and implications of this study inspired by the goal of CS for all can interest worldwide education researchers focusing on CS education and inter-subject integration with CS, and those participating in this year's ICLS themed with collaborative education for all.

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Sensing Someone Else's Pain: Ethical Historical Traces of Disciplined Interactions in Medical Care

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Abstract: This paper highlights the ethical and moral dimensions of relational work and dignity in technoscientific spaces which are elusive in normative disciplinary practices. Using the lenses of ethical perceptions and embodied actions, we locate how microinteractions within physician-patient interactions during pain diagnosis and care are intertwined with interpersonal dignity, racialized emotions and historicized violence on Indigenous people. We discuss the implications of our work in light of dismantling normative views of disciplinary authenticity that underlie technoscience education.

Introduction

Building on critiques of ethically neutral, ahistorical and apolitical positionings of science education (Bang et al., 2014) and disciplinary authenticity in technoscientific disciplines (Philip & Sengupta, 2021), we offer an empirical critique of professional expertise in medicine that excludes or undervalues the moral and ethical dimensions of relational work (Ducey, 2009; Ducey et al., 2020). Our work arises from the concern that professional work in technoscience is deeply intertwined with historical and ongoing enactments of militarism, nationalism, imperial and colonial violence (Banerjee, 2022; Benjamin, 2019; Sanyal & Sengupta, 2022), which also shapes educational research and praxis in STEM disciplines (Philip & Sengupta, 2021; Takeuchi et al., 2020). This paper advances scholarship on the relationship between the colonial matrix of power that shapes discipline (Mignolo, 2009) and moral and ethical dimensions of experience (Espinoza et al., 2020; Sengupta et al., 2022) that are often invisiblized in the professional practice of medicine. We report findings from an ongoing study of physicians' and caregivers' experiences of the relationship between medical care, technologies and pain. We illustrate: (a) how the misrecognition of pain within a physician-patient interaction is rooted in historical traces of Indigenous erasure and intergenerational trauma in disciplinary spaces; and (b) how a Métis physician, Dr. Campbell (pseudonym), the protagonist in our study, offers a possible re-orientation of disciplined interactions involved in sensing patients' pain through foregrounding ethical, relational and emotional work, based on her experiences of working with Indigenous patients.

Theoretical Background and Framework

Our work builds on the growing body of scholarship in the social and the learning sciences on the intertwined nature of moral and epistemological dimensions in technoscientific disciplines. Vossoughi et al. (2021) introduced the notion of ethical perception as educators' and researchers' "growing awareness of the pedagogical and ethical saliency of their own embodied actions" (p.137). They argued that embodied actions are "public expressions with political and ethical content (p.138), and urged us to reframe micro-interactions in disciplinary spaces through the lenses of dignity and meaningful participation (Espinoza et al. 2020; Tuck, 2011). In this paper, we adopt this lens of ethical perception to illustrate how embodied actions that represent *disciplined* ways of knowing (Sengupta et al., 2022) can invoke racialized emotions (Bonilla-Silva, 2019) for Indigenous and marginalized people of color who have endured a history of disciplinary violence in the context of medicine. These interactions are fundamentally moral and ethical in nature, which are not afforded in technical-rational views of disciplinary authenticity in technoscience (Philip & Sengupta, 2021; Sengupta et al., 2022). This is particularly important given that medical sociologists have also identified moral dimensions of care as often missing in accounts of professional expertise in medicine, particularly in contexts that involve the relationship of pain, harm and the use of new technologies (Ducey et al., 2020). Examining the wide uptake of transvaginal mesh, a surgical device procedure to treat certain pelvic floor disorders in women that resulted in extensive patient harm, medical sociologists have positioned "mindlines" as the collective moral-epistemological "ways of knowing and acting responsibly" (Ducey et al., 2020) that organize medical practice but often remain as ethical undertones in the technoscientific disciplinary practices that are centered in medicine. While initially, patients' bodies were framed as sites of problems that surgery must correct or improve, over time, patients' voices were centered in ways that enframed the medical practices around vaginal meshes in progressively more moral ways. And yet, as Ducey et al. (2020) noted, moral ambiguities continue to undergird medical expertise in this domain. We foreground feelings of responsibility and rightness as disciplined, and offer a fine-grained analysis of how these disciplined

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feelings inform acts of providing care—acts that are embodied and located in relation to specific histories, spaces, and technologies. Surfacing the *moral undertones* (Ducey et al., 2020) of medical carework is also important especially given the history between knowledge creation in Western medicine and violent, forced medical experiments on Indigenous peoples (Lux, 2016; Mosby & Swidrovich, 2021). As our analysis will show, such histories of disciplinary violence leave durable traces on micro-interactions between physicians and Indigenous patients, positioning *disciplined* interactions as inevitably grounded in histories of racial violence enacted by Western technoscience, thus making them ethical, historical and relational, not merely interpretive.

Methods

We report from an ongoing, interview-based study of physicians' experiences of the relationship between bodies, medical technologies and pain. Participants (n=7 and growing) are recruited both through snowball and targeted sampling, and then interviewed. We present here a single case of Dr. Campbell, a self-identified Métis physician of pain sharing her perspectives and experiences, particularly in the context of interacting with Indigenous patients. We utilize the constant comparative method (Charmaz, 2006) to identify examples of ethical perception (Vossoughi et al. 2021) in the participant's accounts. Our analysis involved coding the interview transcript to identify how she framed and oriented her medical diagnosis as being both grounded in disciplinary practices and ethical-historical. Our analysis centers how gestures, postures and language use in physician-patient interactions creates ethical-historical traces in the patients' clinical experiences.

Findings

Theme 1: Ethical-historical traces in physician-patient interactions

In this vignette, Dr. Campbell centers the elusive ethical dimension of professional practice to recognize interpersonal dignity and trauma, as she narrates the case of an Indigenous woman who suffered for a long time from an underdiagnosed case of rheumatoid arthritis. But her pain, as we will see in this case, is not merely a matter of being diagnosed in the moment, rather it is deeply connected with the history of disciplinary violence of Western medicine on Indigenous bodies (e.g., see Lawrence, 2000; Lux, 2016). Dr. Campbell learned that the patient felt traumatized every time her previous doctor, a white male person, turned his back towards her to draw up a syringe during a clinical procedure, evoking painful memories of the violent use of Indigenous bodies for medical experimentation. To the patient, the posture of the doctor represented a hidden view of Western medicine and a lack of acknowledgement of the patient's dignity from a historical perspective, thus hindering medical care. The apparently simple act of turning away is thus morally and historically salient. She further added:

> "When I started hearing that, I realized, like, wow, I have to be so transparent. I have to do everything in front of her. I have to explain everything. It'll probably take several visits for us to get [from] this scared point of being [to be able] to move ahead because she's just been traumatized by these prior experiences with this rheumatologist [….] And I can totally see it from her perspective. Like it's a very rushed, it's very, you know, not really genuine and wanting to get to know people. Lots of transactional medicine. Right? So I saw it from that perspective and realized that if I was going to be able to sort of reach her and help her, then I would have to be really very patient, very slow with proceeding very, very transparent and clear about what we were doing and what was being done."

In a more general sense, Dr. Campbell also noted in the above excerpt that it is important to be open to the patient about what the possible outcomes and effects of the intended procedures that might result from any diagnosis. But the ethical dimensions of the clarity of such communication is multi-faceted: it requires explaining what the diagnosis means or can mean to the patient, both in terms of the anxieties that the patient might experience as well as the benefits of the proposed treatment. For example, she noted that the previous physician could have engaged differently with the patient if he could have "actually balance[d] what are the benefits of this decision or benefits of this treatment or benefits of whatever [the doctor has decided] to do [with] this injection, with the risks." Even apparently simple and commonplace medical procedures such as injections may be difficult experiences for patients, as Dr. Campbell noted that patients themselves often find needles to be "intimidating" and "invasive." The physician-patient discussion of why a procedure like this may be useful should be dialogical, rather than authoritative, in which the patient needs to be presented with the benefits of the treatment while also acknowledging the perceptions of fear and apprehension on their part. Dr. Campbell also recognized the historically situated nature of this interaction, noting that for the patient, the syringe as held by the patient was interpreted as a marker of colonial violence. The syringe, held by the physician while turned away from the

patient, does not communicate transparency of the physician's intention to the patient. On the contrary, this produces anxiety for the patient because it is consistent with other forms of racialized experiences of Indigenous people in clinical spaces, both historically and on an ongoing basis. Dr. Campbell noted that the details of treatment, including medical tools, technologies, diagnosis and benefits of the proposed care are often not disclosed to Indigenous patients. She also noted that much of the relational and ethical aspects of physician-patient interactions are missing in clinical interactions because of the rushed nature of visits. For example, many Indigenous patients have shared with her that during examinations of joint pain, they felt that their joints were squeezed, "like, really roughly", and that they were prodded and poked "in different places" while not being afforded the dignity of clinical privacy. Offering another example, she noted that during the diagnosis of certain forms of arthritis that get activated by sexually transmitted infections, Indigenous patients were indelicately and invasively asked about their sexual lives, without providing any explanation for the pursued nature of questioning. Their accounts were also doubted by the physicians, and they would often be admonished for their lifestyle and social practices in racially offensive language: "Why are all of your people like this? Why don't you just get over it?" The use of such disdainful stereotypes in professional conversations reproduces feelings of being unwanted and unwelcomed at clinics. Dr. Campbell felt that clinics typically lack a deep understanding of what it means to live in an Indigenous community, which subsequently leads to a lack of care.

Thus, the overall picture that emerges from Dr. Campbell's interview is one where micro-interactions between physicians and Indigenous patients are sites of a historical present, where normative, *disciplined* (Sengupta et al., 2022) interactions may (inadvertently) further reify marginalization and historical trauma for the patients. The intertwined nature of expressions of pain with trauma and fear rooted in histories of medical violence on Indigenous patients in such contexts can also be understood as racialized emotions (Bonilla-Silva, 2019). How can such micro-interactions be oriented ethically and historically in disciplinary spaces? We offer such an illustration in the next theme.

Theme 2: Disciplined sensing as multi-temporal and multi-perspectival "weaving"

This theme focuses Dr. Campbell's metaphor of "weaving" that is rooted in an ethical and historical approach toward caring for patients during a diagnosis. Dr. Campbell explained weaving as an intertwining of various forms of observations and interactions, such as tactile examination of relevant parts of the patient's body, a mix of clinical procedures and tests, and the patient's verbal recounting of their lived and historical experiences. In the diagnosis of arthritic pain, perceiving a patient's condition can occur through sensory probing, technological sensing, and routine diagnostic examinations. For example, she uses both hands to palpate around each joint to feel the skin, bone and the gap between bones to assess the nature of inflammation or accumulation of fluids in joints. Dr. Campbell, thus, is careful to "never put all of [the] weight in that inflammatory marker" to decide upon the diagnosis, rather constructs the diagnosis as "a combination of [the physical] exam, the history and the labs." We have already seen the multi-temporal nature of moments of physician-patient interactions in the previous theme; the point here is that an apparently in-the-moment touch also needs to be reframed in light of histories of disciplinary hegemony and violence on Indigenous and marginalized peoples. A rough and unconsented palpation of an inflamed joint can simply recreate a historical trauma for Indigenous patients.

Weaving is also an essential interweaving of perspectives. Along one dimension, physicians sense through their disciplinarily grounded perception (e.g., seeing the inflammation, palpating the joint) and interpretation (e.g., interpreting medical reports, patients' life histories, etc.). The discipline, as Dr. Campbell noted, is historically present in such moments in the sense that she can "tease out" the diagnosis "based on the patterns that people have observed for… hundreds of years with arthritis" through interactions with a patient. However, along another historically oriented dimension, disciplines are often enacted oppressively on endarkened bodies (Philip & Sengupta, 2021). An ethical-historical re-orientation of disciplinary practices, as evident in Dr. Campbell's words, necessitates acknowledging and interweaving both these historical perspectives. Dr. Campbell noted that it is through such perspectival synthesis that a physician can "... get at what's the real situation with their disease", as the patient could be experiencing "psychosocial pain... emotional pain and intergenerational trauma". Thus, even an apparently simple act of touching a patient necessitates perspectival heterogeneity, because as Dr. Campbell noted, it is conjoined with "historical pieces of how patients are functioning".

Reflective Summary

To summarize, in this paper, we have highlighted interpersonal dignity, racialized emotions and historicized violence occurring in the spaces of medical care. At the heart of valuing patients' dignities, we argue, is an ethical reorientation toward perspectival heterogeneity, through which the disciplined gaze of the physician must be ruptured and interwoven with the patients' emotions, hidden fears, which in turn may be grounded in historical enactments of disciplinary violence. Dr. Campbell gifts us a metaphor—*weaving*—to describe the relational and

emotional work at the heart of a medical diagnosis and care, which is particularly striking given that technological professions, including medicine, tend to "disappear" and devalue such work (Ducey, 2009; Fletcher, 2001).

Our analysis suggests that ethical-historical re-orientations of disciplinary practices (e.g., Dr. Campbell's metaphor of weaving) are essential for *dismantling* (Sengupta, 2020) normative views of disciplinary authenticity that are emplaced within an ethical neutrality of "proper conduct or action" (Stevens & Hall, 1998, p.109) of disciplinary practices. As Philip & Sengupta (2021) argued, notions of disciplinary authenticity that underlie and shape technoscience education typically center epistemic and representational work while ignoring, and worse, further invisiblizing oppression of endarkened people that enables "discipline" in the first place. Our work illustrates how paying attention to the ethical-historical traces of physician-patient interactions may help acknowledge histories of oppression *within* disciplinary practices in ways that affirm dignity of Indigenous people on whom these practices are being enacted. This is an image of a fundamental re-orientation of disciplinary practices in a technoscientific profession, and as an obvious corollary, has implications for reimagining disciplinary authenticity in the context of technoscience education through ethical-historical lenses.

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International Society of the Learning Sciences

Proposing a Role-Based Framework for Data Literacy

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Abstract: Efforts to cultivate critical data literacies in youth calls for further research that emphasizes supporting collaboration in team environments. We propose a role-based framework of four roles (Journalist, Detective, Scientist, and Artist) that seeks to go beyond just facilitating data analysis by representing the multitude of ways data literacy plays a role in people's lives. We pilot our role-based curriculum within an advocacy-focused summer program to study how our approach facilitates collaboration and critical data literacies.

Introduction

The advent of Big Data has spurred new theories and practices to prepare a new generation of learners for a future increasingly reliant on the epistemic powers of data. Given data's growing importance for communicating issues and establishing credibility, learners' ability to both comprehend and critique data could be fundamental to bringing about change in the world. Scholars have drawn comparisons between data and the emancipatory capabilities of literacy, extending aspects of *critical literacy* to form the theory of *critical data literacy*. While this theory establishes objectives of using data to empower and transform, the methods for cultivating critical perspectives in learners are not yet well established. Similarly, data literacy and science are often collaborative in practice, calling for a greater understanding of how to support data literacy in team contexts.

Data science teams can be composed of members with a variety of abilities, such as technical, narrative, theoretical, and visual, which can complicate how data literacy is framed and taught. Such diverse competencies call for frameworks that do not simplify data literacy or prioritize one dimension, but rather highlight the multifaceted nature of the domain. Critical data literacy itself has been decomposed into the technical abilities for using data and the critical capacity to understand the context surrounding data and the reality it portrays (Tygel & Kirsch, 2016). Forming critical insights requires going beyond technical or statistical knowledge sometimes favored in curriculum.

Accordingly, our main contribution was to develop and propose a role-based framework that can better represent the various elements of data literacy, while also supporting collaboration and fostering critical data literacy. These disciplinary roles aim to highlight pathways for contribution that can appeal to a wide range of learners and help them engage with the context surrounding data. Curriculum that breaks down data science into more recognizable disciplinary roles can better align with learners' reality, promoting the critical, and social aspects of data that provide various ways to co-construct knowledge. We report on the deployment of our role-based curriculum in an advocacy-focused summer program. Our primary research goal was to investigate how breaking data science into disciplinary roles facilitates collaboration and critical data literacies.

Critical Data Literacy

There has been growing interest in exploring how to support learners' critical engagement with data in the learning sciences community. Such an interest was well represented in a recent special issue of the Journal of Learning Sciences (Wise, 2020) as well as a symposium at ICLS '20 (Irgens et al., 2020) which specifically called for more research supporting critical sociocultural perspectives. To better engage learners and demonstrate a direct relationship with data, some scholars have developed curriculum around personal data. Such examples include data storytelling using personal data collected from daily lives (Stornaiuolo, 2020) or exploring family geobiographies and personal family migration stories (Kahn 2020). However, these studies noted the need for more explicit support or additional interactions to tackle issues of injustice or inequality (Stornaiuolo 2020; Kahn 2020). In contrast to personal data, which has a more individualistic focus, other scholars have utilized local community data which provides more opportunities for collaboration. Van Wart et al. (2020), described two participatory mapping activities where youth worked together to tackle local community challenges such as air quality and park planning. Similarly, Rubel et al. (2017) describes a classroom module where students investigate their city's distribution of various financial institutions (e.g., pawn shops and banks). We build on this work to explore how a collaborative framework related to data literacy roles can guide interactions in this context.

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Roles to Play in Data Literacy

Recent research has also explored the different facets of data science and literacy in curriculum, helping describe the various roles that can be played in collaborative settings. Such approaches highlight the interdisciplinary nature of data by integrating other creative fields, such as art and journalism. An arts-centric approach called *Data Murals* (Bhargava et al, 2016) engaged the community to reflect on their data and create a visual design that tells a data-driven story. The project, informed by critical pedagogy, aimed to utilize art's history of helping people engage and critique power structures in their lives. D'Ignazio (2017) further described such interdisciplinary uses of data as *creative data literacy*, which highlights non-technical aspects of data. Another related study integrated aspects of journalism by having students generate infographics in a science classroom (Gebre & Polman, 2020). Students were able to creatively communicate with statistics, labeled figures, and data visualizations about a topic of interest. These examples helps explore and inform the various roles youth can play when working with data.

While new in the context of data literacy, role theory has long been used as a framework for explaining characteristic behavior patterns (Biddle, 1986). The theory grew in popularity in collaborative learning for studying both naturally emerging roles as well as scripted roles to facilitate collaborative processes (Strijbos & Weinberger, 2010). In an effort to engage learners in interdisciplinary learning and integrate science and literacy, Jiang et al. (2019) implemented "discipline-specific roles," a type of functional role related to academic disciplines. In the study, students could assume the role of writer, scientist, artist, or engineer to produce multimodal science fiction stories in small groups. Though not yet applied to the domain of data literacy, using disciplinary roles could help capture the many dimensions of using data.

Curriculum and Framework Development

We developed our role framework by generating 8 aspects that are encompassed in using community data science for advocacy: narrative, artistic, investigative, activist, technical, making, scientific, and exploratory. Our next step was to consolidate aspects into roles by minimizing redundancy and preserving diverse ways to participate and engage with data. The roles of *artist* and *journalist* were conceived to cover the narrative, artistic, and making aspects of data. For the remaining aspects of investigative, technical, scientific, and exploratory we created the *detective* and *scientist* roles. Last, we reasoned that activism was an aspect all roles could adopt. We piloted initial role concepts in a youth advisory board, consisting of 3 high school youth from underrepresented groups in data science. Sessions were focused on understanding their attitudes and impressions on proposed disciplinary roles and identifying technologies to aid in data analysis. Using local datasets and data analysis software, youth assumed roles to work collaboratively with their own individual role-related objectives (such as forming a story). Feedback on the role and experience was collected through discussions at the end of each activity. The advisory board helped refine role concepts and identify Tableau (https://www.tableau.com), an interactive visualization and analytics software, as a suitable technology due to the affordances for tinkering and user-friendly interface.

After roles were finalized, we began planning to implement them in a broader curriculum for an advocacy-focused summer program. The research team mapped learning objectives of the curriculum to each role and developed four sessions, each focusing on a single role. Our goal for the sessions was to introduce each respective role and develop the proficiencies needed to enact them in a collaborative context. Each session began with instructional lessons among all youth covering learning objectives and role competencies which was followed by a collaborative activity in smaller groups with facilitators. Our four role-based sessions were:

- Journalist: Exploring personally relevant data (e.g. popularity of one's name over time), sharing results in groups, and writing headlines to communicate the most interesting insights.
- Detective: Learning how to explore datasets with Tableau through an interactive tutorial. Working in groups to find interesting insights in data using summary statistics (counts and averages) and charts.
- Scientist: Watching a video that introduced statistical hypothesis testing and confidence intervals. Applying confidence intervals in Tableau to draw insights from their own data.
- Artist: Introductory activity looking at examples of data art and engaging in sketching to represent data

The sessions were designed to empower the participating teens to use data to inform the advocacy campaigns they developed to redress systemic injustice in their communities, wherein all activities were designed to build towards their final projects (Figure 1). An additional fifth session was planned where students assumed a role according to their preference and collaborated to incorporate prior work with data into their own advocacy campaign.

Summer Program Curriculum

All sessions were in the context of a partnership with a non-profit organization, The Women and Girls Foundation (WGF). For the past fifteen years, WGF has run GirlGov, which is a civic engagement and social justice advocacy

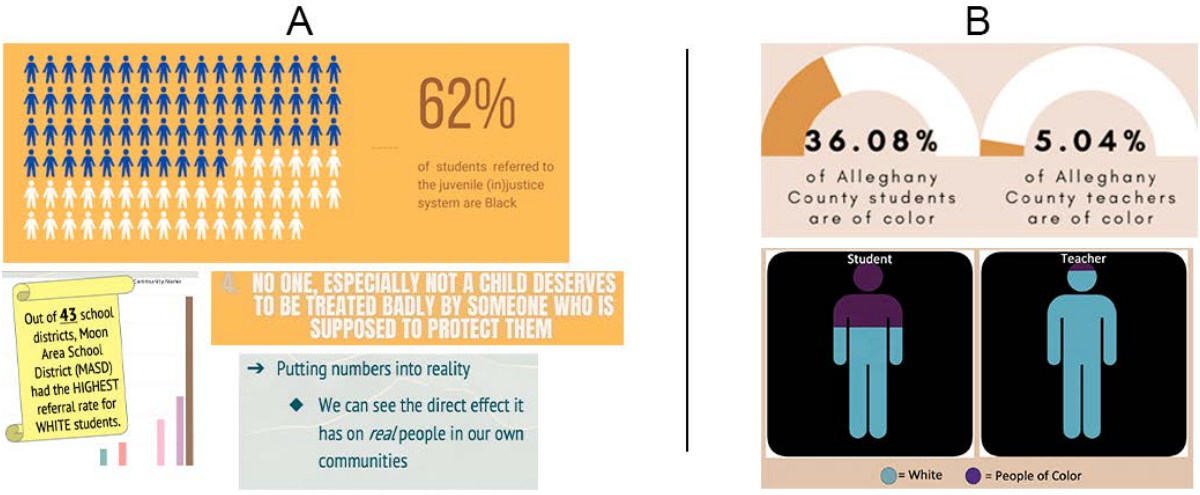
program for high school-aged women and femmes. The primary goal of GirlGov is to train teens to translate their passion for social justice and equity into tangible systemic change. The GirlGov curriculum is rooted in critical theory and community organizing and aims to develop teens' civic knowledge, critical consciousness, connection to community, and confidence as they develop an advocacy campaign around an issue they are passionate about. First, the teens break into groups based on their passions and identify an issue they want to address. After they identify an issue, they participate in a series of lessons, activities, and sessions to research root causes, learn from experts and other advocates, identify a SMART goal or intended objective of their campaign, participate in power-mapping to identify who holds the levers of power to create change, and identify the multiple strategies they will use to convince those in power to change policies. There were also additional opportunities for teens to use the arts and creative expression towards activism.

Program Deployment

The summer program occurred over three weeks and lasted 3.5 hours per day (4 days a week). In coordination with program leaders from GirlGov, we designed five sessions, each lasting approximately 75 minutes, occurring twice a week for the first two weeks and once for the final week. Due to the ongoing effects of COVID-19, all but the first of our sessions happened remotely utilizing video conferencing software and breakout rooms for small group work. As part of the program registration application, the youth provided advocacy-based topics of interest; for example, “education and desegregating school”, “racial equality”, or “school-to-prison pipeline.” Based on these topics, the researchers identified relevant datasets which they introduced in an initial session with the youth. The GirlGov team then held a session for teens to discuss their personal connections to each of the data sets and share examples of the issues in their own lived experience. Based on these discussions, youth formed their own groups around two prominent issues: *the school to prison pipeline* and *teacher and student racial disparities in high schools*. The first dataset contained records of juvenile referrals in the local county. The second described the school demographics of public schools in the county. A total of 24 students enrolled in the program with session attendance varying from 17 to 23 students (ages 14-17). For smaller breakout sessions, each advocacy group was divided further within the two topics by program leaders to create 4 subgroups (4-6 youth) for collaborating and 1-2 facilitators (including research team and GirlGov staff), wherein the youth worked on their selected dataset. Sessions and breakout rooms were recorded, transcribed, and de-identified for analysis

Figure 1

Collage of youth’s work developed for social media posts or final presentations that pertain to advocacy campaigns focusing on either the school to prison pipeline (a) or teacher and student racial disparities (b).



Results and Discussion

From a curriculum perspective, there was promising evidence that framing data science around roles facilitated critical engagement with data by helping youth form insights about reality, consider the context surrounding data, and use data to enact change. Specifically, roles were unique in which critical aspects they most fostered. For example, the Artists and Journalist roles promoted creative ways to connect with the human element of data while the Detective and Scientist roles supported critical reflection on how the data was generated. Such diversity suggests a role-based approach could provide more affordances for students to critically engage with data.

However, our analysis struggled to draw conclusions on how assuming a specific role facilitated collaboration. While roles seemed to demonstrate ways in which students could contribute, they did not always lead to clear division of labor or responsibilities. Groups often focused on a single role at one time, leading youth to sometimes shift to that role. This shifting, similarly observed by Jiang et al. (2019), could be embraced by a role framework where roles responsibilities are modeled as leading and coordinating the group in a task. For example, Detectives could be prompted to lead the group through data analysis, rather than conduct it alone.

Out of all roles, the Scientist was the least represented in the work produced by students. It proved the most challenging role to implement, as students struggled to latch on to ideas of statistical hypothesis testing. This was not surprising, as the role required more specialized knowledge making it the least intuitive to youth. Similarly, the term Scientist might draw connotations from natural sciences or chemistry, which differ in practices from data scientists. Furthermore, there may have been less clarity into how this role was to contribute to a final deliverable. Although fundamental to data literacy and data science, a role centered around Scientist may need to be reframed around a less statistical curriculum to be more intuitive and easier to engage with for youth.

Future Work

Our future work will further analyze the results of this deployment to support the refinement of our role-based data science curriculum. Our analysis will also attempt to describe collaborative aspects of the program, such as inter-role collaboration, and potential methods for future support. Insights will inform our plans to design and develop a collaborative learning system specifically for facilitating role-based critical data literacies in youth.

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Atunements to Socioecological Histories of Places in Learning and Decision-Making in Complex Socioecological Systems

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Abstract: Socio-ecological histories of places are political, contested, and intimately linked with ways of knowing and being in the world. Supporting students in perspective taking and reasoning through contested histories of places are equity practices that allow for multiple and diverse stories to be told, honored, and incorporated in science learning. In this paper, we describe an approach to teaching about socio ecological systems from the Learning in Places project using a framework called *Socioecological Histories of Places*. We first describe the framework and its design within the Learning in Places project. We then analyze one teacher's implementation of this approach and discuss implications for understanding issues of power, historicity, and ethical decision-making in field-based science learning and teaching.

Introduction

Socio-ecological histories of places are political, contested, and intimately linked with ways of knowing and being in the world. Supporting students in perspective taking and reasoning through contested histories of places are equity practices that allow for multiple and diverse stories to be told, honored, and incorporated in science learning (cf. McGrath & Jebb, 2015). Oftentimes, science education in the U.S. has positioned humans as separate from the natural world, or in ways that are ahistorical, which render the intersections of social and ecological systems invisible and thus ensures that students do not have access to powered and historical analyses of these intersections (Authors). Further, our failure to incorporate these histories reduces learners' opportunities to understand the complexities of social and ecological systems central to 21st century challenges.

The work we describe in this paper describes Learning in Places (LiP), a four-year, participatory design research study funded by the National Science Foundation. Learning in Places seeks to co-design (with classroom educators, families, and community-based organizations) learning engagements that support young science learners in Kindergarten to 3rd grade with equitable, culturally-based, socioecological systems learning and sustainable, ethical decision-making using field-based science education in outdoor places (e.g., gardens, parks, neighborhoods). The pedagogical model incorporates students' observations and wonderings, family cultural and community practices, critical historicity of place, and ethical deliberation and decision-making in the form of "should we" questions. The project intentionally designs porous learning environments, where learning happens across time and place, in classrooms, homes, neighborhoods, and community settings. To provide an exemplar of how and why exploring socioecological histories of places is critical to learning and teaching about complex socioecological systems, we analyze one teacher's implementation of this approach and discuss implications for understanding issues of power, historicity, and ethical decision-making in field-based science learning and teaching. **Research questions that guided this analysis are: (a) How does this educator use elements of the framework in their science-related planning, instruction, and reflections on their practice?, and (b) What challenges did this educator grapple with when attempting to embody and actualize the ideas and practices in the socioecological histories of places framework?**

Theoretical framing

We draw heavily from work in social design experiments (Gutiérrez & Jurow, 2016) and participatory design research (Bang & Vossoughi, 2016) to conceptualize our approach to co-designing field-based science learning environments toward just, equitable, and culturally thriving communities. Social design experiments work toward social transformation "by creating a significant reorganization of systems of activity in which participants becom[e] designers of their own futures" (Gutiérrez & Jurow, 2016, p. 566). Similarly, participatory design research requires a fundamental examination and critique of structural sources of inequity, and collective dreaming of alternative, more just forms of partnering (authors). In the Learning in Places project, we intentionally engaged in co-design with district leaders, leaders of community-based organizations, teachers, and families to support the development of co-designers as *historical actors* (Gutiérrez & Jurow, 2016), or "designers of their

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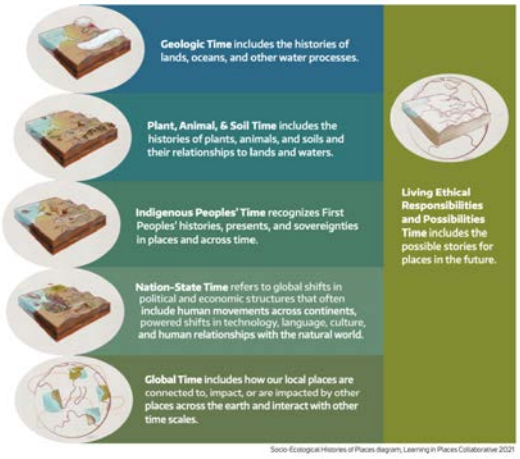
own futures" (p. 567). This involves not only a sense of one's own identity in broader cultural and systemic contexts, but also a historicized understanding of how certain practices--in particular, practices that perpetuate inequity--came to be and are sustained over time. We use this as a lens through which to examine the episode presented below.

Design

In the Learning in Places project, we have designed a set of *educator frameworks* that make visible core dimensions of practice for just and equitable field-based science education. We focus on one of those frameworks, called *Socioecological Histories of Places* (Learning in Places Collaborative, 2021). When scientists study complex systems phenomena in places, they need to understand those places across different scales of time and space. For example, when engaging in restoration, scientists need to first understand the history of a place and the various historical decisions that have been made to shape the land and waters of a place. They need to think across timescales–from geologic time to nation-state time to global time to the future–to understand how natural processes intersect with human decisions and the effects those might have on the future health of a place for all of its inhabitants (cf. Santos-Martin et al, 2019).

The socio-ecological histories of places framework involves thinking across six time scales. These provide a framework for supporting learner sense-making within and across time and place. A key reason to engage learners in this thinking is that it will support them in understanding how things may have changed slowly or rapidly, and how decisions lead to ethical, just and sustainable futures and possibilities. Learners should also reason across multiple time scales to understand the impacts of slow or rapid change in any one of these scales and how this affected/affects another. For example, learners can wonder about how rising temperatures (compared across geologic, nation-state, and global histories, for example) have impacted and are impacting plant, animal, and soil time.

Figure 1: Histories of Places visual graphic



Methods and analysis

For this analysis, data sources included video and audio-taped recordings from a classroom implementation involving the use of the Histories of Places framework with this focal participating teacher. Data sources also included affiliated documents (e.g., student work samples, transcript of a teacher post project interview). Video and audio recordings were transcribed and then coded in Dedoose. Codes included the six timescales in the Histories of Places framework (e.g., plant, animal, and soil time, Indigenous People's time), as well as elements of language use (e.g., past, present, or future tense).

Initial findings

As an exemplar of how these ideas were implemented, we present an episode from one second-grade teacher and co-designer, Ms. Poppy (all names used in this text are pseudonyms), and her subsequent reflection based on her post-interview. To get ready for this lesson, Ms. Poppy had created a timeline out of pieces of paper that spread across the length of the whiteboard, with a picture of Creekside Elementary (their school) at one point on a horizontal line that ran the length of the papers. To begin the lesson, Ms. Poppy engaged her class in a reflection

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using the question “What and who was here before me?”. Ms. Poppy asked students to go to their desks and draw their ideas, and when they returned to the front of the room, Ms. Poppy put their drawings on the timeline. Ms. Poppy then facilitated a whole class discussion during which students shared their ideas. At the beginning of the discussion, students shared that dinosaurs, bugs, trees, and grassy fields were all in the place now occupied by Creekside Elementary and its surrounding neighborhood. Then one student, Simon, shares the following idea:

> Like our great, great, great, great grandfathers, like, had developed guns and then we took like canoes and rode over here. Then we're like, "We have guns. You only have bow and arrows. We will shoot you if you don't come and give us some of this land." Since the Native Americans were nice, they gave the land to us. But then we were kind of not so nice to the people who were, the Native Americans who were nice and we like kept saying "We will shoot you with our guns unless you give us more land." And they were scared and then they kept giving us more and more land and they had smaller and smaller land until this was all ours. Then they only had like a small bit of land for them.

In this example, we see Simon engaging with Indigenous people’s time, nation-state time, as well as global time, as he made visible the deeply powered relationship between Indigenous peoples and European settlers. In his response, the complexity of his thinking spanned across temporal and spatial scales to connect past events and present positionings of both himself and others with a shared ancestry to the settlers. He uses the term “we” to refer to settlers, and “they” to refer to Indigenous peoples. This positioning shows a shared assumption of identity of Simon with the rest of the class, and the subtle ways that whiteness is present as implicit identities amongst students. We also see Simon attending to differences in orientations to nature-culture relations, particularly the relationship to land.

In addition, we see power and historicity emerging in Simon’s comment as well. Settler colonialism, which is premised on removal of Indigenous peoples from their lands, often through violent means, is acknowledged by Simon. He is making explicit how the immoral ethical decisions made by non-Indigenous settlers were displays of power imbalances, exacerbated by differential access to and use of tools and weaponry. Not only was this powered relationship something that led to the forced removal Indigenous peoples from their lands, but Simon also uses the terms “we” and “us” when referring to the settlers, recognizing his shared ancestry and implicitly acknowledging that this history is connected to the present day. Finally, Simon is surfacing the different orientations to land between the Indigenous original inhabitants of the land and the settlers. This orientation, and the relation between the two groups of people, reflect different values - what we hold to be right and ethical - as we see in the “nice vs. not so nice” sentiment.

As the class continues to delve into ideas of Indigenous presence in the region occupied by Creekside Elementary, the following episode emerges:

> Ms. Poppy: Do you think they go when Native Americans were-
> Class: No.
> Ms. Poppy: Oh sorry, I apologize. I just said "Native Americans were." We have plenty of people in this area who are Native Americans whose ancestors have been here for a really long time. So I meant to say, "When," or "Before Europeans came and started living here, do you think they were long before that, the dinosaurs?

At the end of this episode, Ms. Poppy engages in self-correction by recognizing that she referenced Native Americans in the past tense, a move that invisiblizes Indigenous presence and futurity. We argue that this form of humility is an important step in dismantling power hierarchies between educators and learners, and between educators and communities. This is a recognition of the limitations of the educator’s own knowledge and understanding, and indicative of the challenges of engaging across multiple timescales that are often left invisible in science education. This is also a model of making repairs in micro-moments of instruction, repairs that remediate epistemic violence against children when we make their histories invisible in classroom

interaction.

> In Ms. Poppy's post-interview, she reflects on this episode and what it taught her. She says:
>
> I think a lot about the history of places conversation that we had, and how just like really subtle language, but that ends up being really, really powerful language, like talking about Native people in the past, rather than the present, like these little things. And again, so much of this comes from watching tape and reading scripts. And I think that we get, when we're in the moment, we're responding to things. And we're not always like thinking it through every single piece of language. And then when you get to go back and look through it, you're like, okay, this is what I need to think about for next time, or this is how I need to word that differently. So I think those, you know, the history of places is really big for that power. And...historicity? And then I think equity. I mean, I really do feel that I needed a lot to grow as a teacher with my need for like, control of behavior, on walks was something that was so big for me to like, need to have that control.

We see a gradual attunement to the importance of language choice during instruction, and the connection between language and power. Ms. Poppy also reflects on the need to have time to "watch tape and read scripts" as a way to reflect carefully on her language and learn how to continually improve her teaching practice. In this way, Ms. Poppy is emerging as a *historical actor*, in deepening her reflections on how her own practices perpetuate invisibilization of Indigenous peoples, as well as how her actions reflect powered dynamics that carry across time and place.

Conclusion & implications

Shifting the dynamics of power and historicity in moment-to-moment interaction in learning environments is central to actually creating educational equity and forms of education that can contribute to just, sustainable and culturally thriving communities. However, as of yet we have a paucity of work that has traced the learning pathways of educators who are learning to shift their paradigms and to see and enact more just learning environments. This is particularly true as it relates to Indigenous peoples and histories. There is a dearth of empirically based classroom study of these learning dynamics. Further, there is nearly no literature about the role of Indigenous peoples in the scientific study of place. This study marks an important new dimension of how place and field-based science education can and should start to take up the complicated and layers social histories of places as central to learning.

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Draw a place where you learn important and useful things: developing an analytical framework to investigate students' conceptions of learning environment

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Abstract: In this study, we discuss the potential of a new methodological approach to assess children's educational ecology. 1444 drawings from 11-17 years old students were collected in order to ascertain how they conceptualize their learning environments. The drawings categorization scheme was based on the three elements of the Activity System Model (Engerström 1987, p. 115) – subject, instruments, and communities. The majority of the students' drawings portrayed traditional learning spaces like home or classroom, which is consistent with the literature on the subject. As for the analysis of the three elements of the model (subjects, instruments, and communities), the proposed coding scheme describes the community element particularly well.

This paper presents the methodological approach of analyzing drawings made by elementary school students (N=1444) as primary sources of data about their conceptual understanding of learning environments. We analyzed drawings elicited from school students in order to ascertain how they conceptualize their learning environments – including not only such spaces of formal schooling as schools and classrooms, but also informal learning situations (purposefully organized and spontaneous), and new environments like computer - and Internet-based activities (Sawyer, 2014).

Drawing has a well-established history in educational research as a way to document educational phenomena (Chang et al., 2020; Katz, 2017; Harris et al., 2014; Haney et al., 2004; Weber & Mitchell, 1995). For decades, draw-a-picture technic have been used to understand students' conceptions of scientists, e.g. the Draw-a-Scientist Test (DAST) (Chambers, 1983); to explore students' mental models and conceptual understanding of science concepts e.g. internal structure of trees (Rybska et al., 2017); and to investigate attitudes and beliefs toward science and learning (Quane et al., 2021). Hsieh and Tsai (2018) conducted a cross-sectional drawing study of 8-to 18-year-old students' conceptions of learning (i.e. students' views of what learning is) and found that most students held traditional conception of learning - teacher-centred classroom, with students as passive listeners.

The evident benefit of using drawings in educational research stems from the fact, that drawing enables the expression of complicated ideas and thoughts even under conditions of limited writing and reading skills (Selwyn et al., 2009). By using drawings to investigate students' conceptions of their learning environment, we sought to overcome certain limitations of traditional methods of obtaining quantitative data, like written questionnaires and expensive and time consuming interviews and direct observations. However, this decision in turn gave rise to further methodological issues regarding the data coding frameworks and procedures.

The usefulness of draw-a-picture method in educational research depends on its power of assesment. Even the well-known and frequently used DAST method has several modifications of the procedure and different coding schemes (Ferguson & Lezotte, 2020). To obtain results that are generalizable and comparable, we developed a checklist of features the drawings may contain based on existing model of learning enviroment. Directly invoking the concept of *Learning in Activity* (Greeno, Engerström, 2014), we view the learning process as a unit that is larger than an individual person – a group of people, a classroom or a community. On this approach, key roles in learning are played by the agent (student), the object, and the resources which the subject uses to transform the object in line with his or her goal. The process happens within a given community, with its own division of labor and rules. While this model is mainly used to analyze situations in which learning occurs, it also appears useful and relevant in attempting to categorize and analyze static concepts, i.e. the metal models of learning environments illustrated by children.

The primary research questions of the presented study are as follows:

- How do students conceptualize their learning environment? How rich is this conceptualization?
- What elements make up the space as the learning environment? Which of them are recurrent?
- What is the structure of the presented concepts?

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The research project presented herein formed part of an educational program developed by Copernicus Science Centre and financed by the Polish Ministry of Science and Education, aimed at bolstering the development of science capital among students from smaller towns and villages in Poland (in 2019, the program involved approx. 50,000 students, their families and teachers).

Method

Study participants

In total, 1444 primary school students (702 girls, 49%) participated in the study; they were between 11 and 17 years old (M = 14.00, SD = 2.00) and were students of 12 schools located in villages and small-to-medium sized towns and cities in Poland (below 130,000 inhabitants). Non-probability sampling was used to gather participants: the students who participated in this study were recruited from the schools participating in the "Science for You" educational program.

Instruments and Procedure

The "Draw your learning environment" task was a part of a 16-page questionnaire booklet. The questionnaire in a paper-and-pencil format was administered by teachers during school hours. Children were given 45 minutes to fill out the questionnaire. Data collection was anonymous. The school authorities and students were verbally informed about the study and their consent was obtained. Participation in the study was voluntary. Instruction stated "Draw a place where you learn things that are important and useful for you. Label it". Additional open question was placed under the drawing space ("What place is this?")

Data coding framework

To explore how the learning environment is conceived by students we developed a checklist based on the *Activity System Model* (Engerström 1987, p. 115). Of the six-element set that makes up the *Activity System Model*, we chose to describe only three, shown in the table below. We found it impossible to analyze the remaining three elements from the perspective of children's drawings (*objects*; i.e. the scope of the learning process; *rules*, i.e. the set of principles guiding the actors in the process; and *division of labor*).

Table 1

Categorization scheme, taking into account selected elements of the Activity System Model

	Description	Category	Indicators
1. Subject	People involved in the learning process	number	Are people present in the drawing? How many people?
2. Instruments	Tools / learning aids used in the process	number, characteristics	2.1 Traditional (book, notepads) 2.2 New technology (smartphones, laptops)
3. Communities	Varieties of spatio-cultural elements	number and characteristics of learning spaces	3.1 context: formal (school) / informal (forest) 3.2 type: public (museum, library) / private (home, garden) 3.3 dimension: physical (buildings, spaces, nature) / enacted: - symbolic (love to parents, my mind, whole life); -virtual (computer games, social media).

Each drawing was coded using the checklist developed by authors to determine if a feature was present or not.

Preliminary results

Subject

Most of the drawings (88.1%) did not include any people, while 8.4% of the images depicted a single person, and only 3.5% of drawings depicted more than one person (see table 2). There were no significant differences between

boys and girls. This result may be related to the way the task was formulated, which could be interpreted as only concerning space.

Table 2

Subject: Number of people depicted (N = 1444)

	n	%
No people	1272	88.1%
One person	121	8.4%
More than one person	51	3.5%

Instruments

Learning tools were presented in 22% of the drawings, including both traditional (books, notebooks) and modern sources of information (computers, smartphones, the Internet). Traditional learning aids are present in 11.1% of pictures, while modern sources are visible in 8.2% of pictures. Both types (traditional and modern) together are visible in 2.8% of drawings.

Communities

The number of learning environments depicted in the drawing

The vast majority of the respondents (88%) drew and described one learning environment in their drawing. Two such environments (mainly: home and school) were depicted by 7.34%, and only 2% of student drawings indicated 3 and more places of learning (table 2).

Table 2

Communities: The number of learning environments depicted in the drawing (N = 1444)

	n	%
1 learning environment	1276	88.38%
2 learning environments	131	9.08%
3 or more learning environments	51	3.5%
No place of learning declared	7	0.48%

Context and type

Most of the respondents depicted informal learning contexts (62.8%), of which the majority were domestic spaces (a home, a room or part thereof, pieces of furniture such as a desk or bed) 55.9% of all indications. More than 70% of the respondents depicted public spaces (school building, stables etc.), while private spaces were visible in slightly smaller number of drawings (60% of depictions). Most of the drawings contained representations of physical learning spaces, whereas less than 10% of the students depicted either symbolic or virtual spaces (see table 3).

Table 3

Communities: Context and type (N = 1444)

			n	%
Context	Formal		537	37.19%
	Informal		807	62.8%
Type	Private		874	60.53%
	Public		1045	72.37%
Dimension	Physical		1150	79.64%
		symbolic	13	0.90%
	Enacted	virtual	118	8.17%

Conclusions

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Our findings indicate that the "Draw your learning environment" method, presented herein, appears to be well suited to the study of learning environments in children. The relatively small non-participation rates (no drawing and description n=152, no drawing n =44, no description n =81) indicates that the task is suitable and understandable for 11-17 year old school students.

In the presented study, majority of the participants presented similar interpretations of the learning environment concept - mainly as a physical space. Most of the participants drew their home spaces as places related to the practice of learning. In the traditional model of formal education, students receive their learning at school and practice it at home by doing homework and preparing for tests. Although the drawings do not directly point to the home as a continuation of the school experience, the descriptions suggest describing this type of activity (*e.g.*"the desk where I do my homework"). Drawings depicting informal areas of education and free-learning settings such as museums, the forest, and dance were in the minority.

As for analysis of the three elements of the model, the proposed coding scheme describes the community element particularly well. However, it has a certain shortcoming in the sense that it does not allow for the assessment of processual elements and relations (dependencies, hierarchy) between particular elements of the Activity System model. Further limitations are as follows. Secondly, we think that while drawing might provide a promising way to investigate school students' mental models of learning environments, in future studies, it should be supplemented by interviews.

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Disruptions, dissent, and discontinuities: What tensions in intergenerational learning dynamics reveal about learning design

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Abstract: This paper describes family member participation in an informal learning setting called Family Create Nights. With attention to the design of equity oriented STEAM learning experiences, we argue that looking at moments of tension or disruption in families' work together may reveal important needs and desires of learners. Our analysis reveals the ways families positioned themselves in terms of expertise, created collaborative arrangements for working together, and asserted creative control through their project creation. Findings point to the importance of holistically attending to families learning needs, to highlight parents' own curiosities as well as the roles of youth as facilitators and educators within their families.

Introduction

In recent years equity oriented researchers and educators have increasingly turned their attention towards the design of programs that engage families in learning with creative technologies. One model for this brings in families' funds of knowledge through storytelling for culturally responsive computation learning (Roque, 2018; Tzou et al., 2019). As researchers' exploration of this type of family learning is relatively new, there is a need to better understand families' social organization to support the design of pedagogical and facilitation practices..

In this paper we look at family members' participation in the Family Create Night (FCN) workshop series aimed at creating joyful and personally meaningful experiences with technology for families historically marginalized from computing spaces. In this learning context we asked: When did tensions or disruptions arise in families' collaborative work together, and how did families negotiate them? Through our analysis we identified moments of disruption or indications of tension as families made projects using creative technologies. We propose that these moments reveal the needs and desires of learners in ways that can inform program design and the development of facilitation practices. In looking at tensions and disruptions, we saw curiosity and a desire to make creative contributions from both youth and adult learners, and argue that parent's learning must be centered along with those of youth in these collaborative learning environments,

Theoretical Approach

The social organization of informal learning contexts is key to understanding how participants learn together (DiGiacomo & Gutiérrez, 2016; Rogoff et al., 2016). In this short paper, our analysis focuses on the social organization between family members in FCN, which we understand as joint activity. Joint activity positions youth and adults as, "active co-participants in knowing and learning" (Vossoughi et al., 2021, p.215, citing Rogoff, 1994). Each family has their own culture of interactional arrangements and values that all members contribute to shaping, and "while practices may be sedimented, they are nonetheless reified in particular moments of interaction and potentially transformed in those same moments"(Keifert, 2021, p.267). This means that facilitators and designers must attend to how the design of collaborative learning environments might contribute to reifying or reshaping families' cultural practices.

In the learning sciences, disruptions, tensions or breakdowns have been used to understand collaboration and joint work through theories of boundaries and infrastructure (Akkerman & Bakker, 2011; Penuel, 2019; Penuel et al., 2015). We take up these theories to see families as their own cultural communities with their own sets of cultural tools, roles, and practices. Penuel et al. (2015) describe joint work as the negotiation of differing goals and desires for individual participants within these cultural communities. From this theoretical perspective, points of tension or disruption can be leveraged to inform the redesign of collaborative structures, norms and activities. We define tension or disruption in the context of families' work together as: moments of negotiation that disrupt the flow of work, moments of dissent or refusal, disengagement or discontinuing work, and/or expression of an unmet desire. We do not place a value judgment on these expressions or moments of tension, but view them as places of negotiation in collaborative engagement.

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Context and Methods

This study draws on data from an iteration of Family Create Night (FCN) designed to serve Spanish-speaking families who recently emigrated to the US, and held in partnership with an elementary school in the mountain west region of the US. In this four-week workshop series, families engage in creative computing together, using ScratchJr, a block-based programming software designed to be accessible for young learners. The workshops use a four-part structure where families share a meal, connect with their peers, make a project together, and share their creations (Roque, 2016). A university professor, graduate, and undergraduate students acted as both researchers and facilitators to support families to create a favorite family story.

We recruited 9 families: 14 children (ages 5 to 10 years) and 11 adult caretakers. Our analysis focuses on the 5 families who attended at least 3 of 4 workshop sessions and participated in interviews. Ethnographic data collection from the workshops included facilitator fieldnotes, screen recordings capturing activity in ScratchJr, and post-workshop interviews with families. The research team applied a first round of iterative coding to fieldnotes and interviews to identify references to family interactions during project making. Authors then coded fieldnotes, interviews, and screen recording transcripts for moments of disruption or tension (as defined in the Theoretical Approach section above).

Findings

During FCN workshops, families took up a range of different collaborative arrangements in which they negotiated roles, contributions, and turn-taking. These arrangements included whole families working on one project, children working on projects individually while their parent took a hands-off role, and a parent working with their youngest child(ren), while older children paired-up to work on their own project. All families had moments where collaboration flowed; they took up each other's ideas, embraced complementary roles, and transitioned smoothly while turn-taking. However, families also experienced moments of tension or disruption, which emerged around the positioning and negotiation of roles, creative control of projects, and physical control of the materials and tools (often concurrently).

Collaborative Arrangements and Negotiating Contributions

Tensions or disruptions frequently arose when participants voiced a desire to increase their participation in a collaborative project. In these moments of disruption, we saw different styles of negotiation. Some parents, like Nina whose whole family worked on a single project, were very assertive in their establishment of turn taking across family members. In an exchange between Nina and one of her daughters, Lorena, Nina was selecting a character to represent herself, when Lorena asked, "Can I pick it?" Nina responded, "yo la escogo. < *I'm choosing it.*>" Lani, a volunteer from the school reinforced this by explaining to Lorena, "You chose yours, now it's your mommy's turn."

Another family, Julia (parent), Kiara, Cal and Hamid, worked in pairs, with Julia and Kiara on one iPad, and the two boys on another. Cal and Hamid argued throughout the workshops about who got to contribute to the project. During one workshop, a facilitator attempted to demonstrate how to work more collaboratively on the iPad, saying, "Here, put it on the table so you can both do it. Set it down so you can both work on it." The two obliged, but when they returned to fighting a few minutes later, Julia tried to intervene by inviting Hamid to help with her and Kiara's project, saying, "Ven, tu auydame aqui Hamid. < *Come, you help me over here Hamid*.>" Julia defused conflict in that moment by soliciting Hamid's help, and reconfiguring the family's collaborative arrangement.. These kinds of interaction were characteristic of the negotiations families engaged in as they tried to join their familial structures for collaboration with those required by the workshops.

Physical control of device

Tensions over contributions often manifested in a need to negotiate who had physical control of the device, as seen in the example above with brothers Cal and Hamid. This sometimes came up when one family member tried to help another with something they were struggling with by taking the iPad from them and performing the programming action. For example, in a moment of tension between Hamid and Kiara, Kiara rejected Hamid's help and started crying, while Julia affirmed that Kiara could do it herself, " Dejale, ella lo esta haciendo. Ella sabe que hacer. < *Let her. She knows what she is doing. She knows what to do*.>"

It was common to see both children and parents pushing family members hands away as they worked on projects. Sometimes this gesture was used to assert control or ownership of the activity, like when facilitator Amy observed Kiara push Julia's hand away and say, "yo muevo las cosas! < *I get to move the things!*>" after Julia tried to move some characters. In other instances pushing a hand away was done in service of scaffolding learning. As one facilitator Coreina observed, "Nina would push her daughters' hands away from the screens sometimes, which led me to actually closely observe the family's dynamic. What I noticed was that Nina was

very intentionally doing things in ScratchJr herself, but narrating her actions and what she was making happen to her daughters. Then, once she had completed her action, she would then get Mia or Lorena to do the same thing on their own from start to finish." This observation points to facilitators' ability to gain significant insights about family dynamics through attention to moments of disruption. However, caution must be exercised in initial interpretations of the meaning of a gesture or action in the context of a family's collaborative practice.

Creative control

Role negotiation also played out in moments of tension when both parents and kids expressed desires for creative control. For example, Julia discussed the challenge of everyone in the family, including herself, wanting to "make what I wanted to make." Negotiations around creative choices were most often around aesthetics (ie. "*No, I like the pink one more*"), or continuity or percieved fit (ie. "*We do not need flowers in a library*"). Within aesthetic negotiations, tensions over the visual representation of family members were by far the most common. In prior analysis (Roque et al., 2021) we found that families faced limitations and tensions in how they were able to visually represent themselves in ScratchJr, especially when it came to race and body type. We found here as well, that frictions emerged as individual family members tried to assert their agency over how they were represented in the projects.

Both parents and children commonly expressed displeasure at how they were portrayed when other family members selected or edited characters that represented them. In an exchange between Lucia and her daughter Jasmine, Lucia started to select a character for Jasmine saying, "ponemos una foto Jasmine? ¿Cuál quieres? Oh, esta, esa. < *Should we add a picture, Jasmine? Which one do you want? Oh this one, this one.*>" Jasmine dissented, "No, esa no. < *No, not that one*.>" Lucia responded affirmatively, "andale pues. < *Okay then*>," and let Jasmine select the one she wanted. In other instances, family members' expressed desires about their own representation was not respected. For example, Hamid became upset when his brother Cal represented him with a cat character, saying, "Noo that's not me." Cal responded by selecting a pig character and saying, "Okay you can be this one," which made Hamid more upset. Cal only agreed to change Hamid's representation to a human character after Hamid got their mother Julia to intervene.

Another form of tension related to creative control was caused by what we interpreted as discontinuities in participants' priorities regarding their projects. We saw several instances where one family member (usually a child) wanted to take more time to work on aesthetics, while another (a parent or sibling) wanted to move on to develop other aspects of a project, often in service of completing the project by the end of a workshop. In one example, daughter Camila fixated on the selection and aesthetics of a dog character, while mother Ana said, "Corrale que tenemos que hacer todos estos, y no hemos hecho ni uno. < *Hurry we have to make all of these, and we haven't even made one*.>" In a related dynamic common between children and parents in the workshops, parents shut down their child's assertions that they wanted to continue drawing instead of working on the ScratchJr project. These dynamics may point towards children prioritizing whatever form of creative expression was most compelling to them in the moment, while parents generally seemed to be more product oriented.

Expert/ Novice Positioning

In interviews, some parents discussed a dynamic where children were positioned as experts and parents as novices with technology. One mother, Marta said of her sons, "Arturo enseñó a Roberto, porque me quitó el tablet, 'no mami, es que tú no sabes.' <Translation: *Arturo taught Roberto because he took the tablet from me, 'No Mom, you don't know what you are doing.*>'" During the workshop that Marta described, Amy, a facilitator, had also observed that Roberto and Arturo "had taken over their mom's iPad and deleted her project so they could restart with their own… Marta, was sitting off a little from them and was not participating actively with the boys."

In an instance during the following workshop, facilitator Amy observed a further interaction between Marta and her son Arturo. "Marta asked Arturo if he would teach her how to do Scratch this time, and he said 'no' that he was the expert. After a bit though, he said he might be willing to teach her some." Even though Arturo had positioned himself as an expert (as did Marta by asking for his help), he was hesitant to teach his Mom. Later in the workshop families outlined their family story through storyboards and then translated them to ScratchJr. Marta said that because her kids wanted to draw and program their story quickly, "yo nunca traté porque ellos ya sabían*. < I never tried because they already knew how to do it.>"* While the positioning of youth as experts with technology did not always inhibit adults' engagement with the projects, it hindered collaborative learning between family members when youth did not take on a teaching role with their parents or pace their activity to actively engage them as collaborators.

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Discussion

While intergenerational collaboration in informal learning settings may often be positioned as joint activity, adult's learning often remains peripheral, as the lens is still focused on children's learning, placing adults in an assistive role. We found that parents were also curious learners who wanted to experiment and make creative contributions. Ignoring the presence of parents' curiosities and desires both marginalizes parents as active learners, and marginalizes the role of youth as potential facilitators and educators within their families, who shape family culture and dynamics. In earlier iterations of FCN, we noticed this curiosity from parents and created space and time in the design of the FCN model for parents to explicitly create with ScratchJr on their own before introducing their kids to the program (Roque, 2016).

Considering parents as learners is particularly important for technology-based family workshops where the expertise may be flipped from the norm of adults holding more established expertise than youth. Designers of these learning environments should consider how all family members can make valuable contributions and hold expertise in these dynamics, e.g. how to support youth as facilitators in their family and see their parents as curious learners too. Taking on a leadership role as educators within their families is something that may be modeled for youth.

While youth may have been more likely to be positioned as experts around technology, parents were more likely to take on roles structuring turn-taking and the negotiation of work together, as well as asserting their ideas about normative storytelling. Based on our findings on the challenges of negotiating turn-taking and legitimizing the contributions of all family members, initial activities that scaffold the practice of building off of each other's contributions could be beneficial. It may also be worthwhile to consider the tensions families had around normative narrative construction (ie. the continuity issue) and how expansive possibilities for world building, remembering, and dreaming together might be designed for in family's collaborative storying with creative technologies. Lastly, our findings suggest that when representations of the self and personal identity are incorporated into family learning activities, participants may benefit from activities that norm individual family members having agency over their own representation.

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Learning Efficacy and Effect of Scaffolding in Online Engineering Education during COVID-19 Pandemic

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Abstract: We explore the challenges of teaching "hardware-embedded Robotic Operating System (ROS) skills" online in a lockdown situation to participants through a hands-on competition. Teamwork is a vital skill in solving modern engineering problems. During Covid-19 lockdown situations, the interaction between teammates significantly reduced compared to regular times. This prompted us to design an engineering problem statement with scaffolding that improves engineering education learning efficacy. A total of 465 teams (1860 participants) were introduced to a problem statement comprising of a autonomous robot navigation, manipulation and a perception task for an indoor unmanned ground vehicle. We study the performance of teams based on several factors such as participant's score, task's difficulty level, number of resources given and the nature of online sessions by instructors. We found the scaffolding approach helped teams in implementing a solution by exploring alternative methods and thus their knowledge.

Introduction

e-Yantra Robotics Competition (eYRC) is an initiative hosted at Indian Institute of Technology Bombay to bring the experience of project-based learning to engineering participants using a competition to deliver hands-on training (Krithivasan, Arya, et al., 2014). In eYRC, participants are given a problem statement called a "theme" to be solved using a robot as a team of 4 undergraduate engineering students. In the past eight years of eYRC, teams collaborated on a hardware-based project physically coming together on their college campus. This collaboration and other aspects of eYRC such as hardware prototyping and fabrication have been challenged by the lockdown caused by the Covid-19 pandemic.

The theme called "Sahayak Bot (SB)" was introduced to 1860 participants (465 teams) in 2020. The problem statement was to program a simulated mobile cobot (a collaborative robotic arm mounted on an autonomous ground vehicle) to assist in inventory packaging activities (Bejarano, 2019). The mobile cobot assisted in packaging by finding objects and moving them to the required location.

The theme problem is divided into multiple tasks spread across six to eight months. The tasks are designed to train novice participants to program a simulated mobile robot to find, identify, and move objects to desired locations autonomously. The theme contains six tasks which focus on getting familiar with Robot Operating System (ROS) (Quigley et al., 2009), Gazebo (Koenig & Howard, 2004), control of mobile robots, mapping and navigation (Filipenko & Afanasyev, 2018), robotic arm manipulation (Chitta et al., 2012), and perception. The mobile cobot consisting of a Universal Robot, UR5 robotic arm mounted on a mobile base was modeled in a simulated environment.

Throughout six tasks, the participants were provided with reading resources, live sessions, and discussion forums to solve a problem statement. In the initial tasks, detailed support was given to ensure participants could gain momentum to tackle the challenges. As the participants progressed in tasks, support was gradually reduced to encourage independent exploration and learning. This approach was inspired by the widely used technique called "scaffolding" (Hammond & Gibbons, 2005) which refers to providing successive levels of temporary support. This helps participants reach higher levels of comprehension and skill acquisition that they might not be able to achieve without assistance.

The challenge is to design a method for teaching skills required to work on industry grade mobile cobot in a simulated environment. Our study analyses the performance of teams on factors such as interaction between teammates, scaffolding in a task's difficulty level, resources given and online interaction by instructors.

The significant contributions of this paper are as follows:

- Designing a scalable methodology to teach the skills required to work on industrial grade mobile cobot.
- Investigation of learning efficacy in the proposed methodology.
- The effect of scaffolding in the proposed methodology is explored.

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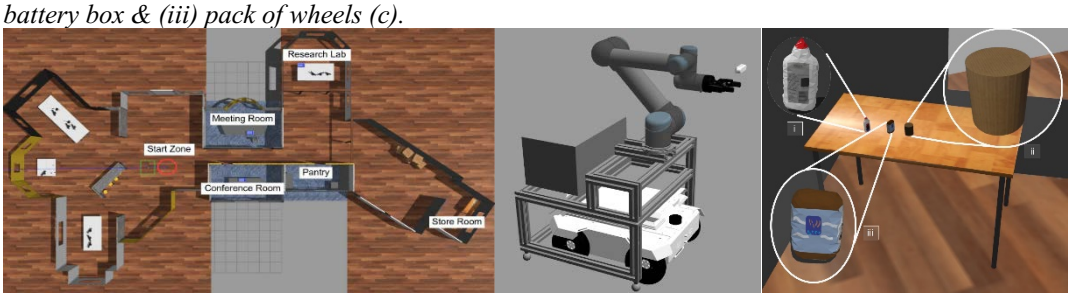
Theme Design and Methodology

The simulated theme arena comprises different locations as shown in Figure 1(a). The start zone (red marker) is the coordinate where the robot spawns every time the simulation starts. Figure 1(b) shows the mobile cobot modeled in a simulation environment. Figure 1(c) shows the object for pick and place.

Figure 1

Theme and Arena (a), The Mobile Cobot (b) and Objects for pick-&-place task (i) blue box, (ii) battery box & (iii) pack of wheels (c).



(a) (b) (c)

The competition integrated hands-on engineering topics as part of the learning activity, inspired by quotidian activities in indoor environments. It was designed in a simulated environment and carefully broken down into several tasks to better understand the problem statement, as shown in Figure 2. After successful task implementation, the participants learned different robotics concepts inspired by this theme, and its efficacy was analyzed based on the gathered data and insights.

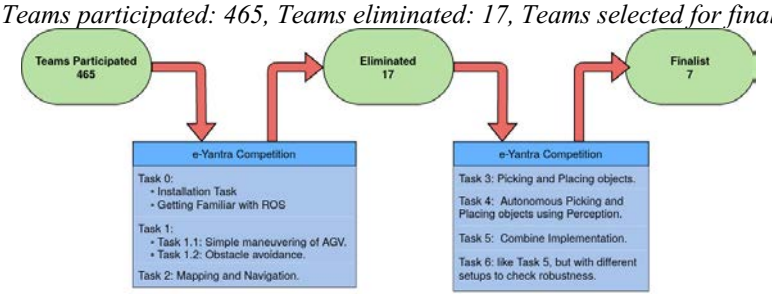
The teaching resources in this theme were mdBook (Klinke & Witzel, 2002), interactive live sessions, surveys, and discussion. The mdBook consisted of resources, learning material, and references for each task. Participants post their queries on the Piazza forum for asynchronous discussion (Andresen, 2009). In surveys, questions related to the task were asked based on participants' experience and time invested in theme. Interactive sessions were conducted to understand participants' problems and provide hints to solve them. Quantitative analysis is based on data collected through surveys, tasks, forums, and learning materials. In contrast, the qualitative analysis relies on resource statistics, performance in each task, and interactive live sessions.

Implementation

The tasks were created based on their difficulty levels which gradually helped the participants to solve a final problem statement There were six tasks given in the SB theme, which are described in Figure 2.

Figure 2

Task flow: Teams participated: 465, Teams eliminated: 17, Teams selected for final: 7



In summary, participants were expected to complete the theme which had several challenges such as autonomously navigating to different rooms (refer Figure 1(a)), searching for randomly placed objects (refer Figure 1(c)), correctly picking and placing these objects in their designated location.

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Resources & Scaffolding

The division of the tasks increases the theme efficacy (Krithivasan, Arya, et al., 2014; Krithivasan, Lala, et al., 2014) by helping the participants understand aspects of robotics gradually. Learning resources in mdBook, support from live sessions, and a discussion forum (as shown in rows 2, 3 and 4 in Table 1) were supplied to them till Task 3. The perception task (Task 4) incorporated scaffolding by removing the learning resources from the mdBook. However, different approaches were suggested to tackle the task. This technique encouraged the participants to look beyond the aid provided which broadened their knowledge of existing literature and eventually helped them to find the best approach for the task.

Results and Discussion

Analysis on performance

Table 1 shows the overall task performance in the competition. The difficulty index row in the table indicates that the higher the value, easier the task is. Note that Task 0 is the easiest and Task 5 the most challenging task. Considering that detailed learning material was provided till Task 3 along with live video sessions till Task 2 to give a better overview of the task and resolve common queries. The resulting teams were able to perform well till Task 3, with a low dropout rate. After Task 4, the support gradually decreased so that teams can learn to collaborate and work upon innovative solutions to solve the problems. We observe that the drop rate increased due to scaffolding. Most of the participants could not complete the task as they found it challenging to learn on their own.

Table 1

Task implementation and outcomes

Row No.	Subject	Task 0	Task 1	Task 2	Task 3	Task 4	Task 5
1	Task Duration (in weeks)	2	3	3	3	4	4
2	References and hints available	✓	✓	✓	✓	✓	×
3	Detailed learning material available	✓	✓	✓	✓	×	×
4	Live session conducted	✓	✓	✓	×	×	×
5	Total submission	390	270	182	139	69	43
6	Difficulty index	0.86	0.71	0.68	0.93	0.67	0.39

Note: Difficulty index (Johari et al., 2011) is calculated as the fraction of average score in a task and range of full score.

Task Difficulty

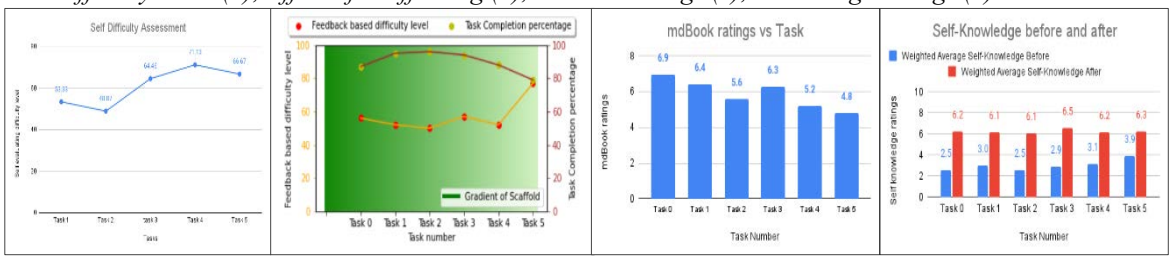
While designing tasks, the instructors scored task difficulties based on the questions that elicited the learning from that task. For instance, in Task 1, difficulty was rated based on *how difficult it is to make the cobot follow the curve path using either P/PD/PID controller? How difficult is it to avoid obstacles?* and finally, *how difficult is it to combine the overall task within a single script?* The task difficulty level trends are shown in Figure 3(a).

The effect of scaffolding on difficulty level (based on participants' feedback) of each task and their completion rate is shown in Figure 3(b). The gradient of color indicates the scaffolding. The green color suggests more support was provided, and the transition of color from green to light green shows the decrease in support. Figure 3(b) indicates, with the gradual reduction of support from Task 3, the participants' future tasks became more difficult. Also, the plot of task completion percentage signifies the difficulty faced in completing the task. As the task became more complex, only a few participants were able to complete the task.

Learning efficacy

All the problem statements, instructions and learning material were provided to participants in the mdBook. Until Task 2, live sessions were held to explain concepts, including verbal task descriptions, some hints and live Q&A. From the surveys, we observed the helpfulness of live sessions, and Figure 3(c) shows their task-wise feedback rating for provided help (Mdbook & live session) in completing the tasks. We see that resources were of significant support until Task 3, while later, the ratings dropped due to scaffolding. However, pedagogical research in engineering education has shown the importance of project-based learning in creating competent engineers (Mills & Treagust, 2003; Panwar et al., 2020). Moreover, from Figure 3(d), enhanced learning efficacy is observed through working on a real-life problem statement in a step-by-step approach.

Figure 3
Task difficulty trend (a), Effect of Scaffolding (b), mdBook ratings (c), Knowledge ratings (d)



(a) (b) (c) (d)

Conclusion and Future Scope

The scaffolding approach encourages teams to work more efficiently by assigning roles and responsibilities that helps teams to find the best solution for a given problem. Based on the surveys and feedbacks, we analyzed that a step-by-step approach combined with temporary support that is eventually removed helps the teams gain confidence in the skills developed through the tasks in the competition. The effectiveness of teaching such concepts can be tested further by designing a theme that will take the students from simulation to hardware. The challenges in converting the software in simulation to code for hardware will thoroughly test how well the participants have absorbed the concepts being taught through the tasks.

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Mapping the Landscape of Assessment in Out-of-School Time Arts Learning

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Abstract: This study represents the first USA-based qualitative investigation on assessment in out-of-school time (OST) arts education. While analysis for this project is ongoing, preliminary findings show how arts leaders conceive of assessment and how those conceptions influenced their practices for documenting and assessing arts learning. By mapping the current landscape of assessment in OST arts learning, we can more clearly identify existing practices and opportunities to adapt and reimagine assessment.

Major issue(s) addressed

Discussions around assessment in arts education environments can be fraught "if not overtly hostile...like two opponents in a boxing ring" (Soep, 2004, p. 579). In the United States (USA), concern endures that the current era of accountability testing precludes the arts from being featured regularly in classroom curriculum (Chappell & Cahnmann-Taylor, 2013). Debates persist about the extent to which arts education should conform to standardized testing culture or pave its own way (Willerson, 2019; Winner & Hetland, 2008). Additionally, arts educators continue to express sentiments of frustration at scholars' narrow assessment conventions that fail to capture many of the valued arts learning outcomes (e.g., Omasta et al., 2020). As evidenced by presentations at the 2021 World Alliance for Arts Education Virtual World Summit focused on arts assessment, such challenges transcend international borders.

However, the majority of scholarship and discourse on assessment of arts learning is derived from schools, leaving out-of-school time (OST) environments (e.g., children's museums, public libraries, youth arts programs) to either integrate formal assessment strategies that may not suit their learning goals, adapt or develop their own strategies, or forgo assessment altogether. To our knowledge, no investigation has been done to understand how assessment occurs in situ in OST arts education in the USA, nor how its inclusion is perceived by stakeholders. Without a rich foundation of scholarship, OST arts leaders and educators are left to make sense of fragmented research that was never conducted with their learning settings in mind. This study begins to fill those gaps in scholarship. Drawing from data collected for a nation-wide, qualitative research project on OST arts organizations, we begin to map the landscape of assessment in these learning environments. Analysis for this project is ongoing, but preliminary findings provide a foundation for understanding how arts leaders conceive of assessment, and how those conceptions influence their assessment practices. By mapping the current landscape of assessment, we can more clearly identify existing practices and potential opportunities to adapt and reimagine assessment in OST arts education.

Theoretical and methodological approaches pursued

Theoretical framework

The theory of educational assessment that guided our analysis is primarily based on the work of Pellegrino et al. (2001), which describes assessment as the relationship between "a theory of what students know and how they develop competence in a subject domain (cognition); tasks or situations used to collect evidence about student performance (observation); and a method for drawing inferences from those observations (interpretation)" (p. 36). We chose this theory of assessment as the foundation for our study for two reasons. First, it highlights the connection between theories of learning and assessment practice, which has been historically ignored in educational assessment and led to the proliferation of outdated assessment approaches (Shepard, 2000). Second, the framework does not employ complex terminology from education research, nor does it presuppose any specific theory of learning, which allowed us to be flexible in how we analyzed participants' varied understandings of assessment. Because this study focused on OST arts education, we adapted the model by Pellegrino and colleagues. We expanded the "cognition" element by replacing it with the phrase "models of success," which better described the broad array of outcomes possible in OST arts organizations, some of which have little to do with direct learning (e.g., feeling a sense of belonging among peers and mentors).

Data collection

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Data for this study was collected between September 2020 and June 2021, and was originally used for a report on OST arts organizations in the USA that predominantly serve BIPOC youth and youth from low-income families. In the summer of 2021, sub-groups of the research team conducted five mini projects using the same data to explore in depth several themes that emerged in the report. This study is one such mini project. The main data sources for this study include: (a) 12 individual interviews with nationally recognized experts in OST arts education; (b) 6 regional (1) focus groups with a total of 26 organization leaders; and (c) 7 program-centered focus groups with a total of 36 stakeholders that included organization leaders, teaching artists, and young people. In all, 72 stakeholders participated in the study, with 9 policy makers, 8 researchers, 28 organization leaders, 17 teaching artists, and 10 young people.

We identified potential experts for the individual interviews through nominations by our advisory board (consisting of researcher-practitioners in the fields of OST youth education and participatory design research for learning) and the literature review we developed for the project. We then asked each interviewee to nominate other experts and leaders who might participate in a focus group. This approach to purposive sampling is often referred to as "snowball sampling" (Merriam & Tisdell, 2016). This process led us to include stakeholders who predominantly identify as Black, Indigenous, and people of color (BIPOC), and who mostly serve BIPOC youth.

Data analysis

We approached data analysis by treating assessment as more than a pedagogical tool; we conceived of it as a complex phenomenon in which ontological constraints are interwoven with axiological commitments and implicit assumptions about epistemology that influence how stakeholders experience and facilitate learning in OST arts organizations. Our study was designed as a phenomenological exploration of assessment, a framework we adopted from Omasta and colleagues' (2020) study of assessment in theatre arts classrooms. To capture the full phenomenon of assessment, we sought to answer the following research questions:

- How do arts leaders conceive of assessment in OST arts learning?
- What and how do arts leaders assess?
- How are arts leaders' values for learning and conceptions of success reflected in discussions around assessment?

Analysis occurred in three phases. Phase one and two coincided with analysis for the larger study. Phase one consisted of a literature review on OST arts programs serving communities with a history of oppression. The literature review provided insight into promising practices, persisting challenges, and remaining gaps and tensions within the field.

In phase two, the interviews were transcribed, divided among the research team, and analyzed inductively using emic, open coding strategies: descriptive coding, in which the data was labeled by the response topic (e.g., assessment, art discipline, or success); concept coding, which entailed labeling the data by the response content (e.g., learning by saturation, place making); and in vivo coding, to highlight specific ideas verbatim (e.g., "community-based process") (Saldaña, 2016). Analyzing the interviews yielded a list of codes that were then used to analyze focus groups transcripts. Throughout this phase, scholars developed analytic memos (Merriam & Tisdell, 2016) that were used in weekly team meetings to discuss emergent themes and to triangulate and differentiate patterns of meaning-making. In phase two, broad themes surfaced ranging from descriptions of assessment tools to arguments about the purpose of assessment and were discussed.

For phase three, which focused specifically on assessment, three scholars from the full research team conducted the analysis. The first author had participated in both preceding phases of analysis, and so was familiar with participants' responses regarding assessment. No further data was collected for this phase. Phase three began with an iteration of structural coding, in which we applied a conceptual phrase representing a topic of inquiry to a segment of data as a method of coding and categorizing the data (Saldaña, 2016, p. 97). We used our research questions and related sub-questions as the conceptual phrases. The second iteration of analysis consisted of writing analytic memos about how each expert or focus group answered the conceptual phrases. To triangulate analysis (Merriam & Tisdell, 2016), transcripts were divided into three sets of data, and one researcher was assigned to each set. Moving into memo writing, researchers rotated data sets, so each data set was analyzed by at least two scholars who were then able to make connections and discuss discrepancies in the interpretations that emerged. The final iteration of analysis included compiling all the memos by theme. For instance, all memos about conceptions of success from all three data sets were compiled. Once compiled, the data was then coded by all three researchers simultaneously using concept and in vivo coding. Those codes were then "lumped" together or "split" apart through code mapping, in which codes are organized under a list of categories and then condensed to reveal the central themes (Saldaña, 2016, p. 218). Analysis for this project, including code mapping, continued

until the central themes had reached saturation, the point at which the same concepts or themes emerge over and over again, indicating that the data has been thoroughly analyzed (Saldaña, 2016).

Major findings

Data revealed assessment in OST arts education to be a source of tension and triumph. In this short paper, we focus our major findings on arts leaders' conceptions of assessment, and how those conceptions influence their practices for documenting and assessing arts learning.

Stakeholders in OST arts education define assessment in dichotomous ways. On one hand, they describe assessment as a formal practice of capturing and measuring the knowledge or skills young people acquire as a result of engaging in arts programs. On the other hand, participants allude to assessment as an informal, intuitive process of observation and conversation with young people to gauge their progress. Participants describe assessment results as "tangible" only if they are documented using quantitative data. However, participants also assert that certain arts learning outcomes can only be understood through qualitative evidence like stories. This qualitative evidence is usually considered more impactful than quantitative data, but is less often formally collected or considered credible assessment. It is clear that participants believe quantitative measurement is what "counts" as assessment in the field, even though they personally see the value of, and often prefer, attending to qualitative evidence of young people's progress.

All participants define assessment in OST arts organizations in relation to assessments used in schools. They refer to such school-based assessments as "traditional" or "typical," and associate them with quantitative measures (e.g., increased attendance, high school graduation rates, standardized test scores, and classroom grades) and assessments that seek to capture evidence of discrete skill and knowledge acquisition (Sfard, 1998).Despite the value and preference arts leaders indicate for more qualitative measures, participants rarely articulated an alternative to school-based assessment. One teaching artist suggested that checking off students' ability to play scales in music was characteristic of public school music education, and he set that in contrast to assessing how well a young person is meeting their own goals for learning music (e.g., to develop a joyful hobby, to gain mastery as an artist, or to pursue a specific job). Another participant had no alternative to offer, but asserted that

> one of the greatest things we could do, or try to train this next generation to do, is to change the evaluation process of what people think is supposed to happen or what we're supposed to measure. because if we don't measure differently, people will think we're not doing all the work that we're doing. And we're doing a lot.

Participants suggest that aligning with school-based assessment was either a necessary compromise or an undesirable association they tried to avoid. Many participants consider schools sites of marginalization where BIPOC youth have fewer opportunities to succeed, in part due to assessments that value narrow definitions of achievement. And yet, their conceptions of assessment are deeply tied to school-based assessment. Three categories emerged in participants' approaches to assessment: the **comply/ cooperate** with assessment approach, the **creatively compromise** on assessment approach, and the do it yourself **(DIY)** approach. The **comply/ cooperate** approach represents organizations that conducted school-based assessment practices regardless of whether they produced examples of success valued by organization leaders and teaching artists. We use both verbs to describe this response, signifying both the negative and positive valence participants associated with it. In the **creative compromise** approach, stakeholders engage in assessment in creative ways that both reflect and resist school-based expectations about assessment and achievement. The challenge of the creative compromise approach is to either find a middle ground between different assessment practices or to execute several assessments in parallel. Finally, the **DIY** approach to assessment essentially rejects school-based assessment practices and expectations outright. All three responses reveal that assessment in OST arts education largely revolves around notions of school-based assessment, even if arts leaders choose not to engage in school-based assessment at all.

Across all three approaches, arts leaders have formal tools and practices for school-based assessment and rely on informal processes for gauging qualitative evidence of learning and engagement. Formal assessments are characterized by assessment practices that are employed in systematic ways, and which collect concrete evidence for assessment. Informal assessments refer to instances where arts leaders casually check in on or take note of learners' progress toward goals and outcomes without documenting what they notice or hear (Ruiz-Primo, 2011). Michalchik and Gallagher (2010) refer to the latter as naturalistic assessments and argue that this approach to assessment is not an argument for anti-intellectualism, but an appeal to the idea that assessment is a natural part of everyday activity, a practice that can be honed even when it not accompanied by systematic, and formal documentation. Examples of formal assessments include logs for quantitative metrics (e.g., attendance, programs offered, college acceptance rates, etc.), observation tools that document student behavior, pre- and post-surveys,

and checklists. These were predominantly used to assess discrete outcomes that could be represented through quantitative data. Examples of informal assessment include talking with youth and their caregivers, casual observation, and collecting narrative-based evidence like quotes, impact stories, or testimonials. These were usually employed to qualitatively gauge a young person's level of engagement, joy, or sense of belonging, or the broader impact a program may have had on their life.

Surprisingly, despite how many participants valued qualitative evidence of their impact, most did not have systematic or formal ways of collecting this information. As an explanation for this gap in practice, most participants indicated that they did not know how to "measure" the outcomes they informally assess. Others admitted to feeling immense pressure from outside stakeholders (e.g., caregivers, policy makers, and funders) to use practices that align with school-based understandings of learning and assessment, or risk losing funding. There is a disconnect between the outcomes arts leaders think they should assess and what they perceive "counts" as assessment, indicating that dominant models of assessment do not sufficiently capture all that arts programs have to offer.

Conclusion

Perceptions about what "counts" as assessment greatly influence how assessment is practiced in OST arts organizations. Stakeholders in OST arts programs in the USA largely rely on formal assessment of discrete knowledge and skills or quantitative metrics, which is often associated with school-based assessment, despite their assertion that informal assessment of qualitative data on learning yields more meaningful evidence of their program's impact. There is an apparent lack of resources available (i.e., assessment tools, practices, or professional support) for stakeholders to formally assess the qualitative outcomes they value, or else a lack of access to readily existing resources. Ultimately, more research dedicated to OST arts education is needed to understand why current assessment practices are insufficient, and to identify what stakeholders need for improved (or reimagined) assessment practices that illustrate the full impact of their programs. We are pleased to present this study, which we hope is the first of many that begin mapping the landscape of assessment in OST arts education.

Endnotes

(1) The regional focus groups represent four cultural geographic regions characterized by their physical location and cultural landscape: Urban Midwest, the Indigenous Southwest, the Bay Area, and Texas-Mexico border towns.

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Centring BlackJoy in Design for Learning and Research

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Abstract: This theoretical paper presentation will articulate BlackJoy as a framework for designing research-to-practice spaces that centre Black liberation and flourishing for authentically equitable learning engagements and to counter ongoing deficit narratives and corresponding oppressions that Black and other racialized/minoritized learners experience in schools and other learning environments. The BlackJoy heuristic has four key tenets: Black Excellence, Black Inventiveness, Black Kinship and Black Aesthetics. Data and vignettes from prior research projects will be described of examples of BlackJoy in education and used as a point of departure discussions about the design of research and learning environments that cultivate BlackJoy and expanded ways to think about evidences of learning.

"Centering on Black joy is not about dismissing or creating an "alternative" Black narrative that ignores the realities of our collective pain; rather, it is about holding the pain and injustice we experience as Black folks around the world in tension with the joy we experience in the pain's midst. Black joy is healing, resistance and regeneration."
-Kleaver Cruz

The global pandemic allowed for a collective witnessing of the ongoing and violent inequities experienced by Black and other racialized people especially in postcolonial and settler colonial contexts. For example, Black bodies in the United States disproportionately experienced the grave effects of COVID-19 than others (Poteat et al. 2020). This is compounded by the higher likelihood of Black people working in essential services (Lancet 2020). The circumstances of George Floyd's murder that ignited a global resurgence of the #BlackLivesMatter movement brings to the surface Sylvia Wynter's (1994) essay *No Humans Involved* that she wrote to her colleagues after the Los Angeles murder of Rodney King where she noted the acronym used by the judicial system, NHI, meaning "no humans involved," referred to "any case involving a breach of the rights of young Black males who belong to the jobless category of the inner-city ghettos and noted that "systems of classification direct our thinking and order our behaviors". This classifactory schema, Wynter argues, is based on the colonial logics of race science that emerged from Western Modern Science and contributes to the denial of humanity to Black people.

In education this presents in schooling where Black students are framed with deficit lens and often positioned to be less capable than their non-Black counterparts, especially in science (Mutegi, 2012). Language such as "at risk" and, in certain contexts, "urban students" positions Black and Brown students as lacking in intellect, discipline, stable homes, etc. as impediments to success in the classroom, "the Black is constructed as always already Problem—as non-Human, inherently uneducable, or at very least, unworthy of education." (Dumas 2016, p. x). And yet in these spaces of pain, violence and oppression Black people still manage to seek joy, "…Black people's everyday commitment to locating joy in our lives often pierces through the troubled moments like the light shining in my room…[it] center[s] on our capacity to overcome despite all that might try to harm us (Cruz, 2017)

In North America and other antiblack settler-colonial and postcolonial contexts, Black pain and Black joy exist in a dialectic where Black joy is resistance, resilience and illumination in the darkness of the violence and pain. The lived experiences of Black people, including in learning contexts, like schooling, exist in what in what Sadiya Hartman calls the "afterlife of slavery," which entails "skewed life chances, limited access to health and education, premature death, incarceration, and impoverishment" (Hartman, 2008). It is within these circumstances that Blackness is constructed which is the "cultural material, and political signifiers associated with the lived conditions of African and African-descended communities; [it is] a series of strategic and spiritual identifications that subsume directed, desired, and ascribed connections between endarkended bodies in the afterlife of slavery" (Morton, Gee and Woodson, 2020).

Articulating Black Joy

This theoretical paper presentation will articulate BlackJoy as a framework for designing research-to-practice spaces that centre Black liberation and flourishing for authentically equitable learning engagements. Authentically equitable means a science education that does not simply remove conceptual statues that are

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symbols of the embedded coloniality, antiblackness and oppression, but rather a science education that disrupts and transforms the very foundation on which these oppressive ideals are based (Author, 2020). In authentically equitable contexts, teachers and learners become critically cognizant of the power structures that organize their learning and lived experiences and they work collectively to dismantle while co-creating new structures that afford the agency of all learners. These spaces are centered around cultivating Black joy, and allows all stakeholders to liberate the mind, various senses and emotions in order to move outside of a given reality (Davies, 2013).

BlackJoy, as a framework, could be first thought of as freedom space of imagining alternatives to given realities, "More than a method to endure, however, black joy allows us the space to stretch our imaginations beyond what we previously thought possible and allows us to theorize a world in which white supremacy does not dictate our everyday lives" (Johnson 2015, p. 180); envisaging life outside of the specter of the white gaze. BlackJoy as being able to use the radical tool of Black imagination and the centering of community and love (Cruz, 2017); freedom, imagination, community and love are central constructs of BlackJoy. It is a counternarrative to the poverty, crime, and overall despair as often depicted in media and an assertion of humanity through the experience of a range of emotions—joy, laughter, happiness and imagination—that were denied to Black people during enslavement through present times; it is resistance in a society shaped by oppression, racism, and violence" (Lu and Steele 2019).

Thus, in places that were not designed to support Black existence, Black people have used innovation, creativity and love for each other to generate joy. Language is used to create and shape learning spaces, therefore this framework explores ways to extend BlackJoy into research to practice spaces. The framework of BlackJoy emerges from the authors' various research projects were Black learners and those who teach them were central stakeholders as well as Black identity and learner focused research and theoretical works some of which are cited in this proposal.

Black Identity and Black Joy

Several Black researchers have put forward identity strategies, the moves that Black students do in order to ensure their success in STEM spaces that dominated by white, neoliberal culture and are hostile to Black students. These STEM spaces reflect larger society and are therefore also hostile to Black bodies. Black students who aim to succeed are compelled to find and cultivate Black joy. For example, Terrell Morton, Destiny Gee and Ashely Woodson (2020) named Black X Consciousness as a strategy that Black students use to understand and reconcile their identities in relation to STEM. It is an active, metacognitive process students used to navigate structures that were often unwelcoming. They noted that Black X Consciousness is not emancipatory, but rather it is an adaptive strategy that is "influenced but not organized by inequity and marginality"; Black students made sense of their Blackness in STEM spaces through the performance of signifiers of Blackness that included collectivism, language and love. Sharing spaces with other Black students contributed to their "comfort, connection and even salvation" even in the midst of hostile environments.

Similarly, in a different study Terrell Morton and Eileen Parsons (2018) found that Black women navigated STEM spaces through authoring their own identities while affirming their diverse and intersectional Blackness, , "Being a Black woman in STEM both equates to and transcends the oppression and struggle they endure as a result of social constraints on their identity; their identity as Black women being socially regulated yet self-determined to mean power, strength, and success that manifest through their positive and negative encounters (p. 1383)." In both examples, identity/Blackness is a strategy, a process that Black people use to sustain themselves and each other in challenging and unfriendly spaces.

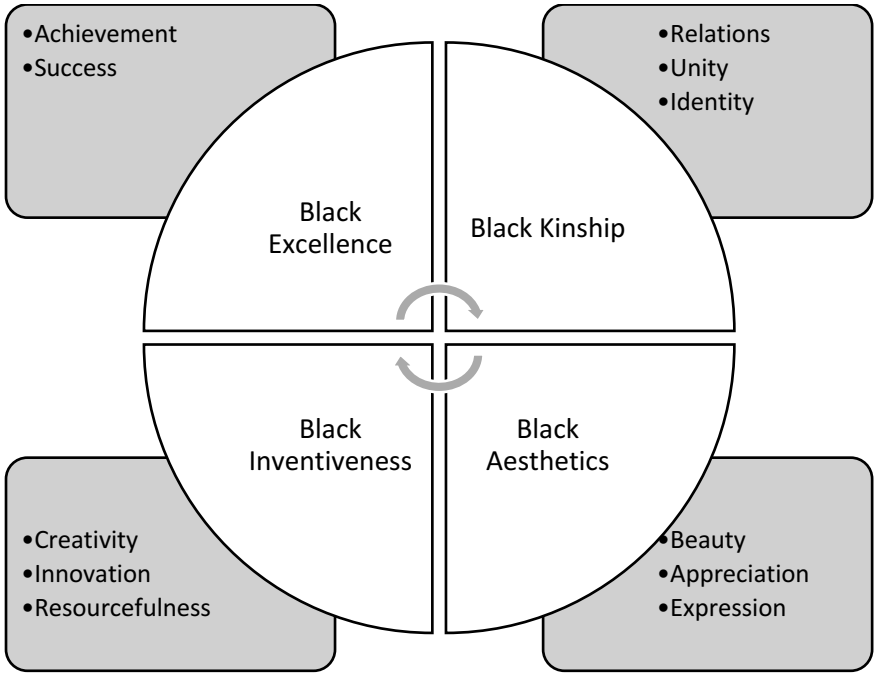
Cultivating Black Joy in Science Education

Miles and Roby (2022) advanced a Black liberatory science education that centres joy and liberation for Black learners, with practices of exploration, questioning, speaking and reminiscing in ways that allow for racial freedom. Building on Ridgeway and Roby, this presentation describes a heuristic for the design of learning environments that afford these and other liberatory and transformative practices for Black learners. Figure 1 shows the key emergent tents of the BlackJoy heuristic. This presentation will elaborate on these tenets with vignettes and interpretations from previous research projects with Black learners and educators and use these as a point of departure for a discussion about creating research-to-practice spaces that foster all four tenets as once and exploring other facets of BlackJoy that could be centred in teaching, learning and learning research.

The BlackJoy Heuristic

The BlackJoy Heuristic is meant to frame the design of research to practice and learning environments that afford liberation and transformative opportunities for Black learners. It includes four tenets that are highlighted in Figure 1 and briefly outlined below.

Figure 1



Black Excellence-this tenet emphasizes positive associations with race and learning. This entails celebrating the achievement and success of Black learners and creating learning environments and activities that allow them to build positive identities and associations with learning.

Black Inventiveness-focuses on leveraging the innate creativity, curiosity, resourcefulness, and innovation of Black learners. This means fostering open-ended explorations of phenomena and allowing Black students to guide the direction of observations and inquiry.

Black Kinship-centers collectivism, values kinships and integrates Black linguistic practices as central to relationships, learning and Black identity. This tenet emphasizes the interconnectedness of language and culture and fostering the role that these play in building trust, solidarity, safety and risk-taking in learning environments.

Black Aesthetics—recognizes things that Black learners find beautiful and pleasing and the ways that Black lived experiences intersect with artistic and creative practices. For example, music for focus, specially fabrics and hairstyles for significant events (i.e. graduations) and dance as a way of expressing community.

Black Excellence, Black Inventiveness, Black Kinship and Black Aesthetics allow us to assert a Black liberatory education and research paradigm that centers Black learning, Black humanity and BlackJoy. This is central to building race affirming frameworks that work towards elevating Black learners. All students come to learning contexts with values, orientations, and practices that are reflective of their culture and when these are supported, students engage more holistically and successfully in learning (Medin and Bang, 2014).

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Decomposing Practice: Developing Reliable Analyses of Complex Classroom Discussion

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Abstract: There is relatively scant conversation about the details of processes through which research teams arrive at desirable thresholds of statistical measures for inter-rater reliability (IRR) in qualitative research. This paper used autoethnography to describe how a team of five researchers achieved a Cohen's Kappa of .7 between each pair of researchers over a period of two years while iteratively developing a codebook to be applied to science classroom discussion transcripts. Detailed meeting notes kept by the researchers were used as data. The findings describe factors that contributed to the complexity of the transcripts, strategies that worked for the team, and the role of the purpose of the analysis in shaping the process of the analysis. Some implications for the field of teacher learning are discussed based on these findings.

Introduction

Establishing rigor and reliability in the analyses is an important aspect of doing credible qualitative research. However, the process of establishing inter-rater reliability (IRR) could be a fraught one given the tension between the superimposition of an objectivity-oriented desired statistical value of consistency between raters (e.g. Cohen's Kappa) over a constructivist orientation of qualitative research. In addition, consistency is further perplexed when the analysis in question seeks to describe, through codification, features of data that require high inferences. Thus a methodological question is, what conventions can be used to achieve very good agreement between raters, and yet still preserve some of the rich description of data that qualitative analysis lends itself to. The field is guided by conventions such as good thresholds for agreement (e.g., O'Connor & Joffe, 2020; Banerjee, et al 1999), but less is reported about the social processes and methodologies used to develop shared ways of seeing data are captured in measures of interrater consistency. Few studies report on how to achieve interrater agreement in the context of dialogic and dialectical processes of team-based research, where *shared ways of seeing* are informed and enriched by histories, cultures, experiences, and expertise (Hennessey et al, 2016). We see these often underreported processes as critical for theory and methodology building. This paper focuses on the process of iterative development of a codebook which a team of five researchers utilized and achieved a .7 Cohen's Kappa. The primary challenge of the process was harmonizing the researchers' individual lenses toward the data developed through their unique professional and personal histories into a collective lens that retained the richness afforded by the individual lenses while also yielding a desirable statistical agreement. Through autoethnography, we seek to surface tensions in this process of codifying a large corpus of rich and complex discourse data within the context of a longitudinal team-based research project and illuminate decision points that led to new ways of structuring the coding process, i.e., iterating on a codebook and developing shared ways of seeing the data and categories to achieve very good IRR.

ClassInSight is a study of teacher professional learning around classroom dialogue. It is a 5-year research-practice partnership with two school districts in north and south county San Diego, which serve a diverse (ethnic and linguistic) population of students. Science classroom discussions of study participants were audio-recorded, transcribed, and verified. These lesson transcripts were then used for analyses to create visual representations in a web-based app to facilitate teacher reflection and learning. An important dimension of this work was to develop a Natural Language Processing (NLP) model to automate the process of coding the transcripts and creating the said visual representations.

The specific analysis task for us (the research team) was to decompose the transcript into codes that captured the dialogic function of the utterances in the transcript. For example, if an utterance was an invitation to elaborate on an idea then it would be coded as (I). The purpose of this analysis in part was to generate data to be used by a collaborating team to develop natural language processing models for automating the analysis and second, to represent codes in the form of analytics (visualizations) for teachers. The first iteration of the codebook started in Fall 2019. As we worked through the challenges of achieving IRR the codebook went through two more iterations and the desired Cohen's Kappa on the third iteration of the codebook was achieved in Spring 2021. This

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paper describes the iterative process and characteristics of refinements as a collaborative team developed a codebook and training of multiple raters on complex conversational data.

The question we intend to answer is *how do we develop reliable shared ways of applying a set of codes to complex classroom discussion data?*

Methods

We used autoethnography to reflect on and distill findings to be reported here from the two-year process of achieving IRR in the context of a longitudinal team-based research project. Our primary data sources for this autoethnography are detailed meeting notes recorded during our IRR-oriented meetings between Fall 2019 and Spring 2021. Two researchers conducted open coding of the meeting notes and identified preliminary codes related to excerpts that would provide insights into the 'how' of our RQ. These thematic codes were discussed and validated by the entire team of researchers that worked on the analyses. An autoethnographic codebook was developed based on the agreements reached during the coding process. For example, "decision point" or "corrective measures/strategies" are examples of thematic codes that were included in the codebook that sought to identify and characterize critical moments, roadblocks, and decisions in our process. The same two researchers then coded the remaining 106 pages of meeting notes using a qualitative data analysis software. A subsequent cross-code analysis of the excerpts resulted in the themes that are reported below.

Findings

Complexity of the classroom discussion data

Our data (meeting notes) is rife with explicit and implicit acknowledgments of the complexity of the classroom discussion data. While various factors contributed to this complexity, we describe below two major contributors to this complexity - context and transcript.

An enduring question in decomposing classroom discussion data for us was to define the limits of context we may use while applying the codebook to a transcript. For instance, it mattered if a researcher was or was not present in the classroom to conduct the observation which resulted in the transcript at hand. If the researcher was present then they had more context to the data than a researcher who was not present. If the researchers were to learn to code reliably, then accessing such information during the coding process, while valuable to the analysis, was not desirable. Similarly, information about the context of the school/teacher/student demographics, type of school - MAGNET, etc., and consequent linguistic practices often had a bearing on how we approached the data. This issue of context made it challenging to arrive at precise definitions of codes whose application relied on a multitude of factors. We resolved this in part through the strategies described in the next section, but this is a work in progress.

Secondly, there were limitations to the recording and transcribing of classroom discussions. In that, we had to wrestle with the question of whether we were coding the *discussion* or the *discussion transcript*. The latter eliminated several features of the actual discussion - modulations, pauses, crosstalk, unrecorded utterances, etc. If the teacher posed a question and the next utterance in the transcript was the teacher responding to the question themselves, then did it mean that there was no response from the students or that there was a response and the teacher then elaborated on that response? In the light of the considerations described in the previous paragraph (and some about machine learning to automate the coding process that will be described later), it was decided to code the *transcript* and not the *discussion*.

Strategies that helped in achieving greater inter-rater reliability

Segmentation

The work of Wells and Arauz (2006) and Hennesey et al. (2015) provided a solid foundation for the third and successful iteration of our codebook. These codebooks provided us with a framework for the mechanics of classroom dialogue in terms of episodes, sequences, and exchanges before trying to classify individual utterances, which focused on cognitive implicature of teacher elicitation and student responses. It was immensely helpful to break down the entire transcript into smaller chunks which helped us understand the relationship between each utterance (part) and the classroom discussion (whole). Then, Hennesey et al. (2015) provided us with a list of predetermined codes which we could then adapt to the requirements of our data. The codes made for rich deliberation about how they may apply to our data which allowed for a far deeper and more meaningful engagement with the complexity of our data than would have been possible if we were not rooted in these prior works.

Historicity as Part of the Coding Process

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Each researcher came to this work with their peculiar history with the processes of teaching and learning which shaped their approach to the classroom discussion data for this project. This afforded several possibilities for the analysis in that the definitions of the codes were made richer through diverse contributions. However, this also made 'sticking to the codebook' a challenging endeavor. The team referred to this as the peril and the possibility of coding in a diverse team. After the first few failed attempts of independently and reliably applying the self-developed first iteration of the codebook to the data, we decided that we needed to undergo additional shared experiences, beyond initial codebook training, that would offer us some common ground to work with while applying the codes.

Three things were done by the team to achieve this common ground. First, the team engaged in several rounds of collective coding where we individually coded 5-10 lines at a time and then immediately shared the codes we had applied with our reasoning for applying those codes. This allowed us to gain a better understanding of each others' heuristics in the coding process and, therefore, make changes to ours if necessary. Second, whenever it was difficult to reach an understanding over which code would be applicable in a particular instance or how a particular code would be applied, there was an emphasis on collective decision-making. The meeting notes repeatedly mentioned the verb 'discuss' at the close of meetings for disagreements that were left unresolved. Lastly, this approach of developing reliable analyses while also valuing the diversity of thought resulted in the codebook being a dynamic document that reflected the evolution of our thinking around the application of each of our codes through the course of gaining these shared experiences. While three researchers achieved a Cohen's Kappa of 0.7 in the current iteration of the codebook, there are several proposals for adding new codes or changing existing ones that are in deliberations for its next iteration.

Reflecting on the Process of Coding

The shared experiences were significant in moving us toward a better reliability statistic. However, they were not enough. At one meeting, as we uncovered the steps that each of us followed to code a particular lesson transcript, we found important differences in our approaches. Some read and coded the transcript simultaneously while others skimmed through the whole lesson to get an overview and then coded in the second, deeper reading of the transcript. Subsequently, all of us decided to follow the two-step coding process.

Systematic differences were also observed in the application of certain codes among researchers. When a question was repeated by the teacher, some researchers coded both utterances of the question as a question while others coded only one. Developing rules for such recurring but systematic differences was helpful. However, on some occasions, it was difficult to decide on the application of a code to a particular utterance. For instance, the distinction between E and I was often difficult to make. E refers to the invitation for a 'new' idea and I refers to the invitation to say more about an idea that is already on the table. Sometimes it was challenging to precisely determine whether a new idea was being invited or a previous idea was built upon. On such occasions, it helped to take a step back from our pursuit of a combination of individual and collective lenses and focus only on the collective (e.g., how can we all learn to think similarly while making decisions like these? What series of questions must we answer to make such a decision?).

Initially, we formatted the transcripts for coding such that each sentence was assigned a code. We realized that multiple sentences together formed meaningful utterances and as such should be coded as a group and not individually. However, these observations about what constituted a meaningful cluster of utterances were made only during the deep reading stage of the coding process. This led to the question of whether one member of the coding team would cluster utterances to be coded and share the segmented transcript with others, thus excluding the clustering aspect from the reliability calculations, or whether this process would be conducted by each rater themselves and clustering included in the reliability calculations? In the light of further challenges with the latter approach, it was decided to code at the turn level. In that, all the utterances in one turn of the speaker were assigned with a code. In instances where there were multiple applicable codes in a turn, the one that was taken up by the following turn was applied. For example, if one turn had both, a reasoning (R) and an invitation for elaboration (I) move, but the next turn responded to the (I) move then the turn was coded as (I). This was a significant step in moving us along in the inter-rater reliability process.

The Impact of the Purpose of Analysis on the Process of Analysis

The project's purpose was to generate representations of classroom discussion data that teachers would use as tools to reflect on their practice. These reflections and consequent inquiry or modifications in practice would constitute a form of ongoing learning for them. Additionally, one important aim of the project was to use machine learning techniques to automate this process of analyzing classroom data and generate representations of it. This would greatly reduce the turnaround time between a classroom observation and the generation of the representations based on it.

Concerning the purpose of facilitating teacher learning, the question of "what is meaningful for the teachers?" came up repeatedly in the meeting notes. This was an important consideration of the analysis process with which the team had been tacitly working with. To illustrate, Hennesey et al.'s (2015) coding scheme included a broad set of codes called cluster codes and a set of detailed sub-codes within each cluster. For example, invite elaboration or reasoning (I) was a cluster code within which there were sub-codes like invite possibility thinking or prediction (I5) and ask for elaboration or clarification (I6) (Hennesey et al., 2015). Early on while adapting the coding scheme to our purposes, we decided to stick to only cluster level codes because the sub-categorization of cluster codes did not appear to add significant value to the affordance of the representations in facilitating teacher reflection.

Another issue concerning the purpose of facilitating teacher learning was that codes like reasoning (R) or building on ideas (B) were not yet frequently occurring in the data. So the challenge was how to use *what is* in the practice of the teachers to help them reflect on what *could be*. Since this is an ongoing project, it is a question we continue to grapple with. A strong contender for a solution is to modify the code definitions such that they may apply to utterances that are proximal to a code but not quite satisfy the current definitions such that the teachers may start to see the beginnings of it in their data. As discussed in the next paragraph, the implications of such a move for machine learning have been a primary hindrance in realizing this possibility.

While we developed shared heuristics for making decisions about codebook applications to data we were also constantly mindful of their complexity vis-a-vis the possibilities of machine learning at a given time while acknowledging the quick strides being made in the field. This meant that we could not, for instance, use information from several hundred turns prior as context to code a particular turn in a transcript. Beyond constraints, machine learning also brought several affordances in our thinking about the analyses. When necessary, we were able to set aside our subjective individual orientations and focus on building a relatively objective collective one because that is what the machine needed to learn. We were also able to plan for the possibility of the machine applying some low-inference and already reliable codes before the researchers even looked at the transcript for the first time allowing them to focus on the more complex codes.

Discussion

Shared experiences, maintaining a dynamic codebook, repeatedly rooting ourselves in literature, and wrestling with the balance between mechanics and content were only some of the things that went into the team achieving IRR. The researchers' deep care for each other and the work were also important ingredients of the *success*. While we have a Kappa value of .7 between each pair of researchers, we acknowledge that there is a lot more work to do and we don't yet have *our* final iteration of the codebook or the final Kappa. These details are entirely masked by the reliance on a single statistic as a bar for rigor. An important question is how do we go beyond the Kappa in our sensemaking around objectivity and rigor in the IRR process? This experience has made us somewhat wary of very high Kappa values, especially in the context of complex data and coding categories. As a field, it may be worthwhile to adopt a healthy skepticism of only statistical values and to seek and provide descriptions of the processes that lead to very high IRR values whenever they are reported.

Lastly, the processes of these analyses described here were deeply intertwined with the purposes of the analyses, which were to facilitate teacher learning and to help develop machine learning models of the analyses. If the purpose were to solely theorize on the nature of dialogue in science classrooms, then many more nuanced codes would have been available for us to use, possibly making it relatively easier to deal with the complexity of the data. While we tacitly acknowledged these purposes throughout the process, becoming conscious of them has given us a new frame with which to approach decisions in the next iteration of our codebook. As such, it may be worthwhile for others engaged in similar work to be explicit about the purpose of their analyses and allow it to conspicuously shape the process.

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How reward- and error-based feedback systems create micro-failures to support learning strategies

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Abstract: Feedback in educational technologies can teach and engage students in math, but questions remain on how to present failure feedback that supports positive learning behaviors. We explore how error- and reward-based feedback influenced students' choices to replay completed problems in *From Here to There!*, a math game-based educational technology. We conducted a multilevel logistic regression in 1,031 seventh-grade students predicting whether a problem was replayed, using whether an error was made during the first problem attempt and how many clovers were earned after solving the problem (with more clovers earned for more efficient solutions). Preliminary results show that making an error or earning two clovers increased the likelihood of replays, whereas earning one or three clovers decreased the likelihood. Our findings suggest that clovers and errors may be "micro-failures" that encourage replays by supporting feelings of competency and/or autonomy, which has implications for game design elements for learning and engagement.

Introduction

Educational technologies are becoming increasingly popular as an engaging medium for teaching math. One major benefit of educational technologies is their ability to provide immediate feedback on students' performance (Moyer-Packenham et al., 2019), but developers must consider how to show students where they can improve without causing them to disengage entirely from learning. It is important to understand how different types of feedback systems motivate students to adopt effective learning behaviors in response to failure. Here, we explore whether two feedback systems—errors made and rewards earned—influence the likelihood that a student will replay completed problems within *From Here to There!* (FH2T), a game-based educational technology that teaches algebra.

Feedback systems and failure in game-based educational technologies

Feedback is often conceptualized in terms of Self-Determination Theory (Ryan & Deci, 2000), which defines three types of motivation: intrinsic (pursuing activities because they are inherently enjoyable), extrinsic (pursuing activities because of some external outcome), and amotivation (lacking any intention to pursue an activity). Supporting learners' innate needs of autonomy, competence, and relatedness can maintain intrinsic motivation or self-determined forms of extrinsic motivation, which have been linked to greater persistence, positive self-perceptions, and engagement (Ryan & Deci, 2000). Thus, feedback may promote these forms of motivation if the feedback makes learners feel competent and in control over the feedback they receive.

Game-based educational technologies overlap with both educational and gaming spaces, each of which brings their own expectations; as such, these tools must grapple with the challenge of evoking "game-like" failure, which can lead to greater engagement and persistence akin to non-educational games, as opposed to "classroom" failure, which can cause students to question their abilities and feel demotivated akin to failing in a school context (Williams-Pierce, 2019). An open learning design question is how to implement feedback systems that increase feelings of game-like failure instead of classroom failure. One answer may be to implement feedback systems that feel low-stakes by using "micro-failures," defined as quiet and gentle failures that encourage the player to seek feedback (Williams-Pierce, 2019). Using feedback to draw students' attention to micro-failures may encourage optional but positive learning behaviors, supporting autonomy and competence. The question then is what types of feedback systems students will perceive as micro-failures.

The current study: Feedback and replays in *From Here to There*

The current study explores error- and reward-based feedback as potential micro-failures, both of which are commonly implemented in game-based educational technologies. We use FH2T as our game context (https://graspablemath.com/projects/fh2t). Students are given a starting algebraic expression (Figure 1a) and must use learned gesture-actions (e.g., in 9·12+9·23, dragging the 9s together to factor them out; Figure 1b-1d) to

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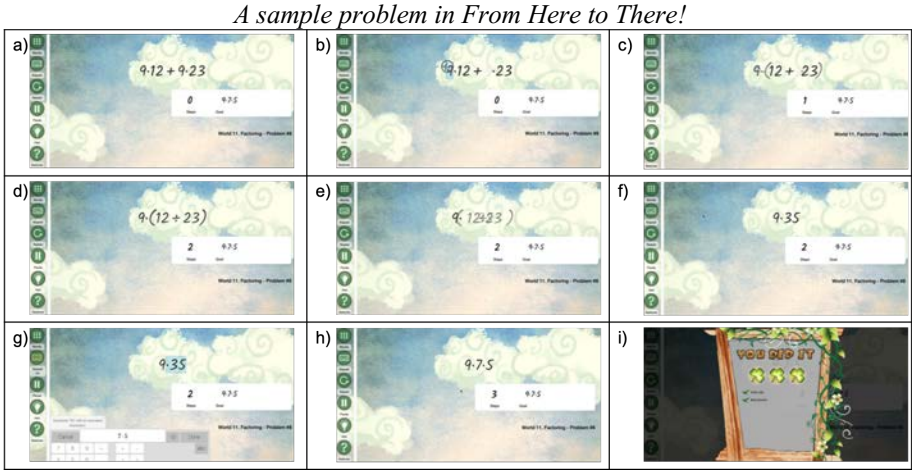
transform the expression into a goal state (Figure 1h). After completing each problem, students can choose to replay the problem or move on. FH2T has been effective for improving elementary and middle school students' mathematical understanding (Chan et al., 2021; Hulse et al., 2019). A cluster analysis found that a sub-sample of FH2T users repeatedly replay completed problems, and these users show among the largest learning gains after using FH2T (Lee et al., under review). We investigate whether FH2T's error- and reward-based feedback systems incentivize replay strategies in students.

Figure 1
A sample problem in From Here to There!



In FH2T's error feedback system, if students make a mathematical error (e.g., attempting to add 12+9 in 9·12+9·23), then the expression shakes and does not change, providing implicit visual feedback that an error has been made. This feedback may help students to understand where they can correct their behaviors and motivate students to replay and fix these errors. On the other hand, students may feel that they have less control over error feedback (as they must fix the error to progress) or perceive errors as indicators of their lack of competence, reminiscent of classroom failure; such feelings may be less motivating to go back after completing problems. In FH2T's reward system, students earn one to three clovers after each problem based on the number of steps taken to solve the problem, with more clovers earned for fewer steps (see Figure 1i). Clovers are one of the primary ways students have to understand how well they are performing, though the rules that determine the number of clovers are never explicitly explained. These performance-contingent rewards could be seen as a gentle micro-failure because earning one or two clovers suggests that improvements can be made, but students are not penalized in any way. Because fewer clovers do not prevent progression, this optional aspect may feel game-like and promote feelings of autonomy, motivating students to replay problems to gain a higher number of clovers. However, failing to achieve three clovers may still be perceived as a form of "classroom" failure since clovers are tied to students' in-game performance, which may lead them to avoid replays. To begin exploring how these two types of feedback systems influence replay behaviors, we investigate:

RQ1: a) Does the number of clovers earned after the first problem attempt predict whether students replay problems? b) Does receiving one to two clovers encourage students to replay problems more than receiving the maximum three clovers?

RQ2: Do errors during the first problem attempt separately predict whether students replay problems?

Method

As part of a larger study comparing the impacts of three technology interventions, 4,092 seventh-grade students were recruited from 10 middle schools within a large suburban district in the Southeastern United States. The current study focuses only on students randomly assigned to use FH2T (N = 1,031). First, students completed a 40-45 minute pre-test of their algebraic knowledge (Star et al., 2015; α = .89) and math anxiety (Ganley & McGraw, 2016; α = .87). Next, students participated in nine 30-minute FH2T sessions across the school year. Because the study occurred between September 2020 and April 2021 during the COVID-19 pandemic, students chose their instructional modality (100% in-person or virtual) prior to the fall semester. Regardless of modality, all study assignments were administered online, and students worked individually at their own pace using individual devices. Students saw up to 252 unique problems; for each problem, FH2T recorded: 1) whether students made an error during their first problem attempt (error vs. no error); 2) the number of clovers earned after

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the first problem completion (three clovers for solving the problem in the optimal number of steps, two clovers for solving within two of the optimal number of steps, and one clover for all other solutions); and 3) whether students replayed the problem after completion (replayed vs. not replayed). Errors were not counted as solution steps and therefore did not influence the number of clovers earned.

Results

To investigate whether clovers and errors influenced the likelihood of replaying a problem, we estimated a multi-level logistic regression predicting whether a problem was replayed or not. The model was estimated using 74,359 problems in which students completed at least one attempt. The model contained two cross-classified levels—problem and student levels—because students attempted multiple problem sets and problems were attempted by multiple sets of students. Random intercepts were entered for both students and problems. Problem-level predictors were the number of clovers earned and whether the student made at least one error on the first problem attempt. Pre-test algebraic understanding and math anxiety scores were included as student-level predictors. The number of clovers earned on first attempt was dummy coded, such that two clovers and three clovers were both compared with a referent group of one clover; this split allowed us to compare whether receiving a specific number of clovers differentially influenced the likelihood of replaying a problem.

For **RQ1,** the number of clovers earned on the first problem attempt significantly predicted the likelihood of replay (Table 1). Additionally, there were differential associations between the likelihoods based on the number of clovers earned: students who earned two clovers were 1.45 times as likely to replay a problem compared to students who compared to students who earned one clover ($\beta_1 = 0.42$, $SE = 0.07$, $p < 0.001$), based on relative risk calculation of students with average pretest scores who did not make an error (Table 2). Those who earned one clover on their first attempt were less likely than chance to replay the problem ($\beta_0 = -2.38$, $SE = 0.11$, $p < 0.001$). As expected, students who earned three clovers had the lowest likelihood of replaying a problem compared to those who earned one or two clovers ($\beta_2 = -2.37$, $SE = 0.07$, $p < 0.001$).

Table 1

Logistic Regression Output for Model Predicting Replay

	β	SE	p
Intercept	-2.38	0.11	< 0.001
Two Clovers	0.42	0.07	< 0.001
Three Clovers	-2.37	0.07	< 0.001
Error Made	0.91	0.03	< 0.001
Pre-test Algebra	0.35	0.07	< 0.001
Pre-test Math Anxiety	0.05	0.06	0.46
Random Effects			
σ_2	3.29		
$\tau_{00\ \text{Student}}$	2.58		
$\tau_{00\ \text{Problem}}$	0.59		

$N_{\text{observations}} = 74{,}359$; $N_{\text{student}} = 1{,}031$; $N_{\text{problem}} = 252$

Table 2

Probability and Relative Risk of Problem Replay by Number of Clovers and Whether an Error Was Made in the Problem.

	Errors		
Clovers Earned	N	Y	Relative Risk
One Clover	.08	.19	2.38
Two Clovers	.12	.26	2.17
Three Clovers	.01	.02	2.00

Note: Probabilities were computed for students with average pre-test math and anxiety scores.

For **RQ2**, making at least one error on the first problem attempt significantly increased the likelihood of replay ($\beta_3 = 0.91$, $SE = 0.03$, $p < 0.001$). Table 2 presents the probability of replay based on number of clovers earned and whether they made errors, as well as relative risks calculations, which show how many more times students are likely to replay when they make at least one error compared to when they do not make an error. Students who made at least one error were at least two times as likely to replay compared with students who did

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not make an error regardless of the number of clovers earned (range: 2.00-2.38), with relative risk being highest for students who earned one clover and lowest for students who earned three clovers.

Discussion

In summary, both errors and clovers appear to incentivize students to replay problems. Earning two clovers on the first problem attempt may have been perceived as a "micro-failure", encouraging students to replay completed problems to improve their solutions and earn the maximum three clovers. Notably, the magnitude of the "micro-failure" appears to influence students' motivation to replay: earning two clovers was associated with a substantially greater likelihood of replaying than earning one clover. One potential interpretation is that students who feel closer to earning the maximum three clovers are more likely to exhibit internal motivation to replay, incited by their feelings of competence that come from being close to perfect. Alternatively, students who are further away from earning three clovers (i.e., earn only one) are less likely to display the internal motivation required to replay because of feelings of incompetence. Students who made more errors were also more likely to replay even though errors are not implicated in clover allocation. It is possible that students do not realize that clovers and errors are independent from one another and they return to the problem to complete it without making errors in the hopes of earning more clovers. The directness of error feedback may also build feelings of competence by helping students identify misunderstandings, encouraging them to replay.

Based on prior work suggesting that replays may lead to higher learning gains (Lee et al., under review), building on performance-contingent reward systems similar to FH2T's clovers may thus be an effective method for improving engagement and learning. In future work, we plan to delineate whether replays specifically are what lead to better learning in FH2T users, and to explore what mechanisms underlie this relationship. Further, because the percentage of students who choose to consistently replay problems on their own appears to be relatively low (especially being optional for progression), we will also explore methods that encourage more students to choose to replay (without taking away the feeling of autonomy from being untied from progression).

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Designing to Support Teacher Reflection on Science Classroom Discourse: Insights from Implementation

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Abstract: This paper informs designs for teacher learning and reflection that advance equitable discourse practices in secondary science classrooms. We share design insights from the initial iteration of a design-based research project, ClassInSight, that supports teachers' facilitation of dialogic-discourse practices in science classrooms through guided reflection on classroom discourse visualizations. We analyze transcripts of reflection sessions of the participants and ask: *How did teacher-researcher dyads interact with the initial design prototypes of classroom discourse data visualization and reflection practices? How were reflections on data visualizations constrained by design?* We found that teachers and researchers did not share an understanding of classroom discourse moves and that teacher reflections did not connect explicitly to issues of equity in the classroom. The findings show the need to design for shared meaning-making between teachers and researchers on classroom discourse categories and make visible the ways they conceptualize equity in science classroom discourse practices.

Design-Based Research to Improve Science Classroom Discourse Practices

Several studies have highlighted a systematic pattern of classroom dialogue that predominantly serve children from minoritized background, that is, a culture of low expectations, whereby the quality and intellective rigor of classroom talk requires low cognitive demand of engagement from students (McNeill & Pimentell, 2010; Kelly, 2008). Research has shown that when teachers lead students in discussions that externalize their reasoning and thinking, students benefit in terms of steep increases in learning (Resnick et al., 2015; Clarke et al., 2016; Alexander, 2018). Our work takes the view that equity (and inequity) can take shape in micro-level interactions in-classroom dialogue, and teachers play a critical role in constructing an intellective space that provides robust opportunities to learn science.

It is for these reasons that we sought to design teacher professional development to support teachers in reflecting on how opportunities to learn are structured in classroom discussions that teachers facilitate, and planning on how to utilize their pedagogical tools to support students' sense-making in science. We view teacher learning as a key opportunity space to make rich discourse in science classrooms more accessible. We conjecture that well-designed classroom discourse data representations and reflection practices can help teachers critically examine and improve their own classroom discourse practices, and have been designing an online application, ClassInSight, that visualizes science classroom discourse data through multiple representations, (Gomoll et al., 2021), as well as reflection practices for teachers and researchers to engage in shared meaning-making, goal setting, and pedagogical refinement with the discourse data (Schön, 1983).

Two threads of existing research frame our designs. First, we draw from research on dialogic science classroom discourse that has been shown to improve learning (Clarke et al., 2015). These discourse practices promote shared reasoning, and include types of talk, or what we here on call *discourse categories*, by students and teachers that surface rationales for claims, build on existing claims made by others, and questioning that connects content knowledge to prior student knowledge (Michaels et al., 2010). We are designing classroom discourse data visualizations to represent student and teacher speech types that are consequential to science learning and equity. Second, following the literature on teacher reflection and learning (Schön, 1983), we conjecture that teachers improve their pedagogy when they engage in reflection-on-action that question, ruminate on, and reason with their classroom practices (Clarke et al., 2020). We situate such teacher learning in their practice contexts, technological resources, and interactions with others, including the researchers (Korthagen, 2010). Our design embodies these theories on reflection and teacher learning in what we call "reflection dyads" - collaborative reflective sessions between teacher and researcher which closely

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examine and surface dissonances between teachers' stated equity-focused classroom discourse goals, intuitive interpretation of classroom discourse, classroom discourse data visualizations, culminating in the refinement of pedagogical actions. While our larger equity goal is to make discourse-rich science classrooms more accessible to students from minoritized backgrounds, here, we make theoretical contributions to the *processes* and *designs* for teacher learning toward these educational outcomes.

Using a design-based research methodology, we seek to contribute to theories and practices that reflect our core learning goals and conjectures by observing the use of designs that embody these conjectures "in the wild" (Lee et al., 2022). This paper seeks to refine theories and designs that support teacher reflection on classroom discourse data. More specifically, we ask: *How did teacher-researcher dyads interact with the initial design prototypes of classroom discourse data visualization and reflection practices? How were reflections on data visualizations constrained by design?*

Methods

Study Design and Background

The present analysis is situated within a larger design-based research project between three universities and two school districts in southern California which serve linguistically and ethnically diverse student bodies. ClassInSight shows visualizations constructed from discourse categories informed by the literature, such as *Teacher and Student Close Ended Statements and Questions*, *Teacher and Student Open Ended Statements and Questions*, *Teacher Lecture, Turn Taking Facilitation*, *Metacognitive Modelling Questions,* and *Student Explanation*. Science lessons are recorded on a monthly basis, transcribed, with talk turns by teachers and students coded as one of the discourse categories. Researchers then shared visualizations of this data with the teachers, before entering into a one hour reflection session with them.

Participants and Data Sources

The participants of this study were 12 middle and high school science teachers. For this analysis, we analyzed data from 12 reflection sessions conducted on video conferencing software (audio recording transcripts and screencasts) from the first round of reflection sessions that immediately followed the research team sharing the first prototype of the classroom data visualizations.

Analysis

In order to understand how teacher-researcher dyads were interacting with the designs for teacher learning and related constraints, we analyzed the interaction between teachers and researchers with the initial data visualization and reflection protocol. Transcripts and videos from initial reflection sessions were analyzed to examine how teachers and researchers sensemaking of the data and articulate pedagogical actions. Using the constant comparative method (Glaser and Strauss, 2017), we surfaced descriptive themes that paid attention to the constraints the teacher-researcher dyads experienced in accomplishing these steps to inform improvements in our designs and theoretical conjectures.

Findings

Developing Shared Understandings of Talk Category Definitions

In many reflection sessions, teacher-researcher dyads undertook a process of developing shared understandings of the discourse categories that were core to the data visualizations. Initially, the teachers' interpretations of the discourse categories often did not align with the theoretical definitions, which the researchers based their own design and analyses on. Two processes emerged in the way that teachers worked with the researchers to construct meaning for the different talk categories: developing a conceptual understanding of the talk categories, and connecting them to prior experiences.

First, teachers sought to develop conceptual understandings of the different discourse categories that were represented in the data visualizations. As a consequence, teachers reported challenges in determining what kind of talk would fall into what particular talk type. In such instances, they turned to the researchers to explain the researcher's conceptualization of these discourse categories. In the following excerpt from a reflection session, Evan, a middle school Science teacher, shared his struggle identifying the difference between two discourse categories :

> I guess if there was clarification on how each of the statements, or how the break down kind of works...I don't know what's the difference between assorted teacher talk and a teacher lecture... (Excerpt 1, [Evan])

Here, Evan asks for a clarification of not only the definition of the discourse categories. They additionally convey a lack of shared understanding about the differences between two of the discourse categories in the visualization.

Second, in making sense of the discourse categories, teachers related the different categories to their own practices. We saw participants connect discourse categories like "open ended questions" to terminology that their schools used, in this case, Inquiry-Based questions. Tom, a high school teacher, shares how some discourse categories are similar to the ones he uses in school

> Instead of *open ended questions*…[we use] *inquiry based questions* or *inquiry modeling*... So we use terms like that and we get instructions. So in that sense it could be helpful in terms of helping a teacher move towards a, a, the definition that the school uses. (Excerpt 2. [Tom])

Here, a teacher translated the discourse category of "open ended question" to language practiced in their own practice context (e.g.inquiry modeling"). Beyond developing an understanding of discourse categories by identifying instances in which they embody these talk moves, the teacher suggested that using categories like "inquiry-based or inquiry modeling" might be helpful in scaffolding teacher understanding as it relates to the definition that schools generally use. We see the distance between the teachers' meaning of the discourse category and the researchers' meaning as a constraint of the design for teacher sense-making.

Tethering Discussion Goals to Science Learning Outcomes and Equity

The initial reflection sessions typically led to teacher goal setting on classroom discourse that was unconnected to concerns of equity in science learning. Teachers set goals that were specifically related to characteristics of classroom discourse. However, these goals were not explicitly tied to broader visions for equity in science learning. When prompted to set goals for upcoming classes, the most common response by teachers was to state that they would like to increase student talk and reduce how much they talk. Even when teachers used specific discourse categories like "open ended" or "meta-cognitive modeling" to formulate their goals, it was challenging for the researcher to support teachers in tethering their goals to equity or specific student learning outcomes or equity. The following interaction between a researcher and Tom, a high school chemistry teacher, shows how a broad prompt by the researcher asking them to articulate a goal moving forward led to a response by Tom that included a specific goal for classroom discourse but was not tethered to particular science learning outcomes, or equity goals:

> Researcher: goals you might set or other things that you might want to keep in mind as we're continuing to refine the design?
> Tom: Well, the same thing I said last time[earlier in the session]. I mean… having students participate in the discussion is a goal. So having more student participation… I tend to think that if the number [of students talk] goes up, that's awesome. (Excerpt 3 [Tom])

In Excerpt 3, we see a teacher respond to the researcher's questions about goal setting. Along with the researcher, they formulate a goal to have more students participate in discussion. Then they provide the rationale for why they think that having more participation should be the goal by tapping into their belief of why it was good. The consequent designed interactions between the researcher and the teacher failed to create space to build on and connect the mentioned goals to student science learning outcomes and equity.

Discussion and Implications

Shared Meaning Making of Talk Categories

During reflection sessions, reflection dyads sought to build a shared understanding of the discourse categories. There was a dissonance between the discourse category codes as the research team understood them primarily through the literature (Clarke et al., 2015) and the ways teachers understood the language of the discourse categories, which were primarily informed by their practice. This constraint speaks to the challenge of leveraging theory and practice in a collaborative Design-Based Research where researchers work with practitioners in the field.

In designing for representations of classroom data and reflection practices, we suggest that there is a need to pay further attention to teacher voices and build on their experiential knowledge while planning the processes of creating and naming these categories. This would allow teachers to play a more active role in the collaborative process of design-based research by bringing in their rich experiences; additionally, it might also allow teachers to leverage their knowledge better to conceptualize their practices to address the project's goals. For the field, it reaffirms the need to be intentional and attentive to create space for dialogue between the theoretical knowledge of researchers and the practical and experiential knowledge of participants. As a research team, we revised the constructions of the codes to build upon the teachers' experiential knowledge in future iterations.

Scaffolding Thinking about Equity and Learning Outcomes

ClassInSight aims to work with teachers to reflect, identify, plan, and implement equitable discourse practices for their science classrooms. Hence, it is important that teachers make explicit connections between their classroom discourse and students' science learning outcomes for all their students in order to work towards equity. We see through the findings that teachers are making goals based on increasing participation in their classrooms. However, the researcher-teacher dyads are unable to extend teacher goals to explicitly connect to student science learning outcomes and equity**.** This is especially important as, as a research team, we are ultimately engaging teachers in a process of developing practice-based theory about equitable discussion in their science classrooms. In response, as a design team, we included further systematic probes into our reflection protocol to work with teachers to explicitly connect their discussion goals with student learning outcomes in science classrooms. Additionally, scaffolding teachers' reflection and goal setting with a mind towards equity must ensure that teachers have the opportunities to make sense of how their actions and decisions for talk in classrooms are linked to creating equitable spaces for *all* students to learn.

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Supporting Empathy in Design Thinking - A Learning Community Approach

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Abstract: Empathy plays an imperative role in human-centered design thinking processes. Our research explores how a learning community approach can help students become empathetic designers. By situating the design experience within a community of peers, there are increased opportunities for norming and exchange, shared strategies and resources, and a sense of collective progress. Such design activities allow students to bring in their voices and identities by offering empathetic feedback into the classroom discourse. Using the Knowledge Community and Inquiry (KCI) model, we explore how the diversity in the dispositions and experiences of students plays a unique and major role in framing and shaping design problems through peer feedback and perspective-taking. This paper reports the findings from six graduate-level courses that offered a design assignment in an education faculty taught over two years.

Introduction and Significance of Study

Within education, design thinking has been recognized as a critical 21st-century competency (Van Gompel, 2019), included widely in the curriculum standards (e.g., NGSS, 2010), and targeted within many reform efforts. Our research explores how a learning community approach can help students become empathetic designers. The graduate-level courses being investigated bring in students from diverse educational, cultural, and professional backgrounds. By situating the design experience within a community of peers, there are increased opportunities for norming and exchange, shared strategies and resources, and a sense of collective progress. In particular, we examine the Knowledge Community and Inquiry (KCI) model, which has been developed to support communities of learners engaged in collective inquiry (Slotta, 2013). Design, as a form of inquiry, is well suited to KCI as it draws upon resources and input from peers. We examine how a design assignment was implemented within six graduate-level courses in the domain of education, media, and society. We report our analysis of students' peer-supported designs, which made wide use of social annotations, scaffolded feedback, and community knowledge using Google Drive as a technology environment. This analysis informs our understanding of how a learning community approach can promote a collective understanding of empathy within the class, and deeply support human-centered design.

The research questions that framed this study are: (1) How can a learning community approach support students in learning about designer empathy? (2) What are some forms and features of a design-oriented inquiry assignment that support designer empathy, and how do they benefit from a learning community?

Theoretical and Conceptual Frameworks

The Knowledge Community and Inquiry Model

A learning community has been defined as "a culture of learning in which everyone is involved in a collective effort of understanding" (Bielaczyc & Collins, 1999, p. 2). The Knowledge Community and Inquiry (KCI) model has been developed to guide the design of "collective inquiry" curricula that integrate whole class, small group, and individual activities and ensure that all students progress on the learning goals (Slotta et al, 2018). Students engage in epistemic orientations (i.e., to the community pedagogy), in which they learn how to learn as a community and come to value the shared nature of artifacts and ideas. This form of the curriculum also prioritizes diversity and democratic forms of learning, student voice, giving students voice and ownership over what they want to learn and how they want to share it with others.

Definitions and Dimensions of Empathy

Training and practical experience can advance the designer's empathic understanding of users. However, in the context of learning design through a semester-long course, it is challenging for designers to engage directly with their communities and often must rely on secondary understandings to frame their design space (Li & Hölttä-Otto, 2020).

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In this study, we use three dimensions of empathy (cognitive, affective, and conative) as offered in literature to form our conceptual framework. Cognitive empathy refers to the study of the ability and accuracy of the understanding of other people's thoughts in different contexts (Cuff et al., 2016). Affective empathy is usually formed after the apprehension of other people's feelings and problems and sometimes entails some responsive actions (Decety & Lamm, 2006). Lastly, conative empathy refers to the study of the practical application of taking supportive actions in response to other people's feelings and problems (Adams et al., 2014). We use these dimensions of empathy for analyzing peers' feedback in a design thinking assignment and to understand the role of fostering empathy in a learning community.

Course Design and Data Sources

Within each of the six graduate courses, a design project was included in which small teams of 2 or 3 students engaged in designing an innovative media application for learning. All courses were taught by the same instructor during two consecutive academic years and were offered to cohorts of masters and Ph.D. students. Course enrollment was between 22-26 students for five of the courses, and 12 students for the 6th. A major course project was conducted by small groups of students who worked together on a design idea that applied course themes within a specific community or context.

Analysis of community feedback

For this study, 547 comments provided by peers during the design process were analyzed and coded by two researchers independently with an inter-rater agreement of 84.712%. While both affective and conative empathetic comments were visible in many designs, there were more cognitive empathy comments per design (see Table 1).

Table 1
Frequency and Dimensions of Empathic Comments

Dimension of Empathy	Number of comments	Designs impacted	Examples
Cognitive	70	30	"However, for beginner-level students, the "writing" part might be a bit overwhelming because writing sentences do need a lot of grammatical knowledge." "When students answer the questions, they might feel more like playing games instead of reciting vocabulary. "
Affective	10	4	"This app worries me as we are putting kids in buckets too soon. I am also very concerned with equity issues. The rich get richer" "My experience with people jumping into open-source coding projects is there is a whole lot of downtime and head-scratching in the beginning. You will need to get them all through this."
Conative	37	28	"Maybe can get students to create videos and demos to be attached with their modules" "Adding a live chat feature (either with a consultant or an AI) would be nice. This would be super useful when a student stressed and is filling in the OUAC application and needs some immediate clarification"

Semi-structured interviews

We interviewed 6 students at the end of their course to understand their perspectives on the use of the learning community approach. Specifically, through a semi-structured interview, we asked them about the identities and roles they brought into the learning community, in what ways did their peers influence or shape their design idea, and how would they advance their design idea in the absence of the learning community. The interviews

were transcribed and coded inductively to let themes emerge that allowed us to understand the nuances of how empathy from the learning community may have shaped the students' designs, as shown below:

Interdisciplinary perspectives

Our interviewees are teachers that gave them lenses from the real world to evaluate their peers' design process and final outcomes. As the nature of the course deals with the application of knowledge media in society and communities, several interviewees identified with others' design because of their situational and personal experience as immigrants, parents, international students, and/or curriculum designers. As one student aptly described what they saw as the purpose of their identity in the learning community:

> "…helped me to understand the complexity of intersectional identities as we shape our designs" (Tiara, 2021).

Hidden biases uncovered

Several interviewees identified that in a course-based design assignment, biases often creep into their assumptions, especially during a time crunch. One student believed that the learning community's comments brought awareness of some of her team's biases. She added that the comments that were made early in the design process led to influencing decisions on the final design.

Sophistication in design

Almost all interviewees indicated that their final design featured nuanced ways of addressing complex issues, connected to a variety of communities' needs and aspirations, and leveraged on state-of-the-art technology. They all attributed these achievements to their supporting learning community as seen in this statement:

> "I would have probably ended up with a less detailed and sophisticated idea. I would have also had more doubts about the value of the design. The community both encouraged me to continue working on my original idea and helped me fill different gaps in the design."

Case study of a design artifact

Using KCI principles, the instructor created scaffolds for design teams to gather feedback through empathy exercises at different stages of the design. Teams asked their peers for feedback informally in breakout sessions during class in the initial stages of the design process. Next a formal peer-review was conducted on a document that detailed the design's purpose statement and features. Students were given the agency to comment on as many designs as they wanted to and were encouraged to leave empathetic comments that would broaden the team's perspectives. Finally, teams showcased their elaborate designs by presenting user journeys. At this juncture, design teams had the opportunity to receive the last round of feedback that challenged their assumptions and pushed them to advance their designs. We present a case study of a design of a career identity formation application for K-12 students. Some of the comments that were given to the design team during the various review channels are indicated below. The commenter's identity has also been considered during this analysis.

Informal feedback during class

Jason, a doctoral student, served as a senior K-12 school administrator for several years before becoming a full-time student. He is interested in understanding how technology can be leveraged to create communities and drive education reform. The team documented the following comment in their learning journal:

> "What would incentivize the students to join your app? I would find ways to get parents trained and more involved. Also, I find that a culture is created if they knew their friends were using it."

Formal peer-review feedback

The design team documented several suggestions for technology enhancements and ways their users may be motivated to use their application during the formal peer-review feedback. An example of a comment that fostered empathy for the design team is shown below.

Zeba is a parent of four school-going children ranging from ages 15 to 5 years old. She is also an online learning experience designer engaging post-secondary students to develop stronger career

identities. She left the following comment on the design team's document which the team chose to highlight in their learning journal.

> "I see the potential for students to view it as part of the school or as an academic tool, hence not use it for intrinsic purposes. Kids would engage if you considered adding some gaming features an indication of progress."

Peer feedback during design presentation

The design team shared their design with their peers through a visual presentation and emphasized how a potential user would interact with their design. At the end of the presentation, the team highlighted several comments made including their colleague Valeria's comment. Valeria is a researcher who builds and studies technology scaffolds for instructors to engage learners and she commented:

> "I would consider an AI "coach" that helped students make progress on certain career goals, and even advocate for that student in the other communities of participants."

Discussion and Further Research

Building empathy in the design process starts with making space for self-empathy. When students approach design thinking by starting to reflect on the identities they bring into the community, they go through the process of "noticing, centering, sensing, suspending judgment, intention setting and attending to self" which allows them to reciprocate by providing spaces for others' experiences (Train & Niezink, 2021). As such, instructors can provide students with frameworks through which they can bring in their unique dispositions, knowledge of the communities they inhabit, and lived experiences. We noticed that the nature of the comments that students provided were often related to their research interests, lived experiences, and professional expertise. Therefore, exhibiting to students that their experiences and voices are valuable for the class community can make them eager to hear others' worldviews and practices (Cartaya, 2021).

This study is among a select few that explores the concept of supporting empathy using a learning community approach. Adopting such an approach enables the class as a community to engage in empathetic discourse. A learning community pedagogy embraces grounding in the theme of the course while engaging openly in dialogue - making student voice an integral aspect of the experience. In this study, we provided the space in which students' voice, their lived experiences, and positionality was an asset for design teams.

Further research must be done to establish the effectiveness in developing empathy with the help of the learning community. Therefore, we propose to conduct future research that seeks to explore the question: how does a learning community pedagogy impact students' generation of empathic solutions to educational problems and the development of empathy?

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Examining Instructors' Adaptive Equity-Oriented Pedagogical Competency: A Validated Measure that Promotes College Students' Success

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Abstract: This study validates an Adaptive Equity-Oriented Pedagogical Competency (AEPC) assessment, a measure of college instructors' teaching effectiveness. AEPC integrates core elements that have together been shown to improve student learning by over a letter grade. These elements include: 1) Clarifying learning outcomes, 2) Aligning formative assessment with learning outcomes, 3) Identifying students' competencies, needs and interests, 4) Understanding equity barriers to meeting outcomes, 5) Adapting based on needs and barriers, and 6) Iterating: Reflecting upon pedagogy to support continuous learning. Developed under Wilson's (2005) validity framework and calibrated using a partial credit Rasch model, the AEPC measure has both high reliability (0.94) and significant correlation with independent reviews of instructional quality. This measure includes materials that are often included in portfolios used in part to evaluate college teaching, such as teaching philosophy and practice statements, learning outcomes, formative assessment, and reflections on teaching (Seldin, Miller, Seldin, 2010). Unlike course evaluations, this measure shows no gender or URM assessment bias. A learning progression of inclusive practices shown to improve student success provides a measurement foundation for the AEPC assessment.

Introduction: Problem statement and research questions

Research shows that college teaching directly impacts student achievement and retention in STEM, especially for underrepresented students (URM; Seymour & Hewitt, 1997; Sax et al., 2018). It is, therefore, beneficial to equip STEM instructors with adaptive equity-oriented pedagogies that have been shown to increase student learning. The purpose of this study is to develop and validate an instrument to measure the progression of adopting adaptive equity-oriented pedagogical competencies (AEPC). This measure can be used for professional development since it helps instructors reflect and respond to students' learning needs. This measure was taken as an assignment by student-instructors who were enrolled in STEM pedagogy courses that taught adaptive equity-oriented pedagogies. The student-instructors were graduate and undergraduate students who served in an instructional capacity under faculty direction and were enrolled in pedagogy courses at an R-1 university.

We have not found other equity-oriented teaching measures in higher education that were validated using Item Response Theory (IRT). We found college-level, observation-based, equity-based checklist measures of universal design for learning (CAST, 2018) and culturally responsive pedagogy (Hammond, 2014). These measures ask observers to examine whether instructors use formative assessment, explain course content in different ways, and promote participation for all students, but these measures are not validated using IRT and we cannot find reliability estimates. We explore the following 3 research questions:

1. Is the AEPC measure valid and reliable?
2. Does this measure have gender and/or URM bias?
3. What are the consequences of using the assessment?

This study contributes to the learning sciences by offering an assessment that defines a learning progression of inclusive behaviors and practices that have been shown to improve student success. The assessment enables us to see where instructors are on a developmental learning progression so that we can further support their learning of inclusive practices. This information can enable professional developers to support instructors as they implement equity-oriented practices measured by the AEPC assessment.

Adaptive Equity-Oriented Pedagogical Competency

Adaptive equity-oriented pedagogy (AEP) is a framework for adapting teaching to address equity barriers to learning based on student data (e.g., formative assessment, observations, surveys) (Phuong et al., 2017; Phuong

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& Nguyen, 2019). Effective AEP practice is characterized by instructors' use of the 6 competency elements listed below, which build on each other and reflect a mastery learning model.

1. Clarify learning outcomes, equitable course policies, and prerequisite knowledge needed for a course
2. Align formative assessments and activities with outcomes
3. Identify students' competencies, interests, and needs
4. Understand equity barriers and contextual challenges to meeting outcomes
5. Adapt teaching practices based on these needs and barriers
6. Iterate: Reflect upon pedagogy to support continuous learning, adaptation, and growth

Methodology

We engaged in the four building blocks of the Bear Assessment System (e.g., construct map, item design, outcome space, and measurement model) (Wilson, 2005). We designed 6 items that aligned with construct map levels that reflect the AEPC learning progression. We defined an outcome space by creating 0-7 point scoring rubrics for 5 of the items and a 0-1 point scoring rubric for the 6th item. The construct measures varying degrees of AEPC on an ordinal scale, with higher positions on the rubric implying that criteria of lower positions have been met.

Table 1. AEPC Construct Map and Scoring Rubric 0-7

Item Score	**Construct Map Level**	**Description**
0	0	Provides an irrelevant answer, does not apply any elements
1	Low	Applies AEP element 1 and/or 2 (described above) Element 1: Clarifies learning outcomes Element 2: Aligns formative assessment with learning outcomes
2	Moderate	Applies elements 1-3: Diagnoses student learning competency ***Or*** Diagnoses interest
3	Moderate	Applies elements 1-4: Diagnoses learning competency and interest ***Or*** Diagnoses learning competency and learning barriers
4	High	Applies elements 1-5: Adapts based on full diagnosis, not only based on diagnosis of learning competency
5	Very High	Applies all 6 AEP elements
6	Very High	Applies all 6 AEP elements citing instructor and student evidence
7	Very High	Applies all 6 AEP elements with supporting instructor/ student evidence and explains how their practice impacts the student ***Or*** Applies all 6 AEP elements with instructor/ student evidence and explains rationale for how practice impacts student

Participants. We examined 124 participating student-instructors' assessments. There are 80 (64.52%) male and 44 (35.48%) female student-instructors. 13 (10.48%) are URM and 111 (89.51%) are non-URM.

Data Sources. We examined 124 student-instructors' responses to the 6 items of the AEPC assessment. This assessment was taken as an assignment in a graduate-level pedagogy course. Researchers scored responses using rubrics and used survey and interview data to assess instructors' experiences with the instrument.

Data Analysis and Measurement Model: Partial Credit Model (PCM). To answer research question 1, we fitted a Partial Credit Rasch Model (Masters, 1982) and estimated person locations on the construct and the item difficulty parameters.

Model 2: PCM with Latent Regression. To answer research question 1 and examine external validity, we conducted a latent regression to account for measurement error when examining the effects of covariates such as fidelity of implementation scores and gender.

Model 3: Differential Item Functioning (DIF). To answer research question 2, we fitted PCM Differential Item Functioning (DIF) models to ensure there is no AEPC item bias between different genders and between URM identities.

Consequences of Use. To answer research question 3, we inductively coded (Saldana, 2006) think aloud, survey responses about the assessment, and reflection questions that asked about instructors' perspectives on teaching and student learning, changes in beliefs, thought processes while completing the assessment, and experience with the assessment. Although this qualitative research is ongoing, we present frequent themes that we found in the findings below. Performing these statistical and qualitative analyses enables us to see if we meet Wilsons' (2006) strands of validity: Construct Validity, Reliability, External Validity, Bias, and understanding consequences of use. We explore these strands in the findings.

Findings

Research Question 1: Validity and Reliability

Construct Validity. The Wright Map is an empirical representation of the construct map (Wilson, 2006). The Wright Map displays the difficulty of each item, overall and by scoring rubric level, in relation to student-instructors' AEP competency. When items are built to align directly to construct map levels, the scoring rubric levels are expected to band together on the Wright Map. Such empirical banding demonstrates a coherence that contributes to strong construct validity. Based on the Wright Map in Figure 1, we see relative banding for each level since each color tends to group together. We notice that the banding is ordered in the way we hypothesized in the construct map. Respondents who tend to score high on the construct tend to score high across items. This mean location increase supports construct validity. According to the Wright Map, the items appear to cover most of student-instructors' competencies. Nonetheless, some respondents are above the highest items. In other words, the most competent respondents need more challenging items for optimal measurement.

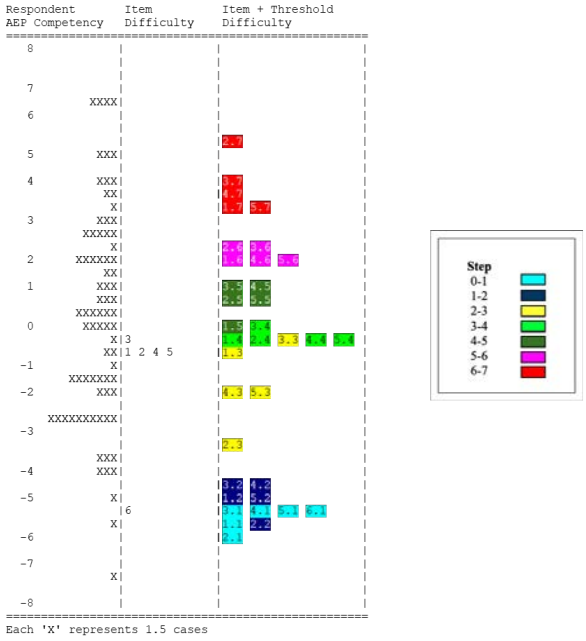

Figure 1. Wright MAP of AEPC

Reliability. We estimated Warm's Weighted Likelihood Estimate (WLE) for the AEP competency of each student-instructor. The reliability estimate of the instrument is 0.94, suggesting the instrument has high consistency in measuring AEPC. We examined infit statistics to ensure that items were behaving appropriately and that there was alignment between what was expected from the PCM and what was observed. An item with an infit statistic above 1.33 is exhibiting more randomness than expected, suggesting that respondents with high proficiency scores tend to score low on that item or vice versa. None of the items had high infit statistics.

External validity. To assess external validity, we conducted a latent regression and regressed student-instructors' AEPC on their fidelity of implementation scores, when controlling for gender. For each unit increase in the fidelity of implementation score, the student-instructor's location in the logit scale is estimated to increase, on average, 1.571 logits in position when controlling for gender (p<0.05). When a student-instructor scores higher on the fidelity of implementation score, there is a higher likelihood that the student-instructor will have, on average, demonstrated higher degrees of AEPC. Moreover, researchers' review of student-instructors' teaching materials and observations of their teaching tended to align with student-instructors' competency estimates. These results further support this measure's validity. When controlling for fidelity of implementation scores, gender does not significantly predict a student-instructors' AEPC at the 5% level.

Research Question 2: Investigating Gender and URM Bias

For all items, we found no evidence of Differential Item Functioning (DIF), or item bias, between males and females because no item by gender interactions (i.e., DIF Contrast) were both statistically significant and above the generally accepted threshold (i.e., 0.426) in magnitude (Paek & Wilson, 2011). In fact, none of our DIF contrasts were of above 0.426 in magnitude, so even had larger sample sizes resulted in statistically significant results, they would not have met the generally accepted threshold indicating a problematic level of DIF. In other words, for all levels of item difficulty, male student-instructors do not have significantly higher item scores than female student-instructors who have the same AEP Competency score, or vice versa. Using the same criteria, we also found no evidence of DIF between URM and non-URM student-instructors.

Research Question 3. Consequences of Use

Benefits. We collected validity evidence on the consequences of the assessment's use. One of assessment's goals is to help student-instructors document equity-oriented practices and demonstrate teaching effectiveness in ways that go beyond course evaluations. We examined the degree to which this occurred. We found evidence that student-instructors documented and improved their AEP practices. Student-instructors stated that the instrument

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helped them improve their instruction and student learning. Many student-instructors also discussed how the AEP framework helped them promote inclusive learning environments. In response to a think aloud exercise, one student-instructor stated the following when asked about what motivated his thought processes and responses to the assessment: "I relied heavily on the AEP methods because many of the principles of AEP agreed with my own teaching philosophy and I had found that based on my experiences with the students the AEP methods were the most effective." Multiple student-instructors also expressed that this assessment helped them apply AEP to adjust teaching practices they were passionate about (e.g., inquiry-based learning, modeling expert problem solving, growth mindset-oriented praise). Student-instructors' AEPC assessment reflections suggest that the pedagogy course impacted their models for effective teaching and learning. Preliminary research also suggests that success on the AEPC measure is associated with greater student achievement.

Discussion

Based on prior research (Phuong et al., 2017; Fink, 2013), we theorized that the highest AEPC level would be the most difficult to reach because it required instructors to demonstrate and act upon all lower-level elements. In theory, reaching the highest level requires ongoing planning, observation, active reflection, and adaptation based on data, which are the traits an instructor with high AEPC mastery would demonstrate. The levels and ordering of the construct and learning progression are supported by the Wright map and mean location increases within all the items of the instrument. We crafted multiple items that tap into all levels of AEPC. Based on the Wright map, these items targeted participants at different competency levels.

Limitations. This study faces challenges with generalizability since this instrument was administered in a graduate-level course in which student-instructors were provided with opportunities to learn and reflect on their adaptive equity-oriented practices and had little to no classroom-teaching experience.

Significance

This study contributes to the literature on communities of practice, groups of professionals who have shared goals and interests such as improving student learning (Wenger, 1998). We provide a way to assess the learning progression within communities of practice focused on equitable teaching practices and interactions with students in STEM. While we understand that such communities can promote learning of new pedagogies, there has not yet been a validated IRT measure on inclusive pedagogies in higher education that can empirically inform their progress.

If validated with a larger sample and elevated in the teaching evaluation process, this AEPC measure could help reduce instructor evaluation bias and incentivize instructors to focus more on high-impact equity-oriented teaching practices that drive student learning. Using item response theory, this study presents a clear and rigorously validated teaching measure that leverages artifacts that are already collected in higher education evaluation. For example, the AEPC items incorporate a teaching philosophy and practice statement, teaching materials (e.g., syllabi, formative/assessment), and evidence of student learning. This measure identifies instructors' developmental progress within a mastery model of learning based on AEPC elements. Using the AEPC measure in this way can prioritize equity in professional development and in conversations around effective teaching practices for all students.

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Students' Self-Regulated Use of Diagrams in a Choice-based Intelligent Tutoring System

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Abstract: Learners' choices as to whether and how to use visual representations during learning are an important yet understudied aspect of self-regulated learning. To gain insight, we developed a *choice-based* intelligent tutor in which students can choose whether and when to use diagrams to aid their problem solving in algebra. In an exploratory classroom study with 26 students, we investigated how learners choose diagrams and how their choice behaviors relate to learning outcomes. Students who *proactively* chose to use diagrams achieved higher learning outcomes than those who *reactively* used diagrams when they made incorrect attempts. This study contributes to understanding of self-regulated use of visual representations during problem solving.

Introduction

In many modern societies, people have access to large amounts of information and resources. Learners therefore need to strategically choose to use available resources so that they can handle learning tasks effectively and efficiently (Schwartz & Arena, 2013). One important class of learner choices involves the use of visual representations. Visual representations can be used as instructional scaffolds that help learners' sense-making processes during learning and problem-solving (Ainsworth, 2006; Rau, 2017). From a cognitive perspective, engaging with visual representations during problem solving can help learners by reducing cognitive effort and making relevant information salient (Ainsworth, 2006). However, to reap these benefits, learners must use visual representations strategically (diSessa, 2004). The strategic, self-directed use of visual representations is an important, though understudied, form of self-regulated learning. To use visual representations strategically, learners need to regulate their behavior (i.e., choose when and how to use visual representations) based on self-monitoring of their own skills and knowledge (Pintrich, 1999).

Despite the importance of understanding learner choices with visual representations, past research has rarely allowed for or specifically measured learner choices in using visual representations during problem solving. Prior work has largely focused on student learning when students are *given* visual representations (e.g., Rau et al., 2015). A few studies have investigated learners' spontaneous use of visual representations (e.g., students constructing diagrams on their own) in problem solving and these studies have shown that students generally tend not to choose to use visual representations when it is optional to do so (Uesaka et al., 2007, 2010). Although prompts to engage with visual representations (e.g., drawing) have been shown effective in encouraging students to use visuals (Wu et al., 2020), past studies do not give deep insights into *how* students make choices in problem solving and how their choices might be related to learning outcomes and performance. A deeper understanding of students' choice-making processes and how they relate to learning could contribute to the understanding of self-regulated learning with visual representations (diSessa, 2004; Zimmerman & Campillo, 2003).

Choice-based Intelligent Tutor with Visual Representations

To investigate students' choices in using visual representations, we redesigned an existing Intelligent Tutoring System (ITS) for algebra problem solving (Long & Aleven, 2014; Nagashima et al., 2021) to develop a *Choice-based Diagram Tutor* (Figure 1). In this *choice-based* tutoring system, students can choose whether and when to engage with a visual scaffolding strategy called "anticipatory diagrammatic self-explanation" with tape diagrams, a representation that is increasingly being used in algebra instruction worldwide (Murata, 2008). Anticipatory diagrammatic self-explanation is a metacognitive scaffold in which learners *self-explain* ensuing problem-solving steps by selecting a diagrammatic representation of a next step (Nagashima et al., 2021).

Anticipatory diagrammatic self-explanation presents a fruitful context for examining students' self-regulated choices with visual representations. It is an effective metacognitive strategy that learners might not

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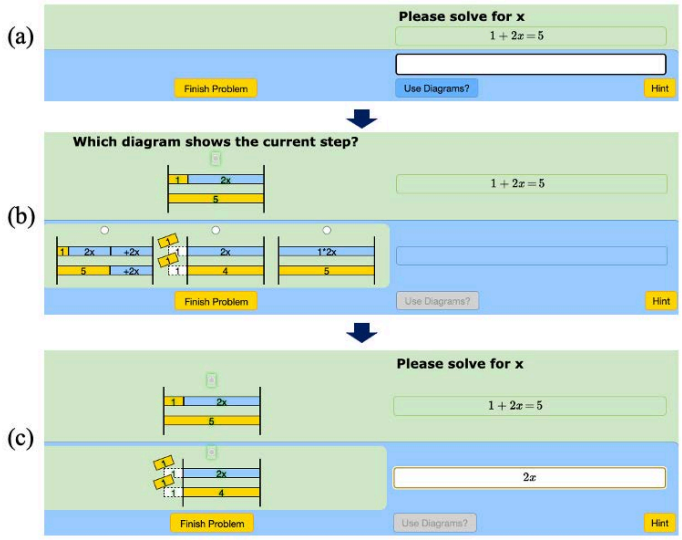
naturally choose to engage with, a critical prerequisite when designing a "choice-based" learning environment (Chin et al., 2019). In the tutor, students may be inclined to avoid using diagrams because doing so would require additional problem-solving steps. Also, tape diagrams are a new representation that students may find unfamiliar (Murata, 2008). However, anticipatory diagrammatic self-explanation has been shown to be beneficial for student learning and performance (Nagashima et al., 2021). Therefore, we investigated students' *spontaneous use of diagrams* (i.e., whether students spontaneously use diagrams when such use is optional; Uesaka et al., 2010).

Additionally, we distinguish the following choice behaviors involving spontaneous diagram use to get insights into students' self-regulated use of diagrams: 1) *proactive diagram use:* using diagrams *before* attempting to solve the corresponding symbolic step, and 2) *reactive diagram use*: using diagrams *after* making one or more incorrect attempts on the symbolic step. These choice categories are informed by the literature on help-seeking in ITSs (Aleven & Koedinger, 2001) and by Zimmerman and Campillo's (2003) cyclical model of self-regulation. Zimmerman and Campillo's (2003) model captures phases of self-regulated behaviors in which learners evaluate the difficulty of the target task ("forethought" phase), self-monitor learning strategies ("performance" phase), and evaluate and reflect on the use of the strategy ("self-reflection" phase). Under this model, in the Choice-based Diagram Tutor, students may choose to use diagrams by assessing the difficulty of the given equation, self-monitor how they perform by using diagrams, and adjust their use of the strategy through self-reflection. Therefore, we expected that proactive diagram use would represent self-regulated, *well-planned* use of diagrams, whereas reactive diagram use would represent *unplanned* diagram use.

The Choice-based Diagram Tutor collects learning process data (e.g., choice behaviors and problem-solving performance measures), enabling us to study students' learning processes, which have not been explored in studies on spontaneous diagram use (e.g., Uesaka et al., 2010). The present study asks: RQ1) *When given a choice, how will students engage with anticipatory diagrammatic self-explanation?* RQ2) *Are students' choice behaviors related to their learning outcomes, performance, and their perceptions regarding diagram use?*

Figure 1

(a) Students start with an interface showing a symbolic algebra problem. They can solve the equation symbolically or choose to use diagrams ("Use Diagrams?" button). (b) Students who choose to use diagrams will select a correct diagram that represents a good next step. (c) After selecting a correct diagram option, students will type in the step in mathematical symbols.



Method

We conducted a pretest-intervention-posttest study in two classrooms in a middle school in the U.S. Thirty 6th graders participated. The participating teachers noted that some students might have previously seen tape diagrams in learning materials, but the instruction had never focused specifically on tape diagrams.

We developed a web-based assessment consisting of seven items that measure conceptual understanding of algebra and four procedural knowledge items that asked students to solve symbolic equations. Of these 11 items, three conceptual and two procedural items included tape diagrams. For these problems, tape diagrams were presented either alongside a symbolic equation so that students could refer to them or integrated into the main task (such that students needed to understand the representation to reach the correct answer). Two assessment

versions were created and assigned as pretest and posttest in a counter-balanced way. Following the posttest, students answered five survey questions about their perceptions of tape diagrams (e.g., "Do you think that diagrams helped you solve problems?") and their confidence in solving equations (based on a questionnaire in Uesaka et al., 2007). All students were given the choice-based diagram tutor, which included 22 problems of four different problem types (called "levels" in the tutor): Level 1) $x + a = b$, Level 2) $ax + b = c$, Level 3) $ax = bx + c$, and Level 4) $ax + b = cx + d$, assigned in this order. According to the teachers, students had seen Level 1 problems but had never solved equations in a formal way (by subtracting "a" from both sides of "$x + a = b$").

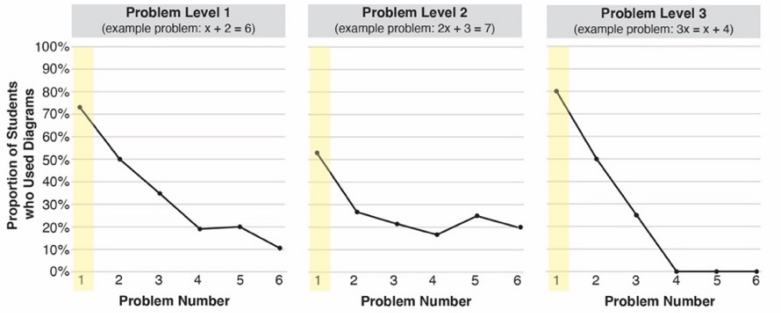
Researchers joined the classrooms remotely to conduct the study. On the first day, students worked on the 10-minute pretest. On the second day, one of the teachers gave a brief lecture on how tape diagrams visualize equations to all students at the beginning of the session. Students then used the tutor for about 25 minutes. Students then completed the posttest and the survey about perceptions of tape diagrams and their math skills.

Results

Four students were absent on the second day of the study; we analyzed data from the remaining 26 students. To answer RQ1, we calculated the frequency of diagram use. On average, students solved 9.12 problems ($SD = 5.14$) and chose to use diagrams 3.15 times overall ($SD = 2.88$). Students *proactively* used diagrams in 72% of cases ($Mean = 2.27$, $SD = 2.38$) and *reactively* used diagrams in 28% of the cases ($Mean = 0.88$, $SD = 1.21$). Students tended to use diagrams on the first problem in each problem level, and diagram use declined as students practiced the same problem type multiple times (Figure 2). The trend was not observed for Level 4 problems because very few participants advanced so far (therefore not included in Figure 2).

Figure 2

Proportion of students who spontaneously used diagrams at least once for each problem.



To examine RQ2, we tested whether self-regulated behaviors predicted learning and performance. We constructed separate linear regression models with the following dependent variables: posttest score, posttest score for problems without tape diagrams, average time spent per symbolic step, average number of hints used per symbolic step, and average number of incorrect attempts for the symbolic steps. We included each of the spontaneous, proactive, and reactive diagram use frequencies in each model as independent variables. Overall pretest score was included to control for students' initial knowledge level. Spontaneous diagram use predicted higher overall posttest scores; however, this relation did not reach statistical significance ($\beta = 1.47$, $p = .07$). Spontaneous diagram use did not predict any other dependent variables. Proactive diagram use, however, predicted higher overall posttest scores ($\beta = 2.01$, $p < .01$) and higher posttest scores on items without tape diagrams ($\beta = 1.03$, $p = .04$). Reactive diagram use, on the other hand, was associated with lower overall posttest scores ($\beta = -4.75$, $p = .03$) and lower posttest scores on items without tape diagrams ($\beta = -3.39$, $p = .01$). Reactive diagram use also predicted greater use of hints ($\beta = 5.21$, $p < .01$). Prior knowledge, perceptions of diagrams, and confidence in solving equations were not associated with spontaneous, proactive, or reactive diagram use.

Discussion

Although students' use of diagrams was generally low, students' *proactive* diagram use predicted higher learning outcomes. This association was also observed on test items that did not include tape diagrams, suggesting near transfer of learning. However, as we cannot establish any causal relationships from the results, it is possible that certain characteristics that we did not control for led both to more proactive diagram use and better learning. For example, proactive diagram use might be indicative of superior monitoring ability or a propensity to monitor one's comprehension more frequently, which might lead to other behaviors that might contribute to better learning.

The current work contributes understanding of self-regulated learning with visual representations. Specifically, it provides evidence that effective use of visual representations involves more than simply using the visual representations spontaneously; rather, proactive use, which we consider as a form of self-regulated diagram use that involves assessment of task difficulty and planning of whether or not to use diagrams, leads to better learning. In a related, pilot study with eight middle-school students who thought aloud as they used the tutor, we found that students who tended to proactively use diagrams thought deeply about the given problem before attempting to solve it and correctly understood diagrams. On the other hand, those with frequent reactive diagram use did not seem to understand the diagrams, and therefore seemed to process diagrams in a shallow way (e.g., selecting diagrams that *look* right). We acknowledge though that different interpretations of these patterns of diagram use may be possible.

Learners can use visual representations in a range of ways. Our data suggest that proactive use of visual representations is beneficial for students' performance. Future research could explore ways to motivate students to use visual representations proactively, help them make self-regulated decisions as to when to spontaneously *fade* visual scaffolding, and experimentally test whether such strategic diagram use might be facilitated.

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International Society of the Learning Sciences

Designing an Adaptive Dialogue to Promote Science Understanding

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Abstract: We used Natural Language Processing (NLP) to design an adaptive computer dialogue that engages students in a conversation to reflect on and revise their written explanations of a science dilemma. We study the accuracy of the NLP idea detection. We analyze how 98 12-13 year-olds interacted with the dialogue as a part of a Diagnostic Inventory. We study students' initial and revised science explanations along with their logged responses to the dialogue. The dialogue led to a high rate of student revision compared to prior studies of adaptive guidance. The adaptive prompt encouraged students to reflect on prior experiences, to consider new variables, and to raise scientific questions. Students incorporated these new ideas when revising their initial explanations. We discuss how these adaptive dialogues can strengthen science instruction.

Objective

Through a partnership among university education researchers, computer scientists, and science teachers from six middle schools, we exploit advances in Natural Language Processing (NLP) to detect the rich ideas that students use to explain science dilemmas. We test designs for computer-generated adaptive dialogues to affirm students' ideas and support them to refine and extend their understanding. We build on prior work demonstrating the value of adaptive guidance that models behaviors for integrated revision such as making connections between ideas (Chi et al., 2017; Gerard & Linn, 2022). The adaptive dialogue in this study promotes equitable science teaching by assisting teachers in encouraging each student to express and elaborate their ideas about the target science topic including ideas grounded in their lived experiences.

Adaptive dialogue for revising science explanations

We design and test an NLP based adaptive dialogue that elicits the different ideas students bring to science problems and models a path to developing those ideas. The adaptive dialogue may assist teachers by ensuring that each student receives guidance which identifies a spark in their explanation to build on. The dialogue is designed to guide students to engage in integrated revision. Integrated revision is grounded in a knowledge integration (KI) perspective on learning, suggesting that as students reformulate the connections among their ideas, distinguishing which ideas are supported by evidence and how they link together, they deepen their understanding and develop durable insights (Gerard & Linn, 2022; Linn & Eylon, 2011). Central to the process of integrated revision is eliciting the different ideas one holds about a problem. These initial ideas often reflect prior experiences or previous science instruction. Eliciting a learner's ideas promotes agency by enabling the students to generate their expectations before they test them, increasing their interest in the outcomes. In repeated studies across disciplines and age groups, retrieval practice, compared to review and retrieval, has shown learning advantages (Karpicke & Roediger, 2008). Articulating one's ideas allows learners to reflect on their many different ideas and distinguish which among their ideas are relevant and supported by evidence.

Eliciting a learner's ideas in science is tricky since students may be reluctant to express ideas that differ from those of others or that they feel will be rejected as incorrect. Research suggests students with non-dominant views may be hesitant to express these ideas in a classroom context. When the culture of school encourages students to "do school" rather than "do science", students are likely to dismiss their ideas developed from years of experience or prior courses and adopt the idea presented by instruction without distinguishing between the two (Carlone et al., 2015). Research shows that when instruction neglects the ideas students hold while introducing new ideas, students develop a fragmented understanding by holding both perspectives rather than evaluating their knowledge (diSessa, 1998). We build on these findings to design an adaptive dialogue that engages each student in integrated revision by affirming students' initial ideas, prompting them to add new ideas as they reflect on the topic, and supporting them to consider the valuable reasoning and evidence underlying their initial ideas.

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Methods

We investigate two research questions: (1) How accurate is the NLP technology for detecting ideas students hold about an open-ended science dilemma?, and (2) How do students respond to adaptive guidance that promotes integrated revision on a Diagnostic Inventory?

Participants, Diagnostic Inventory, and NLP-based Adaptive Dialogue

We administered a Diagnostic Inventory with one teacher's 98 7th and 8th graders (50 7th graders; 47 8th graders). The majority of the students identify as a part of historically marginalized racial, linguistic and socioeconomic groups (97% Latinx; 95% of parents speak a language other than English at home; 85% eligible for a free or reduced price lunch). We report on the *Car on a Cold Day* problem, described in Table 1.

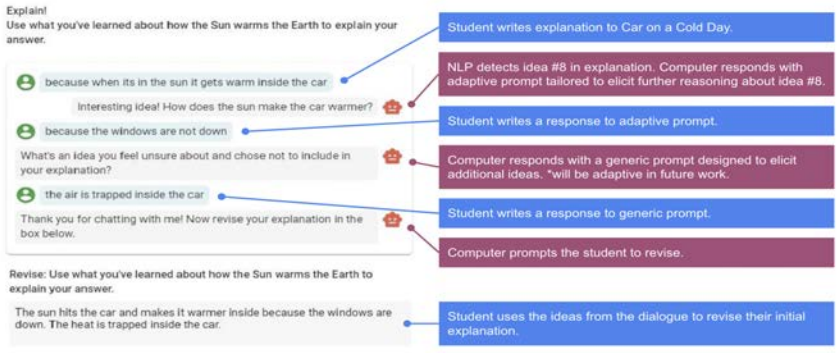
To train the NLP scoring model, a corpus of 1000+ student explanations collected in prior research from 5 schools, including demographics similar to the school in this study, was used. Two researchers developed a 5-point Knowledge Integration rubric to score the student explanations for 'Car on a Cold Day', which rewards students for linking normative, relevant ideas. The researchers also identified the distinct ideas expressed by students (21 ideas, Table 1). One student explanation could include multiple ideas. The researchers refined the rubrics until they achieved inter-rater reliability (Cohen's Kappa > .85). Then, each researcher coded 50% of the explanations assigning a KI score, and a tag for each distinct idea within each explanation. Data was used to train an NLP model.

Table 1. *Sample of "Car on a Cold Day" Scoring Rubric and Guidance for Adaptive Dialogue Round 1*

Item prompt: *On a cold day Akbar walks to his car that is parked in the sun. The sun has been shining on the car for the whole day. How will the temperature inside the car feel? Use what you've learned about how the Sun warms the Earth to explain.*		
#	**Sample Ideas**	**Assigned Guidance in Dialogue Round 1**
3	car same temperature as outside	Can you tell me more about how the temp. inside the car changes the longer it sits in the sun?
4	car warmer than outside	Can you tell me more about how the Sun makes the inside of the car warmer than outside?
7	Heat comes from the sun	Can you tell me more about the forms of energy that come from the sun?
8	Direct sun warms the car	Interesting idea! How does the sun make the car warmer?
9	Metal/car attracts heat/cold	Can you tell me more about how the material impacts how the car gets energy from the sun?

To build the NLP model, we used a word classification or sequence labeling approach (Riordan et al., 2020). First, the words in each response are transformed into numerical vectors with state-of-the-art language models that have been previously trained to capture latent relationships in the English language via the self-attention mechanism. Second, for each word, idea detection is cast as a multi-label classification problem. Consecutive word-level predictions of a targeted idea form a predicted idea span. The idea detection model was trained, evaluated, and deployed with 10-fold cross validation for hyperparameter tuning and evaluation. Final model building used all available data. Adaptive dialogue prompts for each idea were designed to engage students in conversation, modeling an integrated revision process and promoting science understanding (See Figure 1).

Figure 1*: Screenshot of a Sample Guidance Dialogue from the Car on a Cold Day item on Diagnostic Inventory.*



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Data Analysis

We determined the most frequently detected idea across all students' initial explanations (idea 8). We then identified the subset of students (N=53) who expressed idea 8. Focusing on these dialogues enabled comparison of the students' paths of reasoning rather than the impact of different adaptive prompts. Next, we selected a sample of 10 students who would be likely to express unique paths of reasoning in the dialogue based on criteria that they had varied levels of English and prior instruction about the greenhouse effect. Three researchers individually annotated each response to characterize students' revision moves. Researchers discussed annotations until reaching agreement. One researcher used the resulting categories [Fig.2] to code the 53 dialogues.

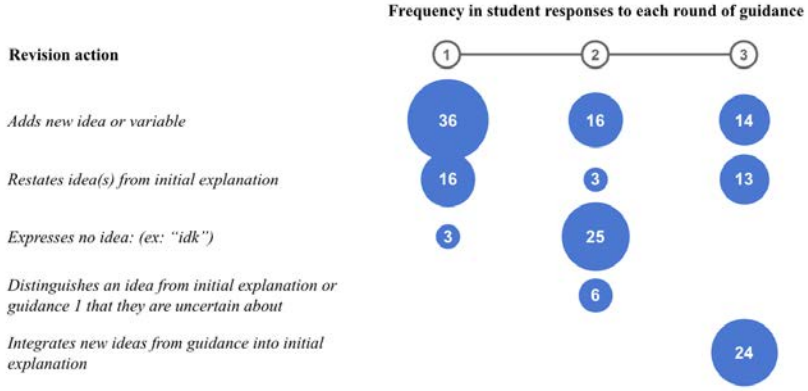
Results

To evaluate the NLP model accuracy, word token-level micro-averaged precision, recall, and F1 scores were used. These metrics account for the imbalance in idea classes. Despite often inaccurately predicting the length of idea spans, the model accurately predicted spans for many of the idea classes. Aggregating across all targeted ideas, we obtained a word-level micro-averaged precision of 0.71, and a recall of 0.51, yielding an F1-score of 0.60. The F1 score (0.60) suggests the difficulty of achieving high accuracy across all idea classes from our relatively small dataset. The model is relatively conservative in predicting idea spans, resulting in higher precision (0.71) but lower recall of ideas (0.51). Some idea classes were sparsely represented in the data (e.g., idea was tagged with less than 300 words of the 27000 words in the data set), thus the model tended not to predict idea spans for these ideas.

Analysis of students' revisions indicated that overall, the dialogue supported students to revise their explanations: 91% of the students (87/96) revised their initial explanation after engaging in two rounds of dialogue. In contrast, in our prior research only 69% of students revised in response to two rounds of knowledge integration adaptive guidance (Gerard & Linn, 2022). Additional studies report that under 50% of students engage in sustained revision when the activity calls for it (e.g. Zhu et al., 2020).

The analysis of student revision moves suggests that the dialogue effectively elicited student ideas (Fig. 2). In response to the *adaptive* first prompt in the dialogue, 36 of the students (68%) added a new idea to elaborate the mechanism underlying their initial explanation. In response to the *generic* second prompt (same for all students), 16 (30%) of these students added another new variable they considered relevant, and 6 (11%) distinguished a part of the mechanism from their initial explanation that they were uncertain about. Twenty-five (48%) of the students however struggled to recognize another relevant idea in response to the generic prompt (e.g., "I'm not sure; IDK"). This could be due to the generic nature of the prompt or because it is the second prompt. After the dialogue, students were encouraged to consolidate the ideas they raised in the dialogue and revise their initial response. When revising, 24 (46%) of the students integrated an idea that they had raised in the dialogue to explain more fully the mechanism they had initially expressed. Fifteen (28%) expressed another new variable, in addition to those raised in the dialogue, in their revised explanation. Overall, the dialogue elicited an increasing number of ideas each student held about the problem. The adaptivity of the prompt in the first round was more effective than the generic prompt in the second round in supporting students to recognize and express the relevant ideas they held.

Figure 2. *Student revision sequences in the dialogue [N=53];* ***1****= Response to adaptive guidance in round 1;* ***2*** *= Response to generic guidance in round 2;* ***3****=Revising initial explanation*



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Case analysis. We describe the dialogues for three students who started with a similar idea, yet had distinct sequences of revision to illustrate the revision moves. Each of the students started out by expressing a vague idea that the car will be warm inside because of the sun. The computer accurately detected this idea (idea 8: sun warms the car) and started the conversation with, "Interesting idea! How does the sun make the car warmer?". Each student responded by retrieving a new idea they held, likely by reflecting on their time spent in a hot car and distinguishing relevant evidence to elaborate their view (e.g. (student 1) sun is hot; (2) car windows up; (3) metal material of the car). The computer then asked the generic prompt (what's an idea you felt uncertain about?). At this point student 1 distinguished their uncertainty about how the mechanism worked (how does the inside of the car get hot). Student 2 recognized an additional relevant new idea (air is trapped inside the car) to elaborate the idea they raised in the previous round of dialogue. Student 3 explored the feasibility of their initial idea (will metal overheat and explode?).After these two rounds of dialogue, each of the students revised their initial explanation. Student 1 incorporated new details to elaborate their initial explanation [*When you leave your car parked in the sun it is usually warm when you get in and when you park in the shade it is cool inside.→The sun is very hot and when it shines on the car the car eventually heats up for many hours that it is parked on the road*]. Student 2 linked the new ideas they raised in the dialogue and integrated them with their initial ideas to create a more complete and accurate mechanism [*when its in the sun it gets warm inside the car→The sun hits the car and makes it warmer inside because the windows are [not] down. The heat is trapped inside the car*.] Student 3 abandoned their initial ideas in favor of new ideas they devised to consider and generated an alternative explanation [*sun warms the earth by its hotness Its kinda like a warm blanket wrapped around earth but its actually the sun hotness→The car will feel cold on the inside even though it was in the sun for a long time, it'll be the same temperature as outside*]. The analysis illustrates how the dialogue supported students to recognize the multiple ideas they held relevant to solving the problem, and to reflect on how these ideas link together to refine their science explanation.

Conclusions & Next Steps

This study suggests that asking adaptive knowledge integration oriented questions in a computer generated dialogue can encourage students to make steps toward integrated revision of their ideas. The dialogue supported students to generate many ideas, developed from prior experiences as consideration for solving the science dilemma. Once students added new ideas they either distinguished among these, or used the new idea to buttress or modify their initial ideas. Guiding students to reflect on the different ideas they have, initiates a process in which students raise scientific questions and consider new variables. This may position students to further explore the variables or seek answers in subsequent instruction. This analysis aligns with previous findings on retrieval practice, where prompts to retrieve more ideas from a passage fostered learning (Karpicke & Roediger, 2008). Future work will embed dialogs in instructional units to more closely test impacts of retrieval practice on learning, and to explore guidance strategies to support use of evidence for distinguishing among ideas. We will also explore how adaptive dialogues may support teachers to tailor their instruction to student's specific ideas, and to affirm the paths that lead the student to their ideas.

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Implementation of Dialogic Teaching: Exploring Teachers' Perceptions, Attitudes, and Practical Challenges

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Abstract: Research interest in discursive strategies for orchestrating vibrant classroom interactions has burgeoned. Few studies, however, have given details about teachers' perceptions and attitudes. This paper reports on an on-going study that explored elementary and secondary school teachers' perceptions and attitudes towards dialogic teaching and the challenges they encountered in the implementation. We recruited three elementary and middle school teachers from different subjects in China to participate in the video-cued interview. The results showed that some teachers with professional vision on dialogic teaching, though attitudinally in favor of this pedagogical approach, tended to be reluctant to adopt it for fear of losing face or being challenged by their students. In parallel, students' learning ability, learning efficiency, and willingness to participate in class may obstruct teachers' efforts to unfold classroom instruction in a dialogical way. These findings help enrich our understanding of the effective implementation of dialogic teaching.

Introduction

According to sociocultural perspectives (Vygotsky, 1978) and situated learning theories (Brown et al., 1989), classroom discourse is viewed as a vital role in influencing student learning (e.g., Resnick et al., 2015). Special emphasis has been put on the fruitful classroom dialogue, which is construed as a key feature of effective teaching and learning. Against this backdrop, a range of theories on dialogic teaching have been proposed to help teachers orchestrate productive classroom discourse (e.g., Alexander, 2017; Mercer & Littleton, 2007; Michaels et al., 2008; Pehmer et al., 2015). Dialogic teaching is a newly advocated pedagogical approach that engages students in the joint construction of knowledge by encouraging them to share their ideas with others and to interact with the thoughts of peers.

Although scholars have long endorsed classroom dialogue (Howe & Abedin, 2013), dialogic and vibrant teacher-student interactions are rare in authentic classrooms (Chen & Chan, 2022; Nystrand et al., 2003). In fact, teachers face many obstacles when they attempt to adopt dialogic pedagogical approaches as a legitimate means and successfully implement them in their classrooms (Chen et al., 2020; Resnick et al., 2018). In one sense, dialogic teaching skills are developed gradually (Clarke et al., 2016; Rapanta et al., 2021; Sedova, 2017); however, teachers are not given adequate time to acquire the necessary knowledge and skills to organize classroom discourse (Resnick et al., 2018). According to some researchers, lacking theoretical strategies and not being aware of the precious functions of language may be hindering teachers (Ruthven et al., 2017). On the other hand, even if teachers realize and value the virtue of dialogic teaching, their attitudes towards adopting this pedagogy are crucial, in particular when faced with intensive teaching tasks and fixed learning objectives.

Despite this, there is little research that delves into the teachers' perspectives on dialogic teaching. Therefore, this study aimed to explore teachers' perceptions and attitudes toward dialogic teaching through video-cued interviews, which could enhance our understanding of implicit teaching practices.

Video as a vehicle for teacher reflections

With the emergence of learning sciences, video research has become increasingly popular (e.g., Chen, 2020; Gröschner et al., 2018). As exemplified by Sherin's studies on the video club (Sherin, 2007; van Es & Sherin, 2010), video serves as a tool not only for capturing classroom interactions, but also for teacher reflection. Teachers can watch and discuss the videotaped lessons together and thus reflect on their own teaching practices. Teachers' perceptions of teaching phenomena can be discerned through their interpretation of the teaching behaviors demonstrated in video recordings. As Goodwin (1994) pointed out, individuals with a professional vision perceive and interpret events in a particular way.

Further, video-cued interviews have been developed and introduced into education research to further enhance our understanding of the implicit cultural practices of teaching and learning (Xiao, 2018). While watching video clips of other teachers' lessons, the videos can be used as interviewing cues to stimulate the teachers' relevant thoughts and reflections as insiders. Therefore, it is a promising avenue for researchers to tap into teachers' perceptions and attitudes, thereby contributing to their professional development.

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Accordingly, this study used video as a vehicle to investigate the following research questions: (1) How do teachers perceive dialogic teaching and what are their attitudes towards it? (2) What are the challenges involved in implementing dialogic teaching?

Method

Participants

In this on-going study, we are recruiting participating teachers from various subjects and grades in different regions of China, including Henan province, Jiangsu province, and Shanghai municipality. As a pilot, three female teachers were invited to participate in the interview, including Ms. Min (elementary school mathematics, from Jiangsu), Ms. Li (middle school Chinese, from Henan), and Ms. Gao (middle school science, from Shanghai). All three teachers have three years of teaching experience, and they each hold a master's degree in education.

Data collection and analysis

The video-cued focus group interview method was used to collect the data in this study. In this research method, we could gain insight into respondents' perceptions and attitudes towards an event or issue, as well as their experiences and the meaning of their behaviors. The video-cued interview allowed for impromptu discussions among the interviewees, which provided a collective exploration and interpretation of the issues. Such an interview would even break the shackles of the researchers' predetermined questions.

Three steps were involved in this interview: First, the researcher stated the purpose of the interview and described the basic characteristics of dialogic teaching to clarify interviewees' understanding. Next, the three teachers were shown a video clip of approximately ten minutes due to time constraints. The video clip we chose was from a fifth-grade math classroom in a public elementary school in Shanghai, China. In the video, the teacher was demonstrating how to calculate the volume of a rectangular object. After discussions among researchers and experts, this videotaped lesson was identified as a dialogic teaching style. Finally, we invited the teachers to evaluate the teaching style in the videotaped clip and to share their perspectives related to their own experiences.

Approximately one hour of audio from the interview was transcribed verbatim. Teachers' attitudes and perceptions of dialogic teaching, as well as the implementation challenges they faced, were noted in the transcription. These initially marked themes were then grouped into broader thematic categories. Finally, in order to answer research questions, we further scrutinized the interview transcript connected to these themes.

Findings

Teachers' perceptions and attitudes

Three teachers commented unanimously that the teaching practices presented in this video clip tended to be student-centered and dialogic. They think this teacher has attempted to delegate as much responsibility for discourse as possible to the students. Ms. Min commented, "*The questioning culture is good in this class. After answering the question, the student would ask other pupils if they agreed with his or her answer. And the next evaluator would state his/her position before giving reasons*." In fact, the video showed that misconceptions were corrected during peer interactions. Furthermore, when a child's statement was incomplete, "*appropriate reminders and corrections by teachers could help this child develop a deeper understanding.*" The teacher's comparison of the two students' ideas "*actually gave many other children a hint*" to awaken their attention. Ms. Li echoed Ms. Min and pointed out that this type of thinking exercise and expression could help students transfer their skills to other areas. Taken together, these comments by the interviewed teachers implicitly reflected their perceptions and claims about dialogic teaching, such as "say more", "agree/disagree", "explain others", and "revoice". These results demonstrated that teachers have a certain level of professional vision.

Though all three teachers favored dialogic teaching, they also acknowledged the difficulties of its implementation. Interestingly, the reasons for agreement and the concerns about the difficulties of implementation were both related to high-stakes testing (such as entrance exams). The interview transcript revealed that exams serve as a baton that requires teachers to deliver content with quality and quantity, but also examines students' higher-order competencies that need to be nurtured in dialogic, interactive instruction.

Challenges teachers face in implementing dialogic teaching

In addition to several objective factors (e.g., intense teaching tasks and busy schedules), the interview transcript revealed that teachers were hesitant to adopt dialogic teaching due to several factors such as *students' learning ability*, *learning efficiency* and their *willingness to participate in classroom discussions*. Ms. Min noted that,

especially in the early grades, the sequential act of listening carefully to others' utterances, comprehending their meaning, and then evaluating them places high demands on students' attention and learning ability. She said, "*For students who are able to concentrate, the interactions make sense*." Ms. Li continued, "*Otherwise, you will always find the same group of students raising their hands in a large class*."

Even though all three teachers acknowledged the importance of previewing before classes, *the unequal knowledge reserves* between teachers and students were identified as a potential constraint. As illustrated in the dialogue below, *the fear of losing face* was a concern when the power of dialogue was given to active students who asked questions beyond the teacher's capability. Students who were highly engaged in learning actives and who had a wealth of prior knowledge sometimes came up with unusual and quirky ideas that are difficult for teachers to deal with.

Ms. Min	Giving students the right to open discussions should be based on their pre-reading.
Ms. Li	I agree with Ms. Min. If I am required to complete all the teaching contents in a demonstration lesson, students' in-depth pre-reading ensures an effective lesson. Also, classroom interactions also require a high level of knowledge on the part of the teacher. For instance, Chinese lessons may involve other subjects, such as history, culture, and science. If I do not reserve this knowledge in advance, I may not be able to unfold the class better when the students refer to it.
Ms. Gao	Interactions may be less effective if (the students) don't have a knowledge base. But I am faced with a situation where many children have already studied in advance and they know the answers to my questions. In this case, the interactions are meaningless and the discussions are dull.
Ms. Li	What I just said is that the students' knowledge is sufficient. When it comes to extended knowledge beyond the current subject matter, the teacher may not be as knowledgeable as the students. Teachers may not be able to pick up the conversation.
Ms. Gao	New teachers like us are afraid to engage in open-ended conversations. Children have active minds, so it's humiliating when they challenge me and I can't answer.

Conclusion and implications

This study explores teachers' perceptions of, and attitudes towards, dialogic teaching, and to identify the barriers that hinder implementation of this pedagogy. Despite recognizing the virtue of dialogic teaching, the findings indicate that teachers have difficulties executing it effectively due to personal reasons and other considerations related to students.

This work provides a glimmer of evidence regarding the reasons for teachers' reluctance to adopt dialogic teaching. The success of innovative pedagogies in the classroom hinges on the teachers. Thus, teacher professional development entails more than just equipping teachers with teaching strategies; it requires that teachers be attitudinally, cognitively and emotionally fulfilled. Our on-going research is digging deeper into the influencing factors with a larger sample of teachers.

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Understanding and Leveraging Contradictions of Instructional Activities for Fostering Students' Agency

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Abstract: Instructional activities are situated in a web of interdependent activity systems such as students' families, educational institutes, research programs, industries and governments. Historically accumulating tensions between these systems are said to impose contradictory demands on students. For example, during learning, students often feel compelled to choose between being a grade maker versus a sense maker. Such deep-rooted problems cannot be addressed by simply finding better ways of implementing existing practices. Hence we revisit key ideas such as instruction, feedback, competence and their interconnections by considering contradictions across activity systems. Then we carve out a space for students' agency within such interconnections by introducing and investigating a construct called 'students' feedback seeking actions' using cultural historical activity theory (CHAT). Finally, its affordances in further uncovering and leveraging contradictions of instructional activities for fostering students' agency are explored using a case study from undergraduate chemistry education.

Introduction

Currently, there are multiple notions of instruction and feedback varying significantly in terms of whether they limit or extend the scope for students' agency (Askew, 2000). Such variation arises from the underlying contradictions in how different learning research programs view knowledge, competence, learning and individuals (Engeström, 2018). Some programs view knowledge and competence that is worth learning as stable, well-defined and out there to be acquired and transferred; while others view it as distributed, evolving, or yet to be discovered, constructed and validated. Similarly, learning is a linear process for some and a non-linear process mediated by multiple cultural factors for others. Then some account for just students' and teachers' cognition while others consider their emotional, motivational and identity aspects. Acknowledging these contradictions has led to a shift in viewing both instruction and feedback as dialogue (Ajjawi & Boud, 2018; Skidmore, 2017). However, their relationship when both are viewed as dialogue is unclear. Also, studies with instruction as dialogue have focused mostly on different kinds of talk (Kim & Wilkinson, 2019). On the contrary, there is increasing recognition that instructional activities, culture and dialogue all shape each other. To address these and other contradictions discussed below, we use CHAT to reconceptualize key notions as follows:

- Instructional activity is a teacher's predetermined plan involving the organization of certain tasks, tools, representations, norms, individuals and ways of cooperation (division of labor) estimated to support students' learning towards particular valuable outcomes.
- Feedback is any information concerning the given instructional activity that addresses students' needs tied to their knowing, doing and being for accomplishing, modifying, or even avoiding the expected outcomes by the teacher. Students can derive feedback either by working with representations and tools or having a dialogue with themselves and multiple others or using a combination of these modes.
- Students' feedback seeking actions are those where decisions such as purpose, timing, mode, amount of feedback seeking, choice of feedback source and how feedback is used are all made by themselves.
- Competence is a set of students' interconnected actions tied to their knowing, doing and being judged as valuable in relation to particular activities and culture within which they are (or will be) enacted.

The above definitions also account for contradictions across interdependent activity systems. This idea of instruction acknowledges the complexity of any goal directed activity and does not reduce it to just tasks or talk. Further, instruction as an estimate and predetermined plan accounts for classroom realities such as student diversity, teacher workload and large pupil-teacher ratio. Consequently, we also do not view teachers' role as orchestrating instruction and feedback on a moment-to-moment basis. Then the idea of feedback acknowledges that it can be any information that meets students' diverse cognitive, emotional, motivational and identity needs. Especially, viewing feedback's role as not always accomplishing teacher's expected outcomes aligns with the notion of instruction as an estimate where it may or may not address students' diverse needs. This along with the idea of students' feedback seeking extends the scope for students' agentic actions significantly. That is, students

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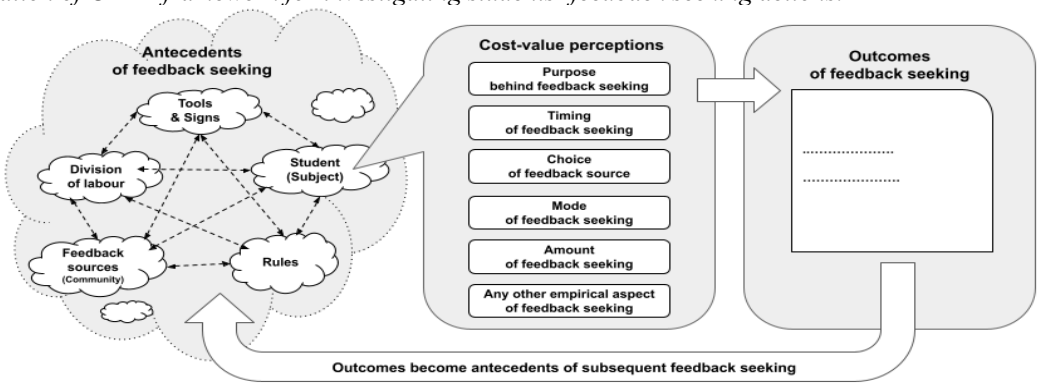
can choose to seek feedback from multiple sources and through multiple modes for accomplishing, modifying, or even avoiding the aspects of instruction. This is unlike many prevailing practices where teachers initiate and drive feedback events even when peers exchange feedback. Moreover, the focus on students' feedback seeking aligns with Nicol's (2013) emphasis on getting students ready for life beyond university (like occupational settings) where feedback seldom comes from others proactively. Instead one has to identify potential sources from multicultural communities and elicit and judge feedback from them. Also, feedback thus received can be vague, ambiguous, and even conflicting. Compare this with the formative feedback guidelines in education which require an external agent such as a teacher to continuously monitor student performance, simultaneously account for various student and task characteristics and accordingly adapt the content, mode, timing and frequency of the feedback messages to be provided (Shute, 2008). Lastly, the idea of competence acknowledges that it is not an isolated set of stable skills but one which can also become obsolete with the changes in particular activities and culture within which it is situated. Overall, the above notions might help inform sustainable alternatives to prevailing unilateral, expensive and culturally disconnected classroom practices. This in turn may help address large scale educational challenges before governments. Additionally, CHAT also provides a framework to examine students' feedback seeking and its instantiation is depicted below.

Figure 1

Instantiation of CHAT framework for investigating students' feedback seeking actions.



In the above figure, individual smaller clouds and a larger cloud stand for factors of instructional activity and culture (interdependent activity systems) respectively. A cloud indicates that each factor may embody multiple qualities and at a given moment some qualities can be at the forefront in influencing students' feedback seeking actions while others remain in the background. Above instantiation also reflects CHAT's perspective on viewing the relationship between student agency, instructional activity and culture as reciprocal. Moreover, it makes a key CHAT principle explicit i.e, the object of an instructional activity like students' feedback seeking actions carries within it the foundational contradictions i.e, use-value and exchange value of interactions between student, instructional activity and culture (Engeström, 2018). More specifically, interactions between the student, instructional activity and culture are predicted to influence students' cost-value perceptions underlying their various feedback seeking decisions. Here students' cost-value perceptions can be of biological or cultural origins with cognitive, emotional, motivational and identity dimensions. Consequently, our research question aims at uncovering such interactions "How do the factors comprising instructional activity and culture interact to influence students' cost-value perceptions underlying their various feedback seeking actions?"

Methods

To answer the research question, we gave students a representational problem pertaining to the synthesis of a medicinal drug called warfarin. The choice of the problem aligns with the idea that knowledge worth learning is continuously evolving. While there were other methods of synthesis, the particular technique underlying the chosen problem is recent, precise, cheap, fast and environment-friendly. Solving the problem required students to employ major forms of representational reasoning like analogical reasoning and/or thought experimentation in order to predict expected drug's final structure. Complexity of the problem meant that students would experience numerous challenges nudging them to go beyond just verbal exchange and use multiple modes as part of their feedback seeking. Thus the problem helped us generate rich analyzable data where we could examine how aspects of instructional activity, culture and students' feedback seeking dialogue were all shaping each other. For data collection, we invited a group of three undergraduate chemistry students. The study was conducted in a lab setting outside their classroom. The given problem was an hour-long activity designed such that students could either work individually or choose to collaborate as and when needed. This was to ensure that there was no external

compulsion to seek or provide feedback. Besides, worksheets with task details were minimal in design i.e., we intentionally did not include any prompts for self/peer assessment, hints, or questions for reflection. Data collected included video recording of the students' interactions with each other and the researcher and their task specific responses on worksheets such as sketches, highlights and comments. It also included post-activity interview responses. Researcher's presence during students' problem solving was limited and occasional. Data analysis was done using a microgenetic method. It emphasizes tracing emergence of particular student actions to momentary processes by making high density observations (Chinn & Sherin, 2014). Unit of analysis is an episode of a student's proactive feedback seeking from peers and the researcher where one episode was distinguished from another by considering the change in the purpose for which the feedback was sought. During analysis we found emotions as significant markers of students' cost-value perceptions.

Findings

Analysis of students' feedback seeking actions revealed the complex and multilateral ways in which culture, instructional activity, students' characteristics and their actions shape each other. For e.g. in one episode, the purpose behind student's feedback seeking was determined by the task specific difficulty arising out of one's self-directed dialogue while comparing representations. In addition, the timing and choice of feedback source was influenced by the emergence of feedback availability signs with the peer working nearby, one's own hesitancy in seeking feedback due to perceived embarrassment shaped by the prevailing cultural norms (i.e. shaming ignorance or incompetence) and the norms of given instructional activity (i.e. freedom to work individually or collaboratively) which further heightened such embarrassment. Then the evaluative nature of feedback seeking and that the feedback received was subjected to constant verification reflected the student's perceived credibility of the peer as a feedback source. Also throughout the episode, both the student and peer were observed to constantly regulate shifting between having dialogue with each other versus having dialogue at self level to aid their mutual sense making. Over and above, the amount of feedback seeking was influenced by the extent of specificity, clarification or elaboration that was required to meet one's unique feedback needs, cooperation needed by peer to generate feedback, communicative affordances of available representations/tools and also peer's enthusiasm derived in part due to culture where feedback provision was perceived as an opportunity for self-enhancement. Here various emotions of student and peer triggered by the interactions between factors of culture, instruction and student reflected the cost-value perceptions tied to their cognition, motivation and identity aspects. This in turn steered the overall nature of student's feedback seeking dialogue.

Similarly when multiple episodes were analyzed and compared it was observed that in some episodes the purposes for which feedback was sought was influenced largely by students' cost-value perceptions tied to their motivation while in others it was mostly their identity or cognitive aspects. Also, in some instances the purposes were triggered by the emergence of salient feedback availability signs amongst feedback sources (e.g. an utterance signaling new info) without experiencing any prior need at the moment. Further, the purposes for which students sought feedback were not always aimed at accomplishing the goals of the activity, instead some were specifically directed at modifying or even avoiding the aspects of it. These observations suggested that students were probably making changes to the factors of instructional activity in order to adjust it to their actual zone of proximal development as opposed to the instructor's estimate. This inference was further probed and confirmed using post-activity interview. For instance in student group, even though it had members who successfully completed the given tasks, one student who faced difficulties expressed later in the interview that he would have liked to have more members in the group i.e. more feedback sources possibly due to the nature of emotional, motivational and identity aspects shared with the participating members. In addition, students were also observed to prefer feedback seeking at interpersonal level i.e., from peers in some cases and tools in others because of their perceived identity costs such as embarrassment. Here the underlying cost-value analysis was also observed to occur in an hierarchical manner highlighting the historical nature of feedback seeking. For example in a particular instance, where the student anticipated a possible testing event, the opportunity to exchange feedback at interpersonal level was perceived as valuable. In the subsequent instance, when the testing event was now ruled out, anticipated costs tied to interpersonal exchange, i.e., particular reasons for which asking others would be more embarrassing became a major concern.

Overall, students' sensemaking during the instructional activity was observed to occur as a constant comparison with their previous experiences. Here previous experiences were not just limited to their prior instruction but also included those related to family, friends, industry and state. For instance, a student's feedback seeking aimed at renegotiating norms around usage of mobile devices occurred as a comparison with the way mobiles are used in the context of family and friends. It is this comparative sense-making process that gives rise to the emergence of heightened cost-value perceptions culminating in their feedback seeking actions and determining various aspects of it. Also since the triggers for students' sensemaking are both multiple internal and

external factors, the nature of students' feedback seeking is a complex and multilateral phenomena.

Then in line with the CHAT perspective, we also observed that the multilateral nature of students' feedback seeking plays a crucial role in them harnessing as well as adapting to the distributed competence of participating members. For instance, sensemaking in activities rich with multiple representations requires perceiving, analyzing and synthesizing different representational features with the target phenomena. On one such occasion, where a student's feedback seeking from the peer emerged as a result of challenges experienced at individual level, it was observed that during feedback dialogue both became aware of the differences and also errors in their individual perception of representational features. In subsequent conversational turns they together abstracted, analyzed and synthesized different features of representations iteratively, thus gaining a deeper understanding of the target phenomena. Here in essence, feedback dialogue was driven by the distributed nature of their individual attention, memory and thinking. Moreover, the role of feedback seeker and feedback provider was constantly shifting amongst participants as they progressed in the tasks. This again indicates the distributed nature of knowledge and competence amongst participants. Students were also observed to adapt to each other's representational competence by revising use of different representations to get their message across.

Discussion & Conclusion

Findings confirm CHAT's prediction that the nature of students' agentic feedback seeking would be driven by their cost-value perceptions resulting from interactions of instruction, culture and individual characteristics. Findings also suggest that feedback seeking plays an important role in students harnessing as well adapting to the knowledge and competence distributed across peers. Further students' feedback seeking actions aimed at modifying instructional activity supports CHAT's key assertion that the nature of relationship between individual's agency, immediate activity and culture is essentially reciprocal. Together these findings validate the significance of reconceptualization of key notions such as instructional activity, feedback, students' agentic feedback seeking actions and competence by accounting for contradictions across activity systems. Narrow conceptualization of these interconnected notions naturally limits the scope for students to exercise their agency. Findings also suggest that teachers can further uncover and leverage contradictions of instructional activities by viewing them as open activity systems. That is, viewing instructional activities as open to student modifications will help invite individual student's culture into the classroom. It could in turn help foster students' agency along with their self-learning capabilities, eliminate culturally obsolete skills and trigger teacher reflections. However, student modifications can be a source of both problems as well as innovation. Here collective cost-value analysis as per CHAT can be used to help resolve such issues. That is, teachers should try to uncover both the underlying cost and value perceptions that might have guided students' modifications of instructional activity. Then regarding sustainability, if student groups of different academic years worked in a single classroom on activities of varying complexity and overlapping learning goals, then their various actions might help signal and elicit each other's feedback seeking on much more diverse purposes. This hypothesis is based on finding that feedback seeking also occurs as result of emergence of salient external feedback availability signs.

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Increasing College STEM Instructors' Equity-Oriented Teaching Competencies

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Abstract: This study examines what helps university STEM instructors learn and adopt inclusive teaching practices, such as Adaptive Equity-Oriented Pedagogy (AEP). AEP has been shown to improve student achievement by over a full-letter grade. This study randomly assigned 129 student-instructors to treatment and control pedagogy courses. While the control course *taught* student-instructors *about* AEP, the treatment course *modeled* AEP explicitly by using weekly student-instructor reflection data to continuously adjust course discussion and activities. Using multilevel-regression modeling, we found the treatment significantly improved student-instructors' AEP competencies over time compared to the control (p<0.001). Compared to the control, more student-instructors in the treatment used multiple data sources to adjust teaching and address equity barriers to advance student learning. Through the novel application of mixed-methods research and validated AEP measures, this study offers insights on what values, motivations, and practices characterize those who do and do not implement AEP.

Introduction: Problem statement and research questions

Research shows that college teaching directly impacts student achievement and retention in STEM, especially for underrepresented students (URM; Sax et al., 2018). To improve STEM teaching, we studied adaptive equity-oriented pedagogy (AEP). Experimental research has found that compared to an active learning control course, instructors applying AEP increased student achievement by over a letter grade for all students (Phuong & Nguyen, 2019; Phuong et al., 2017). This study examines how pedagogy courses teaching AEP principles can support student-instructors' implementation of inclusive pedagogies. The pedagogy courses primarily serve student-instructors who teach large introductory STEM courses. For simplicity, we use the term "instructor" for graduate and undergraduate students who teach and are enrolled in the pedagogy courses. The term "facilitators" refers to the pedagogy course instructors. 129 instructors participated in a treatment or control AEP pedagogy course where they completed a teaching portfolio that included written reflections, evidence of student learning, and feedback on their teaching. The treatment course was adapted weekly based on instructors' written reflections, whereas the control was not. Using mixed-methods, multilevel modeling and AEP competency assessments, we examine whether pedagogy courses impact instructors' learning progression of AEP. We explore 2 research questions:

RQ1: Is there a greater increase in mean AEP competency scores across time in the treatment vs. control pedagogy courses, controlling for gender, URM status, years of teaching experience, years of tutoring experience, and number of students?

RQ2: How do low- and high-growth instructors on AEP competency differ with respect to their data use and responsibility for learning lenses?

AEP Pedagogy Course Design and Conceptual Framing

The AEP pedagogy courses teach instructors about the key AEP principles. AEP is a framework for adapting teaching to address equity barriers to learning based on student data (e.g., formative assessment, observations, surveys) (Phuong et al., 2017). AEP practice is characterized by instructors' use of 6 competency elements: (1) Clarify learning outcomes, equitable course policies, and prerequisites; (2) Align formative assessments and activities with outcomes; (3) Identify students' competencies, interests, & needs; (4) Understand equity barriers and contextual challenges to meeting outcomes; (5) Adapt teaching practices based on these needs and barriers; and (6) Iterate: Reflect upon pedagogy to support continuous learning, adaptation, and growth.

AEP builds on culturally responsive pedagogy (CRP) by offering a framework to adapt CRP practices: engaging learners' experiences, critical consciousness, and cultural knowledge to make curricula more relevant and effective (Hammond, 2014). We draw on AEP as a conceptual framework to understand how pedagogy course facilitators adapt their practices to address instructors' learning needs and perspectives in the treatment.

Unique element of treatment: Facilitators modeled and applied the 6 AEP elements explicitly as a tool for instructor learning by using weekly instructor reflection data to continuously adjust pedagogy course

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discussion and activities. *We hypothesize that this process would promote greater reflection in the treatment, which we expect to increase instructor learning over time in the treatment relative to the control as measured by AEPC assessments.* Applying AEP, the facilitators adjusted the treatment based on instructors' reflections of their cultural perspectives and backgrounds, which include their lived experiences, racial experiences, discourse, and STEM department culture (e.g., what is valued methodologically). Both conditions prompted instructors to reflect on how they may have experienced stereotype threat and microaggressions based on their identities.

Lenses on instructional change. We are inspired by the notion of professional vision (Sherin, 2014), which refers to developing ways of seeing phenomena that reflect growing levels of expertise. Accordingly, we identified lenses that seemed to serve as important levers for instructional change. We conjecture that the treatment's effectiveness may be related to the focus on *data* and *responsibility for learning lenses* that instructors may reveal in written reflections. These lenses allow us to understand instructors' values, beliefs, and motivations for learning inclusive practices. The *data* lens is defined as the kinds of knowledge and data that instructors value to make pedagogical decisions. The *responsibility for learning* lens refers to how the instructor views their role and the student's role in learning--e.g., whose responsibility is it if a student doesn't learn a concept? This lens accounts for the systems, structures, and/or beliefs that foreground individualistic notions of learning that have contributed to STEM students leaving the major because they felt under-supported and isolated (Seymour & Hewitt, 1997). Identifying these lenses is beneficial for advancing instructors' learning.

Methodology: Experimental Design and Mixed Methods

STEM instructors at a R-1 public university participated in semester-long AEP pedagogy courses for first-time instructors where they completed a teaching portfolio. The pedagogy courses primarily served instructors who taught computer science, data science, math, and statistics. Instructors participated in either a treatment or control pedagogy course. The treatment and control courses were co-led by the same facilitators who employed exemplary active learning activities and provided an AEP curriculum. Table 1 compares the 2 conditions.

Table 1. *Comparison of Control and Treatment Pedagogy Courses*

Pedagogy course activity	Control	Treatment
Same AEP curriculum content, reflection prompts, assignments/assessments Same planning activities: examined course syllabi, learning outcomes, student data	✓	✓
Provides dialogue and activities based on instructors' expressed interest (e.g., conversation about pedagogical challenges/ needs) for 30-40 mins each week	✓	✓
Instructors write weekly reflections on teaching	✓	✓
Instructors discuss reflections with each other	✓	✓
Using weekly instructor reflection data, pedagogy course facilitators adapt activities to instructors' learning needs, thereby modeling and applying 6 AEP elements explicitly		✓

Instructors were randomly assigned to conditions. To ensure the treatment did not impact the control, treatment data were reviewed weekly by facilitators after they taught the control. The treatment (n=65) and control (n=64) groups have similar gender and URM characteristics. The control has about 31% women and 11% URM. The treatment has approximately 28% women and 9% URM.

In both conditions, instructors completed baseline, midterm, and final AEPC assessments. Each AEPC assessment elicits evidence about teaching philosophies, written reflections on teaching and assessment practices, evidence of student learning, student gain score visualizations, media, and peer/student feedback on their teaching. The AEPC assessment contained reflection questions that asked instructors to provide evidence of demonstrating AEP competencies. The scale was 0-22 with 3 items being scored 7 points each and 1 item being 1 point. A detailed rubric (See table 3 for a summary) was applied independently by two researchers to blindly score assessments. Higher positions on the rubric imply that criteria of lower positions have been met. Based on partial credit Rasch modeling (Masters, 2010), the AEPC measure has high reliability (0.94), has strong validity based on Wilson's (2005) strands of validity framework, shows no gender or URM bias, and correlates significantly with researchers' review of teaching and pedagogical materials (Phuong et al., 2022).

Table 3. *AEPC Scoring Rubric 0-7*

Item Score	Learning Progression Level	Description
0	0	Provides an irrelevant answer, does not apply any elements
1	Low	Applies AEP element 1 and/or 2 (described above)

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		Element 1: Clarifies learning outcomes Element 2: Aligns formative assessment with learning outcomes
2	Moderate	Applies elements 1-3: Diagnoses student learning competency ***Or*** Diagnoses interest
3	Moderate	Applies elements 1-4: Diagnoses learning competency and interest ***Or*** Diagnoses learning competency and learning barriers
4	High	Applies elements 1-5: Adapts based on full diagnosis, not only based on diagnosis of learning competency
5	Very High	Applies all 6 AEP elements
6	Very High	Applies all 6 AEP elements citing instructor and student evidence
7	Very High	Applies all 6 AEP elements with supporting instructor/ student evidence and explains how their practice impacts the student ***Or*** Applies all 6 AEP elements with instructor/ student evidence and explains rationale for how practice impacts student

Analysis. For **research question 1**, we use multilevel regression modeling to examine if there is a greater increase in instructors' mean AEPC scores across time in the treatment than in the control, controlling for gender, URM status, teaching experience, tutoring experience, and number of students. We use multilevel modeling for longitudinal data with random intercepts to account for dependency in repeated AEPC measures.

We examined growth in AEPC by estimating the increase from 1) pre-intervention AEPC scores to mid-semester AEPC scores, and 2) pre-intervention to post-semester AEPC scores, and how much the growth differs between the treatment and control. Models were estimated by maximum likelihood with robust standard errors to protect against misspecifications of the model's random part and residual covariance structure.

For **research question 2**, we randomly sampled 10 high-growth and 10 low-growth instructors from the top 25% and the bottom 25% of AEPC growth from pre- to post-semester. We coded for the *data lens* and *responsibility for learning lens* that these instructors use, and were blind to the instructor's name, condition, and whether they were in the low- or high-growth group. We analyzed the presence, frequency, and contingency of codes to determine similarities and differences in what characterize instructors who implement AEP.

Findings

Table 4 presents statistics on AEPC measures between both conditions. The treatment and control conditions were comparable because they had no statistically significant differences on baseline AEPC (p>0.05). Table 4 indicates that although both conditions experienced AEPC test score increases at each time point, the treatment had greater AEPC increases, on average. The treatment outperformed the control on the post-AEPC by about 8.38 points.

Table 4. Average AEPC scores and standard deviations (SD) across time by control and treatment conditions

AEPC Assessment (0-22 scale)	**Control (n=64) Mean (SD)**	**Treatment (n=65) Mean (SD)**	***p*-value**
Pre (Time 0)	0.16 (.37)	0.12 (.33)	0.590
Mid (Time 1)	7.99 (3.20)	15.65 (1.87)	<0.001
Post (Time 2)	12.27 (3.81)	20.65 (1.61)	<0.001

Research question 1. Table 5 presents model estimates at the 5% significance level. We examine the difference in growth between the two conditions from pre to mid, and pre to post AEPC. On a scale of 0-22, the increase in mean AEPC test scores from pre- to mid-semester is estimated to be 7.69 points (95% CI [6.80, 8.57]) higher in the treatment than the control, controlling for the instructors' gender, URM status, number of students, years of teaching experience, and tutoring experience (z=17.03, p<0.001). Moreover, the increase in mean AEPC test scores from pre- to post-semester is estimated to be 8.41 points (95% CI [7.42, 9.40]) higher in the treatment than the control, controlling for variables mentioned above in the model (z=16.65, p<0.001). Overall, the treatment by time interaction is statistically significant in the model (X^2(2)=327.80, p<0.001).

Table 5. *Regression table for multilevel model with robust standard errors*

	Parameter	**Estimate**	**Standard Error**
Fixed Part	Time Point 1	7.84***	0.39
	Time Point 2	12.11***	0.46

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	Treatment Group	-0.12	0.11
	Treatment Group × Time Point 1	7.69***	0.45
	Treatment Group × Time Point 2	8.41***	0.51
	Female (male=reference group)	-0.46	0.34
	Gender non-conforming (male=reference group)	-1.89	1.24
	URM status	-0.14	0.38
	Number of students	-0.06	0.05
	Teaching experience	0.15	0.15
	Tutoring experience	-0.01	0.08
	Intercept	0.56	0.34
Random Part	Random Intercept Standard Deviation (Instructor-Level)	1.36	
	Residual Standard Deviation (Time-Point Level)	1.76	

*p<0.05, **p<0.01, ***p<0.001

Research question 2. For the bottom 25% of instructors (n=32), the average growth on the 22-point AEPC scale was about 9.22 points (*SD=1.93*) and all these instructors were from the control group. The top 25% of instructors (n=32) had a mean AEPC growth of about 21.84 points (*SD=0.37*). For the top 25% (n=32), we found that at least 31 instructors were from the treatment. 10 instructors were randomly sampled and qualitatively analyzed from the bottom and top 25%. Table 6 provides frequencies of qualitative subcodes for *responsibility for learning* and *data lenses* expressed by instructors in their reflections.

Table 6. *Frequency of selected responsibility for learning (RL) and data lens subcodes in bottom and top 25%*

Sub codes in instructors' written reflections	Bottom 25% Frequency (%)	Top 25% Frequency (%)
1. Indicates student is responsible for proactively addressing learning challenges (*RL* subcode)	10 (100%)	10 (100%)
2. Indicates instructor is responsible for proactively addressing learning challenges (*RL* subcode)	0 (0%)	10 (100%)
3. Values and cites multiple forms of data to adapt teaching (*Data* subcode)	0 (0%)	10 (100%)
4. Gives an example and rationale for how adapting teaching will improve student learning based on data (*Data* subcode)	0 (0%)	10 (100%)

Discussion and Conclusion: Why the Treatment Worked

The treatment provided a culturally responsive and adaptive learning experience that strengthened the scaffolding and accelerated the learning progression relative to the control. Prior to intervention, the facilitators identified that many instructors in the treatment defined equity as equality and placed the responsibility for learning only on the student. Thus, the treatment had conversations on interrogating long-standing beliefs and inequitable ideologies that the "good students are the ones who teach themselves". This approach expanded instructors' critical consciousness since it asked them to rethink common cultural norms, values, meritocracy, and larger systems (e.g., structural racism) that reproduce inequities, where students from underprivileged backgrounds may not have equitable access to resources and opportunities that enable them to teach themselves. Proactively sharing the learning responsibility shifts the pedagogical focus from an individualistic "pull yourself up by the bootstraps" approach to one that is more social and culturally responsive. Furthermore, this study contributes insights on how to increase instructors' adoption of inclusive practices, thereby addressing a long-standing barrier to STEM pedagogical reform. This research offers strategies to support instructors on how to reflect on and use multiple forms of data effectively-- rather than their assumptions-- to address equity barriers and increase student success.

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International Society of the Learning Sciences

Design-Based Research to Improve the Lesson Study Project for Co-evolution of Research, Development and Practices

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Abstract: In order to demonstrate that applying design-based research (DBR) methodology to improve a lesson study project provides an arena for co-evolution of implementation research, system development and everyday practices, this paper analyzed a 12-year learning sciences project in Japan. The project consisted of DBR on three levels: 1) a continuous cycle of DBR on each of the practices in the lesson study cycle, 2) DBR on the development of technologies to support the lesson studies and 3) long-term implementation research on the whole socio-technical system to bridge theory and practice. The analysis revealed that the scheme of the project shifted to support *fast but constructive lesson study* for practitioners to create design principles based on an understanding of how students learn, requiring the co-evolution above.

Introduction

The gap between theory and practice in education remains a central issue in the learning sciences. This paper demonstrates that the issue is best handled by co-evolution of implementation research, system development and everyday practices through our design-based research (DBR) of the *lesson study* approach (Lewis et al., 2006).

The shift from "theory into practice" to "theory through practice" approach (Schon, 1983) requires researchers to support teachers to create their own theory or *principled practical knowledge* (PPK: Bereiter, 2014). To increase the *practicality* of PPK, Janssen et al. (2015) proposed *fast and frugal heuristics* (cost-effective procedures for design and enactment of educational innovations), which indicates the importance of continuous cycle of creating knowledge from lesson to lesson. Lesson study is one of promising candidates of the theory-through-practice approaches, but has swung back and forth between two poles: "teacher-centric" pole (*how and what teachers should teach*) and "learner-centric" pole (*how each student learned*). There is room for improvement in the approaches of lesson study towards integrating the strengths of the both, for example, combining subject matter knowledge with insights into student learning. In addition to the issue of this *how-to-do* lesson study, a *who-is-to-be-involved* issue remains. The aforementioned integration requires contributions from the boards of education (BOE) to create a partnership among teachers and researchers in order to afford teachers with opportunities of learning subject matters across schools and reflecting on their own students within schools.

Lesson study also develops with the help of technology. For the *how-to-do* issue, technology supports a lesson study cycle of *plan-do-reflect* in a timely manner for teachers; for the *who-is-to-be-involved* issue, it helps teachers turn the cycle collaboratively by allowing them to keep a record of lesson study beyond space-time constraints. Vrikki et al. (2019) developed a system for lesson study which made time-consuming dialogue analysis feasible. More importantly, their work came from the accumulated research where they found an integration of various elements essential: support systems, models of lesson study, a teachers' learning community and teacher-researcher partnerships. Their trajectory of research was an evolutionary one in the face of a *scaling-up pressure*, through shifting from working under favorable conditions to less favorable ones.

These findings imply that we should consider long-term implementation research on the whole socio-technical system to bridge theory and practice. For the approaches of lesson study and its supporting system, we need to design, test and improve them in order for teachers to be able to learn the sciences of how students learn. In order to clarify how such *DBR of lesson study* takes place and what is needed for that especially in the face of the upscaling pressure, we conducted a collaborative lesson study project utilizing an instructional framework, the "Knowledge Constructive Jigsaw" method (hereafter KCJ; Miyake, 2013), which was undertaken over a 12-year period by the Consortium for Renovating Education of the Future (hereafter CoREF) of the University of Tokyo and its regional board of education partners from the year 2010. The project builds on the theory of *constructive interaction* (Miyake, 1986) to design 1) a continuous cycle of DBR on each of the practices in the lesson study cycle, 2) DBR on the development of tools and technologies to support the lesson studies, and 3) long-term implementation research on the whole socio-technical system of the lesson study project.

Hereafter, we explain the initial research scheme of the project from the three aspects: research, practice and technology in the Method, and analyze changes in scale, practical and technological aspects through CoREF's eleven annual reports (CoREF, 2011-2021), in which we define the appearance of new ways, formats and digital tools for lesson study as *innovations* in the Results, followed by the analysis of research change in the Discussion.

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The Initial Research Scheme as the Method

Research aspect: Theory of constructive interaction

The project builds on the theory of constructive interaction which came from detailed dialogue analyses of collaborative problem solving in cognitive science (Miyake, 1986). A series of research demonstrates that two persons, when engaged in solving a shared problem, exchange the roles of a task-doer who proposes solutions and a monitor who reflects upon such proposals. Such role exchange potentially deepens each participating individual's understanding of the problem, and eventually leads her/him to arrive at their own solution. Miyake and her colleagues brought such a mechanism into the classroom, finding that students were able to modify their experience-based, folk concepts towards more scientific ones through dialogues (Miyake, 2013). The project also uses that theory as the implementation theory, that is, the core of educational reforms at every level from the classroom level to the policymaking level, in order to "craft coherence" of learner-centered, collaborative knowledge construction among all members including the students and teachers.

Practical aspect: Knowledge Constructive Jigsaw (KCJ) and lesson study

To bring constructive interaction into school learning, the project developed an instructional framework, the KCJ (CoREF, 2011), which consists of five learning activities for students: 1) pre-writing (individual), 2) expert activity (group), 3) jigsaw activity (group), 4) cross-talk activity (class), and 5) post-writing (individual).

The KCJ motivates teachers to engage in lesson study, as they are required to design the "problem (jigsaw task)" and "learning materials (for the expert activity)" by themselves and to be proactive in discussing the content prior to the lesson. It also gives teachers a tool for reflection on learning. Since it lets students write down answers to the same question twice, the improvement between the two answers gives hints to infer what each individual learns. Students' dialogues during the expert, jigsaw and cross talk activities inform teachers what kind of interaction deepens understanding of each. Such a shared framework makes planning, observation and reflection easier before, during and after the lesson, allowing the teachers to focus on the content and learning processes.

Technological aspects

The project uses a mailing list for online discussion on the planning and reporting of KCJ lessons in each subject group across the schools and the BOEs. Recording of class and students' dialogues was recommended, but the project partners were given discretion as to what device to use for the recording (video, IC-recorder, notes etc.).

Context of the study

CoREF started a "new learning project" from fiscal year 2010 with nine municipal BOEs from six prefectures (see Table 1). Each BOE registered one or more core teachers who volunteered to propel the research. The teachers also enrolled themselves in one of the subject discussion groups on the mailing list chosen from Japanese language, social science, mathematics, science, and English. Thirteen core teachers from elementary and middle schools participated in the first on-the-job training workshop run by CoREF to experience the KCJ lesson as students and understand the background theory. The teachers designed lesson plans in the subject discussion groups via face-to-face workshops and online means. They tested the lessons in their schools and opened select practices for the purpose of lesson study. Yet, each BOE was given discretion as to how they conducted the lesson study, which was often done in a *teacher-centric way*. At the end of the fiscal year, the teachers shared their experiences in an open research meeting to extract generalizable knowledge about student learning and lesson designs. CoREF summarized the entire activities in its annual report, including a DVD of the teaching materials of the core teachers complete with teaching plans, learning materials such as worksheets, and reflection sheets to review the lessons. The research team started with three university faculty members at its core, and has still not increased.

Results

Quantitative aspects of upscaling

Table 1 shows how the project was scaled up in quantity with its key events considered to be innovations, to be analyzed from the two aspects. The number of "BOEs" doubled from 2010 to 2011, but dropped in 2012, due to a reduction in financial support from CoREF to the BOEs. After 2013, the number gradually grew again, where the BOEs shifted to work with CoREF on a more equal basis. The number of "teachers" grew more than that of the BOEs; each BOE had more participating teachers than before, indicating that upscaling had been achieved but also the existence of an issue of the peripheral participation of diverse teachers. Similarly, the number of "emails" posted to the mailing list also grew from 2012. "Open classes" indicate the number of classes which the core

Table 1
Number of participating boards of education, teachers, emails, open classes, materials, and key events by year

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
BOEs	9	19	16	17	19	21	25	26	26	26	28	29
Teachers	13	38	33	79	148	298	452	633	657	849	978	1141
Emails	n/a	589	178	213	343	485	610	618	780	686	970	828
Open classes	76		n/a	32	129	105	303	351	624	565	470	521
Materials	17	53	46	55	92	96	117	115	147	127	114	116
(Adapted)	(2)	(6)	(6)	(5)	(17)	(5)	(24)	(12)	(22)	(16)	(19)	(29)
Key events (Practice)	Teaching plan and reflection sheet (2010)		Revised reflection sheet (2012); assessment of pre- and post-lesson comprehension and dialogue (2016)					Simulation sheet (2017); hypothesis-testing lesson study (2017)			-	
Key events (Technology)	-		Conversation Analyzer (2014)					Learning Viewer (2018); Learning Note (2018, 2020)			Learning Recorder (2020)	

teachers in that year had opened up to everybody. Teaching "materials" represent the materials that the teachers selected from their classes. Both numbers kept on fluctuating, but after 2016, the number of open classes was more than 300 and that of the materials was more than 100. In all, 1,095 teaching materials were accumulated by 2021, covering all subjects across all grades from 1st to 9th, providing the next-generation participants with reference cases to kick-start their trials. The numbers in parentheses ("adapted") represent the materials that were modified from the original and adapted for newer lessons. They totaled 163, accounting for 14.9 percent of all the materials. In sum, the project was scaled up enough for the research team to challenge a wider range of conditions. Such upscaling also generated a denser network of teachers within and across the BOEs and knowledge sources such as teaching materials and emails of discussions, yielding resources to overcome the challenge.

Practical aspects

"Key events" in Table 1, with the years of their first appearance in parentheses, were grouped into four periods in order to find commonalities among the innovations. The key events (practice) indicate that CoREF's lesson study shifted first to putting more weight on evidence of actual student learning (revised reflection sheet, analysis of pre- and post-lesson comprehension), followed by analyses of the learning processes including dialogues (multilateral dialogue analysis), and finally, the pre-lesson study to turn the cycle of lesson study as the hypothesis-formation and testing cycle (simulation sheet, hypothesis-testing lesson study).

CoREF revised the reflection sheet in 2012 to explicitly ask the teacher to pick any three students, copy their *pre- and post-lesson answers*, compare them with the learning outcomes he or she had expected, and find points of improvement in the lesson. This additional format was necessary to take advantage of the assessment functions built in the KCJ procedure, as CoREF (2020) reported that over 60% of the materials of 2010 and 2011 omitted pre- and post-lesson questions in the lesson, but less than 10% of them did so from 2012 onwards. In addition to the "assessment of pre- and post-lesson comprehension" using such data, CoREF introduced the "multilateral dialogue analysis" in 2016, by which the teachers analyzed students' dialogues collaboratively from various viewpoints such as cognitive, social, motivational and instructional.

Faced with a scaling-up issue, CoREF devised the "simulation sheet", by which the teachers simulate *how students learn* and make their own hypotheses about the students' learning processes, and a "hypothesis-testing lesson study (HTLS)" that combines hypothesis formation (*how students will learn*) and testing (*how they have learned*). Specifically, HTLS lets teachers 1) engage in the simulation activity before the lesson, 2) continue to observe the same student or group together with multiple teachers during the lesson, 3) share and discuss observations after the lesson on the learning processes of target students compared with the hypothesis of the main teacher who conducted the lesson, 4) make recommendations on the lesson design, 5) listen to the self-reflection of the main teacher and 6) write down their own findings from the lesson study. A typical lesson study often skips steps 1), 3) and 6), lets participants observe freely in step 2), and places step 5) before 3), resulting in negative comments from veteran teachers to the main, often young teacher and aggressive exchanges of lesson techniques and knowledge of the subject matter, lacking any evidence of student learning.

Technological aspects

Along with the changes in the practices, the technologies shifted towards a handier and quicker way of utilizing data to turn the cycle of lesson study as well as providing greater support for the step of designing the lesson. The former shift is well represented by the development of "Conversation Analyzer (CA)", "Learning Viewer (LV)"

and "Learning Recorder (LR)" systems. LV provides the function of auto-transcribing the students' dialogues in all of the groups during the class, and CA does that of providing transcripts, which were electronically searchable using keywords. Two systems were integrated so that the teachers analyzed the transcribed dialogues multilaterally while listening to the actual student voices. Yet, it consumed too much time, and thus CoREF developed the LR, which has a 360-degree video camera to shoot students in a circle when set in the center of the group, and sends the voice data to the LV or broadcasts it live. About half an hour after the lesson, the teachers were able to use the transcription of the dialogue of at least one jigsaw group synchronized with video data.

The latter shift is well represented by the development of a "Learning Note (LN)" system, a website specifically for the project members, which collects and categorizes the emails posted on the discussion list by lesson topic, displays posts with attached files in chronological order, enables searches by keywords and recommends related topics. The system is now equipped with a database page of 1,095 teaching materials, and a topic page that discusses 1,764 lessons, from which the teachers are able to freely download files to replicate and modify a lesson and read the discussions from where the lesson developed.

Discussion

The shifts in the practical and technological aspects coincided with the upscaling and involvement of diverse teachers around 2016 and 2017, implying that, in the face of challenges, CoREF had prepared for a more teacher-centered, self-propelled form of lesson study decentering the role of the researchers. Looking back at the inception phase from 2010 to 2011 and the transition phase from 2012 to 2016, CoREF worked closely with select teachers as if handing over our version of learning sciences along with the dialogue analysis skills. Yet, a full analysis of the whole class takes time, finding no place in a regular cycle of lesson study, and analysis without hypothesis tends to end in vain. Then, we supported the lesson design step, especially on *how each student will learn*, which leads to deeper understanding of actual processes, or *how each student really learned*. These changes imply that how CoREF utilized the theory of constructive interaction changed: we first presented it through student learning processes which were taking place in the KCJ lessons, then let teachers analyze them, and finally utilized the theory to set up the learning environment for teachers by reconstructing the activities of lesson study, where the teachers solved the shared problem of designing better lessons. The researchers stayed behind the scenes, expecting the *fast but constructive interaction* to take place among the teachers. Such DBR of lesson study project accompanied co-evolution of research, development and practices, in the sense that practically, the tools and activities expanded to support a *handier and quicker* lesson study at the sacrifice of *full-fledged and neat* works of analysis, yet securing opportunities to create hypotheses prior to the lesson and to test them with observed processes of student learning; technologically, the accompanying systems came to support such a *handier and quicker* lesson study, yet taking greater advantage of collaboration among teachers and accumulation of data.

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Promoting STEM Careers: Preliminary Analysis of the Young Scholars Program

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Abstract: This paper examines the Young Scholars Program (YSP), a STEM enrichment initiative for middle and high school students in the U.S. that was funded by the National Science Foundation from 1988 to 1996. In particular, the analysis focuses on participation-level and long-term impacts of the YSP on the academic and professional trajectories of students. Guided by social cognitive career theory (SCCT), this paper applies epistemic network analysis (ENA) to examine the data collected from in-depth interviews with 8 YSP participants. It was found that YSP participation was linked to the development of motivation and self-efficacy and subsequent decisions to pursue STEM fields.

Introduction

Maintaining an adequate workforce in the science, technology, engineering and mathematics (STEM) fields has remained an issue of significant national interest in the U.S. To this end, numerous policies and programs have been implemented over the past decades to support the development of STEM-related skills among students and to encourage their pursuit of academic and career paths in STEM-related sectors. Such initiatives are diverse in format, scope and size and can range from scholarships and fellowships to school curricula and enrichment programs. This retrospective study examines the Young Scholars Program (YSP), a STEM enrichment initiative for middle and high school students in the U.S. that was funded by the National Science Foundation from 1988 to 1996. The YSP was intended to: (1) improve participants' knowledge of and exposure to STEM fields; (2) foster interest in STEM education and research; (3) increase awareness of academic for STEM careers; (4) gain familiarity with universities and research institutions; and (5) enhance confidence in making career-related decisions (National Science Foundation, 1993). This paper explores the impacts of the YSP on the academic and professional trajectories of student participants. Guided by social cognitive career theory (SCCT), this paper applies epistemic network analysis (ENA) to examine the data collected from interviews with 8 YSP participants.

Social cognitive career theory (SCCT)

Social cognitive career theory (SCCT) provides a framework for understanding the relationship and interactions among constructs that affect an individual's interests, goals and choice behavior in their own career development (Lent, Brown, & Hackett, 1994). SCCT builds on the assumptions of Bandura's (1986) social cognitive theory, which focused on the connections between variables associated with the person, their behavior and their environment (Lent, Brown, & Hackett, 2000). In addition to the personal-cognitive constructs of self-efficacy and outcome expectation, SCCT therefore incorporates personal attributes, such as predispositions and demographic information, as well as environmental factors and specific learning experiences (Lent et al., 2000). In this manner, SCCT emphasizes the role of self-efficacy and outcome expectation in mediating interest and goals, which lead to choice behavior. Also characterized within the SCCT is the notion of an iterative and dynamic feedback loop, whereby the outcomes of prior career-related action influence subsequent decisions (Lent et al., 1994). SCCT has been used to study career trajectories in STEM fields, both in analyzing academic choices of students (Wang, 2013) and career decisions-making processes. It has also been applied in examining the career paths of groups that are underrepresented in the STEM fields (Fouad & Santana, 2017).

Methods

This paper provides a preliminary examination of the impact of participation in the YSP on the academic and professional trajectories. It analyzes data collected from semi-structured interviews of 8 female YSP participants. Convenience sampling was utilized, as comprehensive lists of participant names and contact information were not retained for many of the YSP projects carried out in the 80s and 90s. As presented in Table 1, the YSP participants interviewed for this paper consist of women from diverse demographic and educational backgrounds, who are engaged in a broad range of professions.

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Table 1
YSP participants interviewed

Demographic Info				YSP Participation		Education	Profession
#	Age	Gender	Race/Ethnicity	Project Site	Year	Highest Degree (Field)	Current Position
1	42	F	Black/African American	Virginia Tech	1995	PhD (Biomedical Sciences, Biochemistry and Cancer Biology)	Research Administrator
2	45	F	White/Caucasian	N. Kentucky University	1990	MA (International Business Studies)	Commercial Banker
3	44	F	Asian	Montana State University	1990	JD (Law)	Judge
4	42	F	White/Caucasian	Buffalo State University	1995	MS (Teaching of Chemistry)	High School Science Teacher
5	46	F	Other	Clemson University	1992	BS (Electrical Engineering) Currently enrolled in MBA	Product Manager
6	38	F	Black/African American	Oregon State University	1995, 1996	MFA (Graphic Design)	Designer
7	42	F	American Indian/ Native American	Montana State University	1992	MA (Art)	University Professor (Art History)
8	40	F	White/Caucasian	Montana State University	1994	MA (Higher Education Administration)	College Administrator

Interview questions focused on the participants' experiences during the YSP, the academic and professional paths they pursued after the YSP, and their reflections on the impact of participating in the YSP. Interviews were conducted via online video conferencing software and were recorded and transcribed. The responses given by the YSP participants were then coded independently by two raters using a codebook consisting of a total of 15 codes organized around two categories: participation-level impact and long-term impact. Table 2 presents the codebook. The two coders reached agreement on the final coding of the data through a process of social moderation (Herrenkohl & Cornelius, 2013).

Table 2
Codebook of constructs included in the analysis

Category	Code	Description
Participation-level impact	Identity	Realization and/or attainment of a sense of oneself or sense of independence
	Self-efficacy	Enhanced belief and confidence in confidence in themselves, particularly in their ability to complete tasks and achieve goals
	STEM Knowledge	Acquisition of STEM-related knowledge & research and critical thinking skills
	Motivation	Development of interest in learning and finding a sense of direction
	Exposure	Experiencing new ideas or activities and a broader perspective of the world
	Interpersonal skills	Improved social and communication skills and the development of personal relationships and social networks
	Satisfaction	Sense of excitement and enjoyment
	Negative YSP experience	Difficult or challenging experiences within the program
Long-term Impact	YSP-related	Outcome associated with participation in the YSP
	External support	Support received from family/friends, teachers/mentors, school/community
	Career Opportunities	Opportunities for academic and professional development offered
	Career Challenges	Academic and professional challenges confronted
	Personal difficulties	Personal difficulties or uncertainties faced
	Towards STEM	Decision or action taken towards a STEM-related field or narrowing of focus within the STEM domain
	Away from STEM	Decision or action taken away from a STEM-related field

Next, epistemic network analysis (ENA) was used to model the connections, or co-occurrences, between the codes in the recent temporal context. ENA is a tool in quantitative ethnography that utilizes statistical and

visualization techniques to identify patterns in discourse (Shaffer, 2017). In particular, ENA models connections between codes in the data by quantifying their co-occurrences in the recent temporal context (Siebert-Evenstone et al., 2017). For this analysis, a unit of analysis (line of data) was defined as a single sentence contained within a turn of talk taken by the participant. A conversation was specified to be the set of lines that were related to the same topical question. A moving window of size 5 was used to model the co-occurrences of codes between a given line and four preceding lines in the same conversation. ENA networks were created at two levels to examine the participation-level and long-term impacts, respectively.

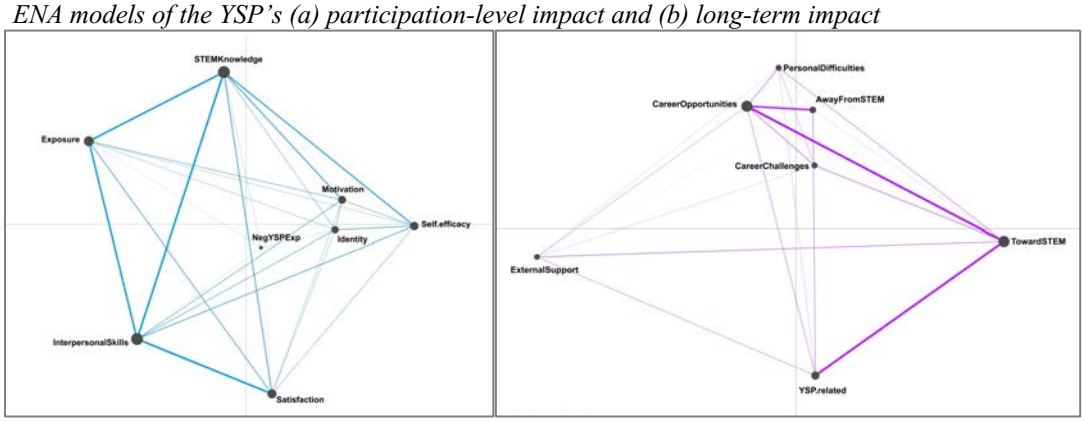
Results

Participation-level impact

The first analysis focused on the participation-level impact of the YSP. Figure 1a presents the ENA model reflecting the discourse pattern of the responses related to the YSP. Strong connections are visible among the codes of STEM KNOWLEDGE, EXPOSURE and INTERPERSONAL SKILLS. This suggests that enhancing knowledge in STEM-related subjects while having opportunities to make friends and gain new experiences was a significant feature of the YSP for the participants. As shown in the strong connections between STEM KNOWLEDGE and MOTIVATION as well as STEM KNOWLEDGE and SELF-EFFICACY, learning more about STEM topics was a key motivator for participants and allowed them to bolster their sense of confidence and achievement. The prominent association between INTERPERSONAL SKILLS and SATISFACTION indicates that social relationships contributed significantly to their overall positive experience during the program.

Figure 1

ENA models of the YSP's (a) participation-level impact and (b) long-term impact



(a) (b)

Long-term impact

In the second analysis, attention was given to the long-term influence of the YSP experience, particularly on the career-related choices made by the participants. Figure 1b displays the discourse pattern of participants' responses to questions focusing on their academic and professional pathways and the role that the YSP may have played in them. A strong relationship between TOWARD STEM and YSP RELATED can be seen, confirming that participation in the YSP had a positive impact for participants pursuing STEM fields academically or professionally. The prominent connections between CAREER OPPORTUNITIES and both TOWARD STEM and AWAY FROM STEM suggest that various opportunities that present themselves during the course of a life can be a double-edged sword for developing Stem workers. For some interviewees, educational and job opportunities allowed them to remain in a STEM-related field, while for others they led them away to other disciplines and sectors. It is interesting to note that PERSONAL DIFFICULTIES and CAREER CHALLENGES were found to have a much lower strength of connection to AWAY FROM STEM, indicating that they did not exert a high level of influence on the decisions of participants to move into other fields of study or work.

Discussion

This paper examined the participation-level and long-term impacts of the YSP on the academic and professional trajectories of young participants. Based on an ENA analysis of in-depth interviews of YSP participants, it was found that a combination of STEM learning, exposure to a diverse set of activities and connections to like-minded peers provided an experience that not only allowed them to develop interest and confidence but was also quite

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enjoyable and memorable. From an SCCT perspective, these findings point to the self-reinforcing nature of interest-driven learning processes. Given that the YSP projects were generally intended for high achieving students, it is likely that the additional learning experiences provided through the YSP often validated and expanded their interest in pursuing a particular STEM area academically or professionally. Participant #7 described this dynamic in the following way:

> And so being able to be among peers who also were academically engaged or at least engaged in learning new things, interested in learning how things work, just gaining knowledge for knowledge sake. That was the first time that that ever happened, and that gave me permission to really encourage that part of myself and not be ashamed of that and to fully embrace pushing myself to learn as much as I could and be okay with that.

The analysis of the long-term impact found that participation in the YSP was influential in some of the decisions made by interviewees toward STEM careers. However, it was also observed that educational and professional opportunities may not only help individuals to pursue STEM-related fields but also steer them away from these disciplines. An example of this was articulated by Participant #3:

> And I think…having that initial exposure to the college campus [through the YSP] made me more confident to apply for the apprenticeship program that I got into the next summer. So I felt pretty confident coming out of high school that I was going to be an engineer. And so I applied to a bunch of different schools. I thought and I was probably going to … [a] School of Mines here… and I got a scholarship and I thought that's what I was going to do. But then I got a music scholarship to [another university], and it was a better scholarship. And my mom was really concerned about debt and money, things like that. So that's the school that I ended up going to. And I started off in the honors program there, and the focus there was not so much science and math.

While SCCT stresses the role of internal factors such as self-efficacy and interest in career-related choices, this finding points to the importance of also accounting for external influences that may significantly impact the academic and professional trajectories of individuals.

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International Society of the Learning Sciences

The Multicompetent Learners

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Abstract: Engineering and science are meant to develop solutions and knowledge for a diverse population, yet Black and Brown communities often remain excluded from these intellectual enterprises. This work builds on prior literature in the learning sciences, sociolinguistics as well as science and engineering education to improve access for culturally and linguistically diverse communities. It aims at creating socially just learning spaces where individuals can bring their whole selves through introducing the notion of multicompetent learners described in terms of their language practices, cultural understandings and cognitive resources.

Introduction

American society has traditionally viewed the practices of non-dominant communities as problems to overcome (Moschkovich, 2012) and has dealt with people who have any cultural or linguistic variability by attempting to transform them into monocultural monolinguals. While there is an implicit embrace of diversity in the melting pot metaphor, in fact the expectation has been that people of color should gravitate to the culturally-dominant model (Ortega, 2020). These societal expectations are inextricably linked with notions of learning as they shape what counts as knowing and speaking, perpetuating structures of power and domination and ignoring the socio-historical contexts that created them (Ladson-Billings, 2006; Lee et al., 2020; Lee et al., 2020; Philip & Sengupta, 2021). Such an approach ignores the strengths that different populations bring to the table – especially in science and engineering (Hofstra et al., 2020; Layne & Arenberg, 2002). This paper puts forward the notion of multicompetent learners to honor and center the cognitive, linguistic and cultural practices of Black and Brown communities that too often are made invisible in the technical and scientific spheres.

Multicompetent learners

People who see the world through different cultural, cognitive and linguistic lenses are multicompetent learners. They come from diverse backgrounds, which equip them with the potential to draw on their experiences and knowledge, including the language practices, cultural understandings and cognitive resources of home and their local environments (Lee, 2003). When provided with opportunities to learn that draw on their background, these individuals are "transformative intellectuals" with multifaceted understandings of social justice issues and disciplinary knowledge with commitments and credibility in their local contexts (Morales-Doyle, 2017).

Although they have dynamic and rich strengths, multicompetent learners are often seen through a deficit perspective as lacking language and understanding of the world around them (Nasir et al., 2006). Labels like English Language Learners (ELLs) or at-risk students limit the potential of these learners by focusing on the quantification of languages and ways of knowing, taking as a standard the dominant society instead of mobilizing the intellectual resources students develop in their lived realities through which they index via language (both cognitively and culturally). But even in instances where the ways of knowing and speaking of non-dominant groups are valued, it is often with the purpose of ushering their resources into dominant, Westernized, and monolithic conceptions of human identity around language, histories, racial and ethnic groups, class and gender (Bang & Medin, 2010). From this perspective, diversity is addressed through helping multicompetent learners become more like dominant learners (Nasir et al., 2006).

In truth, multicompetent learners have many experiences developed through navigating different audiences, which requires a great deal of sophistication in tailoring speech, particularly when it comes to technical and scientific talk. Through the dynamic activity of language choice, multicompetent individuals acquire experiences working with people from a wide range of backgrounds. As compared to monolinguals and monoculturals, multicompetent learners have also lived many realities. While monolinguals in engineering may produce a single exclusionary technical-based culture, the kinds of viewpoints multicompetent learners bring to the table derive from diverse lived experiences and direct interaction with the distributed intelligence in their communities, physical and social world. The opportunities to interact with different kinds of people (e.g., engineers, parents, professors), in various cultural and linguistic settings (e.g., school, home, work) and through different discursive practices equip them with a wide range of valuable perspectives, repertoires of practices and various forms of acting and doing in the world (García & Wei, 2015; Gutiérrez & Rogoff, 2003).

Language practices

One of the means by which people draw on their strengths is through language. By looking at how language works, we can identify ways in which humans can tap the knowledge that resides in their differences from the dominant

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culture and language (Blommaert, 2013). The experiences people bring from living between languages and cultures equip them with the dexterity to navigate different contexts, such as engaging in specific ways of speaking and literacies (Gutiérrez & Rogoff, 2003). Researchers in translanguaging see language as associated with peoples' ways of "acting, being, knowing, and doing" (García & Wei, 2015). Thus, learning is enriched when it occurs within culturally and linguistically sustaining contexts that mobilize students' intellectual resources.

Translanguaging scholars have advocated for pedagogies that grant license for learners to draw on their full repertoire (García & Kano, 2014; Otheguy et al., 2015). However, the reality in learning environments is plagued with social norms that restrict students from drawing on their ways of speaking that feel authentic to them. For instance, industry settings tend to see languages other than English as unprofessional (Ruben, 2020). But linguistically-inclusive environments ensure students develop a deeper understanding and connection with ideas. In these contexts, students focus on cultivating ways of knowing instead of worrying about sounding right.

Cultural understandings

Learning is also cultural. Scholars have described cultural understandings as the plethora of practices developed through social interaction and the historicity and context of communities, which are ever-evolving for the purposes valued in these groups (Nasir et al., 2006). In thinking about the need for "dignity-conferring" interactions for belonging, Espinoza and Vossoughi (2014) invite us to think about how to open spaces for the multiplicity of voices in society to expand the discursive opportunities available to communities for the social futures they imagined to live (Costanza-Chock, 2020). For example, Lee (1995) described the role of wordplay characterized by "ironic, metaphoric, satirical, and figurative language" (p. 360) in learning as a practice from the African American community. Although African American students showed poor performance on standardized test assessments, Lee showed that the assessment instruments failed to capture the linguistic dexterity of these students and led to them not bringing the practices of their communities for learning. She argued for valuing students' cultural and linguistic multicompetences and welcoming them in the classroom as an asset for learning.

Cognitive resources

In her work with Latinx learners, Moschkovich (2012) focuses on the funds of cognitive resources that students bring to support their learning pathways. Instead of seeing their differences as deficits, she follows Vygotsky (1978) in centering the "potential for progress in what learners already know and do" (p.91). Summarizing scholarship in psycholinguistics related to mathematics, Moschkovich (2007) described bilinguals "selective attention" or the ability to focus on important information and reduce noise from non-relevant material. These multicompetent learners also have "translation skills" as they navigate the ways of speaking in their local contexts and those of the broader society (p.128). When engaging in different cognitive tasks, linguistically diverse students should be able to choose the ways of speaking that feel better to them for accomplishing the goals of the activity. The focus on students' backgrounds as a resource for learning transforms the power dynamics regarding who is heard and is allowed to contribute in the classroom (Bell, 2017).

Moving forward

Being a multicompetent learner in engineering and science today typically means having a predominantly monolingual teacher population whose cultural and linguistic backgrounds often differ from oneself. Students have teachers without the training to bridge community knowledge and practices into their pedagogies. And when students do bring the languages and experiences of their communities into making sense of scientific ideas and solving problems, they are seen as lacking objectivity and professionalism in the scientific and technical subjects, diminishing their sense of belonging. The lack of diversity in who teaches combined with assessments created without diverse populations in mind results in multicompetent learners with low academic performance scores.

Changing this dynamic and creating learning environments that see the potential in students as multicompetent learners involves considering their ways of speaking (language practices), what they know to be true in their communities (cultural understandings) and the knowledge and experiences associated with their lived realities (cognitive resources) as crucial for the world of engineering and science. A world that embraces this perspective requires seeing the communities where students come from not as discrete and essentialized groups in their language, culture and experience (e.g., Latinx people only as Spanish speakers). Instead, it involves embracing the nuances of how time and place influence their practices to incorporate who they are in the production of knowledge and problem-solving. It also dictates a teacher population that mirrors the student body, incorporates elements of students' lived realities in the education of future teachers, and investigates the role of the teacher's background and training in creating a culture of belonging in the disciplines. Educators in such a world would focus on developing conceptual understanding and practical experiences rather than grammar or

vocabulary (Warren et al., 1994) while acknowledging the multiple factors (e.g., audience, language boundaries, topics, places, social and political realities, time) that shape the opportunities available in learning environments. In short, there is no silver bullet that will address the needs of multicompetent learners to be welcomed into the science and engineering community, but there are concrete steps that can be taken to address this issue head-on.

Truly valuing these learners means creating spaces that send messages of belonging and reflect what they know to be true in their community while equipping students with the tools to navigate other realities without necessarily having as a goal to leave behind who they are. Students should be able to become proficient in the knowledge and discursive practices of the disciplines while also being able to communicate such expertise to the groups where they claim membership. They should be provided ample opportunities to make sense of scientific phenomena in their communities to understand the potential and limitations of scientific ideas in context (e.g., as shown in the scholarship of Morales-Doyle (2017) on chemistry in urban neighborhoods).

Multicompetent students should not have to pay the steep price of being seen as less knowledgeable or their contributions de-valued when using Spanish or speaking discursively. Ideas should be judged not on the sophistication of the vocabulary nor the language used to communicate them, but on students' conceptual understanding of real-world phenomena. If the goal is learning science and engineering, teachers must allow students to express their ideas in the ways that support their sense-making and honor those ways of speaking as valuable resources for communicating knowledge.

Conclusion

Up until now, much of the empirical and theoretical work on the role of language and cultural understandings has investigated the role of linguistic resources in discursive practices associated with science and engineering (Brown et al., 2005; Lee & Roth, 2002; Millar, 2006) or in social justice movements (without a focus on the disciplines) with the goal to liberate linguistically diverse learners from monoglossic expectations (Creese & Blackledge, 2015; García & Wei, 2015; Otheguy et al., 2015). Such studies have conceptualized language primarily as a medium for instruction. In contrast, this paper puts forward the idea of the multicompetent learners to shed light on how the diversity of experiences in Black and Brown communities (which are indexed through language) equip them to bring a different set of perspectives to learning. It challenges scholars to expand their understanding of bringing diverse perspectives into learning not simply as a matter of investigating the boundaries between languages but as an issue of whose linguistic practices are valued in society. As suggested by Moschkovich (2007), scholarship should focus not on comparing multicompetent learners with the dominant groups. Instead, the learning sciences should pay attention to the ways Black and Brown students make sense of, communicate and engage with different forms of knowledge within meaningful sociocultural and historical contexts.

This paper joins other calls to retire deficit-oriented perspectives toward culturally and linguistically diverse populations (González-Howard & Suárez, 2021), inviting us to embrace asset-based frameworks that see students as multicompetent learners, speakers and doers. The relevance of this work resides in understanding the nature of multicompetent individuals (Cook, 2016; Ortega, 2016) and how we could draw on the assets of these groups for equitable learning. This work advocates for expanding research endeavors that build on the creative insights diverse students bring to the scientific and engineering enterprise. Justice in science and engineering as well as in society demands we invite differences into learning environments and welcome individuals to come as their whole selves into the process of figuring out problems as well as producing, assessing, and creating new human realities (Calabrese Barton & Tan, 2020; Dym & Little, 2003; Sheppard, 2003).

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Symposia

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Frameworks and Methodologies for Epistemic Growth in K-12 Science Classrooms to Address Post-Truth Discourse

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Abstract: Epistemic practices are the goal- and norm-guided actions people use to develop knowledge within a domain, such as analyzing evidence to support scientific claims. Developing sound epistemic practices is critical considering the current rise in post-truth discourse that constrains society's abilities to make informed decisions. Learning scientists have increasingly offered frameworks and methodologies to support improved epistemic performance. However, there is a lack of consensus in the field about what epistemic practices are that students can take up, as well as strategies to best support teachers in this endeavor. This symposium brings together seven teams of researchers who have been working on developing epistemic practices in K-12 classrooms. In conversation with each other and the audience, we aim to understand how epistemic growth is conceptualized in its myriad forms across students and teachers in addition to the design characteristics and indicators of growth of learning environments that promote epistemic performance.

Keywords: epistemic practices, K-12 science education, reasoning and sensemaking, post-truth

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Symposium overview

With the recent rise in post-truth discourse, educators have been concerned with how to develop a citizenry capable of appropriately evaluating knowledge claims (Barzilai & Chinn, 2018; McIntyre, 2018). Recent publications have documented challenges in how citizens understand significant scientific issues. For example, Sloman and Fernbach (2017) discussed the tenacity of false beliefs about scientific matters, such as the causes of global warming; in one study, only 12% of respondents were even partially correct. Nichols (2017) revealed issues in the American educational system that do not enforce the habits of critical thinking to enable the evaluation of complex content to make informed decisions. Because many of the consequential issues are in the domain of science learning, such as climate change and vaccines, researchers have noted a pressing need to include a focus on epistemic practices in K-12 science classrooms (Chinn et al., 2021). Epistemic practices (EPs) are the goal- and norm-guided actions people engage in to develop knowledge within a particular domain. Some examples of EPs include constructing, critiquing, and revising models to fit patterns of evidence (Ford, 2008) and engaging in systematic research to develop patterns of evidence. Despite the growing efforts to promote epistemic education–education directed at promoting growth in students' ways of knowing–there is as yet too little clarity of what high-quality epistemic practices look like in classrooms (Rosman et al., 2016). Some research has focused on facets of reasoning practices without providing a more comprehensive picture. For example, research has focused more narrowly on reasoning strategies, such as checking the authenticity of sources or conducting controlled experiments without accounting for the aims or ideals (i.e., the standards) that are critical for establishing scientific knowledge (Chinn et al., 2020). There is a need for more systematic accounts of what high-quality epistemic practices involve. In particular, there is a need for improved theorizing as well as empirical research on the range of useful practices that students can master in classrooms.

In addition to a lack of consensus or clarity on what epistemic practices are that students can take up, we know very little about how best to support teachers in this endeavor. We know that when implemented well in classrooms, pedagogical practices that engage students in epistemic work can disrupt traditional hierarchies of power in science education (Barton & Tan, 2009; Hand, 2012). Epistemic positioning of students also propels a shift in instructional practices from those that engage students in mimicking "correct" canonical science information to adopting strategies that empower students to develop their own ideas (Haverly et al., 2020; Stroupe et al., 2018). Most schools, especially within formal environments, struggle to engage students' epistemic practices (Erikson & Lindberg, 2016). Supporting students' epistemic practices within science classrooms is a challenge for teachers because of the tensions that arise from maintaining authoritative control over the content while attempting to create authentic opportunities for students to engage with and construct knowledge that is meaningful to them (Braaten & Sheth, 2017). This kind of teaching requires tools and processes that are distinctly designed to leverage students' ideas for an active knowledge production process within classrooms while adhering to structural limitations of formal science classrooms (Brown, 2018). Hence, there is a need to investigate innovative professional development (PD) pedagogies and environments that support teachers to engage in epistemic teaching practices. We also need a concentrated effort to understand what PD supports should look like and, importantly, what PD features help to overcome the structural tensions between the epistemic instructional practices and traditional power dynamics between students and teachers.

With an international group of scholars, in this session we seek to investigate frameworks and methodologies that support students' and teachers' epistemic performance by asking the following questions: 1) How is epistemic growth conceptualized in its myriad forms across students and teachers? 2) What are the design characteristics of the processes, tools, and learning environments that promote epistemic performance in science classrooms? and 3) How are epistemic learning gains measured and what can be agreed upon as successful indicators of epistemic growth?

Structure of symposium

To demonstrate the range of applications, symposium presenters will present both theoretical and empirical research and early and late-stage work that addresses post-truth issues. The symposium will be structured to allow conversations between presenters and the audience about the collective emerging scholarly work, with the ultimate goal of mapping current and future possibilities for advancing the field of educational epistemic performance. We will begin with a 5-minute introduction from each of the 7 posters followed by 40 minutes of participant rotations to each poster. Our discussant Dr, Toshio Mochizuki will offer 10 minutes of remarks on the collective scholarship and then we will open up the discussion to both presenters and participants.

Designing for growth in apt source evaluation performance

Sarit Barzilai, Shiri Mor-Hagani, Fayez Abed, & Danna Tal-Savir

Being able to evaluate the trustworthiness of information providers is vital for navigating "post-truth" information landscapes. Current approaches to source evaluation instruction often focus on teaching students how to apply a set of heuristics or a criteria checklist. There are several limitations to such conceptions of sourcing instruction. First, instruction is often divorced from students' science learning and inquiry. Consequently, the importance of source evaluation for reaching sound conclusions can be under-appreciated (Paul et al., 2017). Second, simple sourcing rules underestimate the complexity of evaluating sources. This requires discerning and evaluating multiple epistemic criteria that students can find hard to grasp (Allchin, 2021). Third, students may have little agency to evaluate sources and determine who *they* trust. Consequently, disagreements about who to trust between students from different social and cultural backgrounds, and between students and teachers, are usually ignored. We use the Apt-AIR framework (Barzilai & Chinn, 2018) to inform our efforts to design instruction that addresses some of these challenges. The Apt-AIR framework posits that epistemic growth means increasing competence to successfully achieve epistemic aims. Further, epistemic growth involves five intertwined aspects: (1) increased practical abilities to employ reliable processes and apply appropriate ideals in order to achieve epistemic aims (2) in an adaptive manner across diverse tasks and contexts; as well as increased (3) metacognitive understanding and regulation of epistemic aims, criteria, and processes, (4) dispositions to value and pursue these, and (5) grasp of their fundamentally social nature and uses.

Through ongoing collaborations with teachers, we developed several principles for designing learning environments to support growth in apt source evaluation performance. One principle is *making sources meaningful*. This means integrating sources with diverse trustworthiness levels in engaging inquiry activities, so that students have opportunities to grapple with diverse sources [Apt-AIR aspects 1&2] and experience the risks of relying on unreliable sources [aspect 4]. A second principle is *making sources visible.* We have developed a scaffold for visualizing sources and mapping how sources relate to competing claims (Barzilai et al., 2020, 2021). We found that visualization helps support growth in practical abilities to evaluate sources [aspect 1]; and that it facilitates individual and collaborative regulation of sourcing as well as understanding of the impact of sources on knowledge construction and evaluation [aspects 3&5]. A third principle is providing *meta-epistemic discourse prompts* that encourage students to explain their source evaluations, describe their criteria, and discuss their disagreements about source trustworthiness [aspects 3&5]. Such discussions become meaningful when students have *epistemic agency to decide who to trust* [aspects 4&5]. We will illustrate the affordances and challenges of implementing these principles using examples and artifacts from inquiry units in which Israeli ninth grade students conducted investigations using diverse authentic information sources. These findings contribute to the design of learning environments that can prepare students for reasoning in a “post-truth” world.

Toward “truth”: Scientific sensemaking through epistemic and social negotiations

Emily Adah & Leema Berland

To address the call for equity, science teachers position students to collaboratively make sense of a phenomenon by using scientific practices and applying science ideas in small groups. Simultaneously, they must negotiate implicit understandings about whose scientific ideas are valued, what scientific ideas count, and how they should be communicated—they must negotiate multiple epistemological perspectives (Bang & Medin, 2006). These epistemic judgments are part of the sense they make of the scientific phenomenon under study—the “truth” they discern. Thus, students must practice addressing and evaluating implicit and embedded claims about the identities of the speaker and the audience, the students’ relationships to science and to knowledge, and bids for what language, culture, and norms belong in science discourse, all while making sense of a scientific phenomenon (Brown, 2004). In this study, we view epistemic growth as change in epistemic practices and ideas (Herrenkohl, 2006), from traditional and fixed, exclusionary understandings and ideas, to flexible and responsive to the situation (Berland & Crucet, 2015). We present our analyses of instances in which students engage in sensemaking as a complex and multi-layered negotiation where the “truth” encompasses more than resolution of scientific ideas.

As part of a larger design-based research project, we gathered data from videotaped transcriptions of 3 small groups’ interactions during an 8-week project-based unit on animal adaptations. We reviewed video and transcripts to identify moments in which students made bids to introduce different ways of engaging in the collaborative sensemaking work. We employed discourse analysis to describe the decision-making criteria being employed, how bids to change it were made and responded to, power dynamics associated with these moments, and finally, the “truth” students constructed (i.e., the sense they made). Through these analyses, we explore the growth of scientific sensemaking as epistemic and relational negotiations. For example, consider an interaction between two Latine, 4th graders making sense of a bird’s life cycle. One student began the discussion in formal English and affected posture, suggesting that science ideas should be communicated in ways that align with historical and institutional scientific norms. With unsuccessful take-up by others, the student introduced

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alternative epistemic criteria (i.e., he spoke conspiratorially in Spanish, using an informal posture suggesting that science ideas come from non-privileged sources). This stance was curtailed by the partner as non-credible. However, when the same student switched modalities and offered ideas with informal English and a gesture for center stage, the partner attended. Hence, scientific sensemaking enabled and coordinated, and was enabled and coordinated by, epistemic negotiations.

This brief interaction underscores the epistemic negotiations that determine "truth" during sensemaking. In our poster, we explore the claim that a key aspect of growth in epistemic practice in the post-truth era is this multilayered negotiation.

Tools to support thinking and regulating scientific inquiry

M. Anne Britt, Steven McGee, Randi McGee-Tekula, Kathryn Rupp, Karyn Higgs, Kathleen Easley, & Amanda M. Durik

The scientific practices students are expected to learn from inquiry units in science classes are the same ones that students need to develop to evaluate scientific claims outside the classroom. Many students, however, struggle to coordinate these skills to create a scientific argument (Osborne et al., 2004). Some challenges for middle school students are: including providing reasoning to demonstrate why the evidence supports a claim and/or why the evidence refutes an opposing claim. Previous research with middle school students has found that students place less emphasis on engaging in scientific practices, as compared to understanding specific scientific phenomena (Rupp et al., 2020). One potential support for students is to help teachers support students' reflection on and development of these scientific practices (Herrenkohl et al., 2011) to improve epistemic competence (Chinn et al., 2014). Our team approaches epistemic cognition as the development of a regulatory task model which includes understanding the goal state (purpose) of each subtask, understanding how to accomplish each subtask (subgoals, tools, and strategies), and valuing the goals of the primary task and the subgoals of each subtask (Britt et al., 2018). A discipline-appropriate task model instantiates epistemic aims and value, epistemic ideals or criteria, and epistemic processes to achieve those aims.

We will describe the development of two tools designed to help teachers guide students through a multi-session inquiry unit that required engagement in and reflection on epistemic practices within the discipline of science. The first tool, *Investigation Steps Chart***,** is a class-level regulatory structure to help students develop epistemic practice of figuring out how the unit and lesson investigation questions will be explored through scientific inquiry, what was found, and what still needs to be done to answer each of the questions. This is intended to help students develop a task model to organize multiple days of inquiry to support writing of a unit culminating with a scientific argument. The *Investigation Steps Chart* uses key NGSS storyline routines (i.e., exploration, navigation, investigation, problematization, "putting the pieces together") to guide inquiry (Reiser, 2017). The second tool, *The Evidence Sorter***,** supports student synthesizing notes taken across the multi-day inquiry to help students construct argumentation by: (a) organizing all evidence collected during the unit, (b) determining which claim is best supported, (c) engaging in reasoning to connect evidence to the chosen claim. These tools were improved upon over the course of two academic years in the context of middle-school science classes in the Chicago Public Schools. Iterations were informed systematically by: teacher feedback provided during workshops, analysis of student written work, classroom observations (pre-pandemic only), and analysis of teacher and student surveys. The key changes to the *Investigation Steps Chart* included reordering the questions so that students did not consider materials not available, improved emphasis on the student's role in scientific practices as they consider how the material that is provided will be used, encouraging separately the connections with the overall goal (unit question) and subgoals (investigation question), and including a prompt for making deliberative connections to the key concepts as a scaffold or a lens for creating reasoning statements. The key change in the *Evidence Sorter* was a revision to decrease cognitive load. Through the use of tools that bring students into the discussion about the process of scientific inquiry, students should develop appropriate epistemic cognition and practices that can be used when they encounter scientific claims.

It did not fly but it would outside: Pushback and purpose in investigation practice

Eve Manz & Chris Georgen

We conceptualize science practice, including empirical investigation, as model alignment, involving representational practice, model-based reasoning, and pushback from people, representations, and the world (Manz et al., 2020; Nersessian, 2008; 2012; Rouse, 2015). We ask how children can engage in iterative investigative work where they seek to make progress on understanding some aspect of the world by modeling it: representing it, playing the model out, making sense of the implications, and then refining their understanding and, sometimes, the investigative model itself. In doing so, we seek to shift current instructional approaches and

pedagogical strategies for classroom investigations, which rely on investigations demonstrating general principles (plants need light; water can shape earth, a magnet's force decreases with distance) and, almost invariably, lead to materials dictating investigation procedures and teachers stepping in to correct children's ways of measuring, interpreting, or making connections so that they will conclude what they need to. These approaches oversimplify scientific activity, omit opportunities for children to engage in critical evaluation of models and their relations, and introduce investigation as a school game that involves following rules, letting go of what you know of the more complex world, and trusting the teacher's authority.

We engaged in co-design and design-based research with teachers to develop, implement, collect video data on, analyze, and revise investigations into seed travel. Second grade (7 and 8 year-old) students plan, conduct, and make sense of how well particular seeds travel by water, wind, and sticking, using the wind tests as a focal case. In the first instantiation, the team focused on children's choice and agency in designing their investigations, providing an array of materials to use (paper fans, straws, an electric fan). We experienced substantial difficulty helping students reason about the results of the investigation and make connections to the form/function and ecological relationships involved in seed travel. In the redesigned investigation, students (1) examined video of seeds travel by wind, beginning to focus on particular mechanisms, (2) argued over what counted as "flying," (3) conducted a shared test and collected data, (4) rejected the test as providing useful information about the maple seed, which needs to be dropped from a high enough height that it will twirl, and (4) re-tested the maple seed by dropping it from a window.

We highlight several design features and aspects of young children's thinking across these two instantiations, using it as a case to invite discussion. First, we found that children's framing of the purpose of their investigative work including, and often laminated, frames for *representing the world, making something happen, and figuring out.* These were dynamic and context-dependent, and further were consequential for the conceptual resources that were called on and refined and children's evaluative and iterative practices. Bringing together representational and figuring-out frames appeared important for allowing children to develop and iterate tests that allowed them to make and evaluate claims about seed travel. Features of the environment that supported these framings included shared experiences with the phenomenon, support to play out and evaluate the implications of investigation choices, focusing uncertainty and discussion on choices that have conceptual import (here the height of the maple seed), and designing pushback into children's work with investigations. We will further share the assessment foci and practices we and our teacher partners are building to consider epistemic growth in children's framings and related practices for evaluating investigative choices.

Students' understanding and caring about placing trust in the time of corona

Jessica Shuk Ching Leung

In a world increasingly shaped by science, there is a pressing need for citizens to be able to make informed judgment about knowledge claims in socioscientific issues. These are ill-structured problems that are inextricably linked with science and require both scientific and ethical reasoning for decision-making. Laypeople's limited understanding of science often predisposes them to placing trust on science experts about these issues. To avoid misplacing trust, students need to learn the nature of science (NOS) – How does science work? What happens when scientists disagree? When should we be skeptical about science? (Höttecke & Allchin, 2020). This is not merely about understanding NOS. It is also about the use of such understanding (Ford, 2008). This may include: (1) identifying whether recognition from peer reviewers has been obtained; (2) examining the credentials of those who claim expertise; (3) determining the level of expert consensus; and (4) identifying possible sources of bias (Leung & Cheng, 2021). Developing students' understanding of NOS as a form of practice, rather than strictly a form of knowledge, has been shown to play a productive role in their evaluation of socioscientific issues (Leung, 2020). This practice-oriented approach to learning NOS was informed by the Apt-AIR framework of epistemic growth (Barzilai & Chinn, 2018), which conceives epistemic growth as increasing competence to successfully achieve epistemic aims. Developing such competence does not only involve the practical abilities of employing reliable epistemic processes and epistemic ideals to achieve epistemic aims, but also entails students' metacognitive understanding and regulation as well as their motivation-affective disposition to value and pursue epistemic aims.

Contextualized within the Covid-19 pandemic, this qualitative case study examines students' growth in understanding and caring about placing trust in a lesson unit guided by a practice-oriented approach to NOS. Seventy-three undergraduate students enrolled in a general education course on making sense of socioscientific issues participated in this study. Reflective journals were used to capture participants' growth in epistemic performance. Findings revealed: (1) an increased awareness on the need and reasons for laypeople to place informed trust on knowledge claims; (2) consideration of a broader range of reliable epistemic processes; (3)

increased consciousness about these epistemic processes; and (4) increased concern, inclination and self-efficacy in assigning epistemic trust. Participants expressing increased understanding about reliable epistemic processes often showed appreciation for these processes. This suggests an association between participants' understanding and caring about reliable epistemic processes, offering empirical support for the intertwining of aspects in the Apt-AIR framework.

Supporting students' development of a "grasp of modeling"

Na'ama Av-Shalom, Ravit Golan Duncan, Clark Chinn, Joshua Danish, Cindy Hmelo-Silver, Danielle Murphy, Christina Stiso, Zachary Ryan & Jinzhi Zhou

Science is a social knowledge-building process, in which scientists collaborate to construct knowledge and ratify it through a process of social critique (Ford, 2008). For example, scientists refine their ideas through a social process of receiving critique from the scientific community (e.g., through peer review or at conferences) and refining their ideas based on these critiques with the aim that the knowledge will eventually be taken up by the community. Often, these knowledge building practices are foregrounded in science instruction with little attention to social critique (Ford, 2008). But, to navigate information in an epistemically complicated post-truth world, students need to develop a robust understanding not only of how science is done, but also how these practices lead to reliable knowledge. For this, students need opportunities to engage in evaluation and critique (Ford, 2008). One context for knowledge construction and critique is modeling (NRC, 2013). An important aspect of modeling practice are the norms that scientists use as they engage in modeling--particularly reliable epistemic processes and epistemic ideals (see AIR framework: Chinn & Rinehart, 2016). Reliable epistemic processes are practices involved in doing modeling, such as defining components and processes in a mechanism. Epistemic ideals are the criteria that scientists use to evaluate models, such as "models are good when they explain a mechanism." A key ideal, fit with evidence, and the associated reliable evidentiary processes (e.g., integrating bodies of evidence; see Duncan et al., 2018) form the foundation for establishing the veracity of models in science (NRC, 2013). Extending work by Ford (2008) and Duncan et al. (2018), we suggest that a "grasp of modeling" involves understanding how models are constructed and critiqued, and how the norms guiding this process are themselves constructed and ratified through social critique processes.

In the Scaffolding Explanations and Epistemic Development for Systems (SEEDS) project, we explore how students develop such a grasp of modeling practice. We designed a fifth-grade model-based science intervention focused on constructing and critiquing models using epistemic criteria. Classes collaboratively developed and revised criteria for evaluating models. Students worked together in small groups using the computer-based Model and Evidence Mapping Environment (MEME) to construct and critique evidence-based models of a phenomenon using different kinds of evidence. In prior and ongoing analyses of written artifacts, pair interviews, and classroom videos of groups, we focused on students' use and metacognitive understanding of reliable processes and ideals for modeling. For instance, in interviews students were asked to rank the importance of each of their class criteria. In their justifications for their ranking, students were able to reason about the nature of different criteria (e.g., redundancies) and their relationships to the aims of the model (e.g., communicating ideas) (Murphy et al., 2021). Although the students did not consistently prioritize evidentiary criteria, they did offer justifications regarding the role of evidence (e.g., supporting accuracy), showing a growing metaepistemic understanding of the relationship of evidentiary norms to modeling. Our analysis indicates that supporting students in developing a sophisticated grasp of modeling—a central aspect of scientific knowledge-building—can equip them to engage with science as they encounter it in the post-truth world.

Epistemic practices that advance learning of complex scientific models

Noora F. Noushad, Amanda Cottone, Huma Hussain-Abidi, Clark Chinn & Susan A. Yoon

With the recent rise in post-truth discourse, educators have been concerned with how to develop a citizenry capable of critically evaluating knowledge claims (Barzilai & Chinn, 2018; McIntyre, 2018). Since many of the issues are consequential to the domain of science learning, such as climate change and vaccines, researchers have noted pressing needs to include a focus on epistemic practices in K12 science classrooms (Chinn et al., 2020). Our project addresses the implications for designing for post-truth reasoning by examining productive epistemic practices (the practices used to establish, critique, and use knowledge within a domain) that occur when students reason with biological models in science classrooms. With the eventual goal of using these practices when evaluating science-related real-world issues, in this poster, we articulate efforts in the first phase of the project, which was to establish a baseline understanding of what epistemic practices students already use. We were also interested in identifying those epistemic practices that are most appropriate for establishing knowledge claims with our complex systems biology curricula. To address these research goals, we use the AIR framework found

in Barzilai and Chinn (2018), who argue that the goal of epistemic education is *apt epistemic performance,* which refers to successfully achieving epistemic goals (such as accurate beliefs or a good understanding) through competence. Epistemic competence involves use of: 1) *Epistemic **A**ims and values*: the goals that people have, such as developing explanations, and the value that people place on these aims; 2) *Epistemic **I**deals*: the criteria that are used to evaluate whether the epistemic aims have been met (e.g., fit with evidence) and 3) ***R**eliable epistemic processes*: the procedures, strategies, and methods that have a high probability of achieving epistemic aims (e.g., selecting representative samples in a study).

We analyzed an archived video dataset of students interacting with the biological models from a previous research project that occurred between 2012 and 2014. The curriculum requires students to run the models, collect and analyze data, and make inferences about the scientific phenomena, e.g., how to create a sustainable ecological system. Using Interactional Analysis (Jordan & Henderson, 1995) to analyze the five videos of student pairs, we identified ten AIR codes related to our modeling curriculum. They comprised six epistemic processes and four epistemic ideals. We inferred that the observed processes were typically governed by an ideal that students were applying in the background. For example, the process, *Inferencing,* was always coded together with the ideal, *Fit with Evidence,* because all instances of making inferences involved students citing evidence from the simulation to fit their mental model. The categories of processes and ideals that emerged with the greatest frequencies were: *Run and Observe* (process), *Describe Trends* (process), and *Fit with Evidence* (ideal). However, we noted that students often drew conclusions based on insufficient evidence (such as single runs of the model rather than averaging multiple runs). Furthermore, we found that there were a number of other processes and ideals not present in student reasoning, such as *Planning an Experiment* (process), *Making Data-Informed Revisions* (process), *Check Plausibility* (process), *Making Sense* (ideal), and *Having a Mechanism* (ideal). We used these findings to modify the curriculum to develop greater epistemic performance in the subsequent summer PD workshop. We also worked with teachers to relate these EPs to issues that are current in the public domain to demonstrate adaptive epistemic practices, e.g., the complexity of global warming. We are currently collecting data to see how the modified curricula worked in classrooms. We further report on these experiences in the poster.

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International Society of the Learning Sciences

Navigating making space: Attending to multiple learning pathways in science learning

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Session Abstract: Over the past decade, science education has been pushed to an inflection point. What was once a given of scalable standards-based science education is now being reimagined as adaptable models for teaching science through collaborative student-led sensemaking. This tension of supporting individual students' ways of knowing and being in coordination with canonical STEM practices has teachers caught between a paradigmatic binary. The field of the Learning Sciences provides comprehensive knowledge about the need for opening up diverse learning pathways in the classroom, yet little is discussed about what to do once those learning pathways are made visible. In this symposium, the authors consider how teachers "make space" for student contributions in classroom-based science education, and consequently, analyze what happens after it is made.

Focus of the symposium

This symposium seeks to put in conversation learning designs that "make space" (Haverly et al., 2018); or open up opportunities for students to make visible, share, and enact their own "culturally organized learning pathways" (Nasir et al., 2020) for collaborative sensemaking in classroom-based learning. However, given the pervasive pressures teachers face to implement canonical, standards-based STEM practices (cf., Horn & Campbell, 2015),

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opportunities to encourage students to participate using their own cultural resources (Gutiérrez & Rogoff, 2003)—that open up diverse connected learning pathways—continues to be a challenge.

Significance and contribution

The works collected here highlight multimodal practices in which teachers use representations (Ainsworth et al., 2020), scaffolds (e.g., Tabak, 2004), and other mediated actions (Wertsch, 1993) to support meaningful learning experiences (Schwartz et al., 2020) wherein students' culturally relevant (Ladson-Billings, 2014) knowledge, skills, and dispositions lead collaborative sense-making about science phenomena. These acts of "making space" redistribute epistemic authority and agency (Miller et al., 2018) towards diverse ways of knowing and being in ways that move beyond the constraints and expectations of a narrow, standards-based STEM pipeline (Cannady et al., 2014). With a goal of supporting the inclusion—and the growth—of diverse ways of knowing and being in classroom sense-making, this symposium explores multiple approaches to teaching in which educators worked to bring out and validate students' ideas and prior experiences for collective problem-solving and context-relevant learning experiences. Since teachers are navigating complex interactions and relationships with students, we also consider moments where teachers' moves missed making-space opportunities as a way to implicate future professional development and science teaching; especially within pedagogical moments that present a greater potential for students to make visible, share, and enact their prior experiences. In our different analytic viewpoints, we offer examples of approaches, tools, and activities where teachers trusted students (and their families) to lead sense-making experiences. When teachers acknowledged that students offered important ideas with which to work, they challenged the singular STEM pipeline narrative and set up emergent trajectories for transforming how learners "do science."

Organization of the symposium

Following an introductory talk that frames the session, each author or authors will describe their work and explain how it expands the paradigm of *making space*. Our discussant will synthesize the works and connect these pieces to the field in a broader sense, then conclude with questions for the audience to consider. This session will use 90 minutes accordingly: (1) 7-minute introduction and framing (Chairs); (2) four 12-minute talks from author(s); (3) 15-minute synthesis of the work and connection to the field (Discussant); and (4) 20-minute conversation with the attendees based on discussant-posed questions.

Paper 1: Making space for heterogeneity in phenomenon-centered science learning

Ashlyn Pierson, Danielle Keifert, Sarah Lee, Heather Johnson, Adam Bell

In the past decade, the call to start "from [students'] curiosity about what they see around them" (NRC, 2012, p. 11) has led to the development of phenomenon-centered science curricula (e.g., Edelson et al., 2021; Krajick et al., 2011; Reiser et al., 2021) that encourage students to co-construct knowledge by asking questions about a phenomenon, then exploring a subset of questions that align with a pre-determined "storyline." Through this process, students develop shared understandings and "knowledge products" (Berland et al., 2016, p. 8). These curricula foreground an image of science-as-convergence, bringing together students' diverse ideas to create a shared explanation. While convergence represents important aspects of disciplinary science, it backgrounds other (messy, nonlinear) images of science. Moreover, it creates tensions between accountability to standards and fully empowering students to engage in "felt" inquiry—feeling puzzled and exploring questions of interest to them (Keifert & Stevens, 2019). For instance, in these convergence-seeking curricula, "it is likely that not all students' questions can be fully taken up" (Reiser et al., 2021, p. 818). In response, we ask instead: how can foregrounding an image of science-as-heterogeneity make space for students to genuinely lead inquiry?

Framework

Research provides countless examples of science as a messy, non-linear process that is shaped by human and material agency, offering an image of science-as-heterogeneity (Gooding, 2006; Latour, 1993; 1999; Pickering, 1995). Rosebery et al. (2010) argue that such heterogeneity is fundamental to K-12 science learning, showing that words like "heat" can take on multiple meanings. Building on this work, we see heterogeneity not only as a starting point for asking questions, but also as an opportunity to empower students to lead inquiry that is deeply felt (Keifert & Stevens, 2019). By valuing the multiple co-existing ideas that students see in a phenomenon, researchers and educators can attend to the generative and disciplined questions that students propose.

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Methods

We present a case (Yin, 2014) that illustrates how a third-grade teacher, Jack, used a heterogeneity-seeking approach to make space for students' questions and ideas in a phenomenon-centered unit about magnets. Data include video-recorded lesson observations and post-observation interviews (to triangulate observations with Jack's intentions and reflections). We used interaction analysis (Jordan & Henderson, 1995) to analyze how Jack made space for students' questions and ideas, and we used co-operative action (Goodwin 2018) as a lens to understand how he brought together multimodal representations and materials in service of these goals.

Findings and Implications

We describe how Jack used a heterogeneity-seeking approach to make space for students' questions and ideas. We focus on a unit anchored with a video: a reporter showed that a car parked at the bottom of "Magnetic Hill" would roll backward uphill in neutral (in fact, an optical illusion). Though the phenomenon is *not* caused by magnets, Jack explained in an interview that investigating these (false) claims could allow students to explore concepts like magnetic fields, attraction, and repulsion. Jack encouraged each student to create and test their own theory about what happened. He provided students with materials to model their theory, and he used questioning to help students refine their theories. In this way, though the unit was centered on a single phenomenon, Jack invited students to bring new phenomena to the group and relate these phenomena to ongoing inquiry (Could a strong, underground magnet from an asteroid pull the car? Could the Earth's core and magnetic field pull the car?). Rather than choosing one or two ideas for the students to investigate as a class, Jack encouraged each student to test the theory that "is most true to you." Through questioning, Jack gave voice to the material agency that pushed back on their theories—he repeatedly asked students "what do [the materials] represent?" and "how does that help you prove your theory?" For example, when a student claimed the asteroid theory worked because he could hold a magnet above a toy car to pull it up a ramp, Jack responded, "but the asteroid is under the road." Jack's case offers one example of how a heterogeneity-seeking approach can allow students to genuinely lead inquiry in their classrooms. With this case, we offer a new paradigm for phenomenon-centered instruction that foregrounds heterogeneity (and epistemic authority) rather than convergence. We propose that reframing phenomenon-centered instruction in this way is one step toward valuing and leveraging students' affective experience in science (e.g., Keifert et al., 2018; Jaber & Hammer, 2016) to support generative disciplined science learning.

Paper 2: Family Engagement and the Kindergarten Classroom

Michelle Salgado

Research has continued to call for family engagement in science education, particularly from culturally and linguistically diverse families (Barton et al., 2004; NRC, 2012; Schwartz et al., 2017). Family engagement is well supported by research which indicates the positive impact on student achievement and influence over gaps in opportunities afforded to children in school settings (Sheridan & Kim, 2015; Henderson & Mapp, 2002). Further, family engagement is not only possible but essential to young children's engagement in science and engineering disciplines (NRC, 2021). The purpose for this study will be aiming to contribute research to the field of science education as it relates to designing learning environments that support family engagement in scientific practices of observation and obtaining, evaluating and communicating information. Research Questions: 1. How do families engage in school direct scientific activities that support scientific practices? 2. What are the design elements of such activities that promote meaningful engagement by families?

Framework

In this study I attended to a situative perspective (Gresfali & Greeno, 2008) where learning occurs within the activity systems utilized by social worlds and actively provides opportunities for families to engage and participate. Authority figures in the classroom, actively problematized the assumption that participation and understanding are solely attributes of the student occurring in school (Gresfali et al., 2008) and instead, views students and families as epistemic agents capable of co-creating a collaborative classroom culture (Stroupe, 2014). Using this perspective allows for a shift in how this teacher-researcher partnership opens spaces where we consider how we view, frame, and design with children and families for disciplinary specific learning.

Methods

A collaborative design study (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) was conducted with kindergarten students over the course of four years. In this paper I present the two cases from year two and year four cohort and examine a set of family engagement activities which were selected using purposeful sampling

(Merriam, 2009; Patton 2015). This video-based research study was conducted in a title one elementary school. The school's demographic composition: 80% Free and Reduced Lunch; 23.3% Special Education; 42.4% Transitional Bilingual; 46.4% Hispanic/Latino, 19.6% Asian, 4.4% Pacific Islander, 8.2% African American, 9.8% white. The selected multilingual classrooms had 24 and 27 students respectively, with over half of the students coming from immigrant or refugee families. Families regularly brought lunch to their children and ate with them in the classroom.

Building off of previous scholarship on family engagement and scientific practices in elementary grades, I analyzed how families engaged with the activities which occurred both at the school and outside of the school in the neighborhoods. I drew out emergent codes to provide additional explanatory significance for the design elements of the family engagement activities and the responses of the families within those activities. After coding transcripts I looked for themes and patterns in the coded data that corresponded to specific designed elements present during particular activities. Particular combinations of conditions generated by the coding scheme and emergent themes led to opportunities that were more likely to result in meaningful family engagement with scientific practices.

Findings and Implications

The findings indicate the importance of design elements that promote *accessibility*, *purposeful engagements*, and *meaningful learning experiences* in which students and their families participated and provided contributions back to the classroom for disciplinary specific use. Through the analysis we learned that family engagement was an essential component to supporting diverse and robust science discussions within the classroom as well as enabling children to receive feedback and engage in scientific practices both within and outside of the classroom walls. In designing for family engagement three key findings emerged, 1) Ongoing, relevant, and bidirectional communication supports the inclusion of families into disciplinary specific content, 2) Designing for activities which extend on everyday family events such as neighborhood walks and playground visits supports accessibility and inclusion, 3) Family science symposiums were designed for communicating information, investigations, celebration, and inclusion into their child's academic endeavors. This design framework afforded students and their families the opportunities to take advantage of a series of learning engagements where they could make diverse, intellectual connections between their ideas, experiences and scientific concepts. Designing for family engagements is important to highlight as our field continues to understand how to support children more equitably from diverse communities in engaging in meaningful science learning within elementary science classrooms.

Paper 3: Opening up or closing down space for equitable sensemaking during disciplinary engagement

Soo-Yean Shim, Christina Krist

This paper explores conditions that led an experienced science teacher to make space for equitable science sensemaking. The call for shifting science education from students "knowing about" content toward students "figuring out" how/why the natural world works has emphasized the importance of providing students with opportunities to engage in epistemic practices of science and take active roles in constructing knowledge (NGSS Lead States, 2013; Schwarz et al., 2017). One of the expectations is that this can promote equitable sensemaking in science classrooms, as students can build on their own ideas, personal experiences, and diverse ways of making sense of the world in the knowledge-building processes. However, disciplinary practices in science classrooms do not guarantee equitable sensemaking opportunities for students, especially if students' everyday ideas and experiences do not obviously align with teachers' disciplinary expectations.

Framework and methods

We observed that an experienced teacher, who had passion and capacity to be responsive to students' ideas, sometimes opened up, but other times unintentionally closed down space for students' equitable sensemaking while facilitating their disciplinary engagement. We explore the conditions and contexts that led this teacher to open up space for students' ideas, experiences, and ways of thinking, especially when she tried to support students' disciplinary engagement. The teacher, Nadine, was a middle school science teacher who had 15 years of teaching experience and multiple years of experience designing and enacting NGSS-aligned curricula and instruction. Her school, located in the US Midwest, served a population of ethnically and socioeconomically diverse students. We used data from point-of-view observations (Sherin et al., 2011) with Nadine over two instructional units. Nadine wore a GoPro camera and tagged moments while teaching in which she was making a decision in the moment about whether and how to pursue student ideas. Nadine was interviewed immediately after teaching to reflect on

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those moments. We identified episodes of equitable sensemaking—where students' everyday ideas and experiences were substantively taken up as part of the classroom community's disciplinary engagement—and qualitatively identified conditions (e.g., context of the lesson, what prompted Nadine's decision-making) that led Nadine to open up or close down space for equitable sensemaking. Due to space constraints, we present one such episode.

Findings

Episode: Pressing for mechanistic reasoning.

This episode occurred during a class discussion to design an experiment to investigate what yeast (as a model single-celled organism) needs to grow and reproduce. The curriculum materials explicitly noted that students would likely already know that water and salt are not "food" (carbohydrates, proteins, or fats), based on their learning in previous years. However, when Nadine asked her students to suggest what they thought yeast would need to reproduce, many of them said water. (Later, some students also said salt, but here, we focus on the class discussion about water.) In response, Nadine said, "So you're saying water," and students immediately responded with ideas and everyday experiences: "Because we need, that's why we drink a lot of water," "People die when they don't drink water for three days," "Our body has a lot of water." Instead of correcting students by saying that water is not food, Nadine decided to approach this by pressing for students' mechanistic reasoning about the role of water. She asked students what cells and water were made of, and students said, "molecules" and "atoms." This connection appeared to prompt an "a-ha" moment for many students. It reminded one student of her experience making bread and putting yeast in water as part of this process, which she shared eagerly ("Oh, that's why you put in like, the bread, the dough stuff, when you put in water, it goes up!"). Through discussion, the class co-constructed three mechanistic arguments specific to yeast: that 1) yeast makes gas through chemical reaction when it meets water, 2) yeast absorbs water like a sponge, and 3) the bread rising is evidence of the reproduction of yeast. The first two arguments in particular were mainly led by students, as they actively built on their personal experiences (e.g., "It *[the gas]* caught up in fresh bread, then all the steam comes out."). Importantly, this conversation also led to students' request to include an experimental condition that included yeast + water alone (in addition to yeast + sugar + water and yeast + salt + water).

Two conditions that led Nadine to make space.

In this episode, Nadine decided to make space for students' mechanistic reasoning, instead of foregrounding the authority of "canonical scientific knowledge" about what counts as food. This decision was a diversion from the curriculum, and based on her interview, was prompted by two major conditions. First, Nadine saw that students were highly engaged with the idea that yeast would need water for growth and reproduction based on their personal experiences. She said: "I felt pushed to change it *[spend more time on the discussion about water]*, because of the class's needs. They *[students]* were really set on water." Second, Nadine herself was not satisfied with the declarative knowledge that "water/salt is not food," and is therefore irrelevant to cell growth, as evidenced by own scientific wonderings during the interview: "And then I was thinking, 'Ok, well, water's made of molecules. If we go down that path of molecules, yeah, water molecules.' So, I asked that, and... oh, the salt, too. That was interesting, they were like, "Yeah, we need salt." ... Do I need to worry about kids figuring out that salt is not food? No, they can easily look at the food label. ... But then, sometimes, I'm tempted in my head to think, 'Well, it must just have something to do with how our body functions. We must need it.'" Here we see Nadine recognizing that students' intuition—that water is necessary for cell growth and reproduction—was not unreasonable, despite its contradiction with the information in the curriculum materials.

Implications

We argue that this space for expansive sensemaking provided students with richer opportunities for multifaceted disciplinary engagement than had she continued to press for "correct" knowledge. At the same time, these rich opportunities rest in the familiar tension between canonical correctness and responsive teaching. These tensions can oftentimes lead teachers to position disciplinary practices as *in opposition to* students' everyday reasoning and intuition: they are used to push back upon, diminish, redirect, or oppose students' everyday ideas. Instead, we saw Nadine use students' everyday ideas as the substance upon which disciplinary practices were deployed. First, Nadine's own continued sensemaking about water during her interview suggests that she recognized how students' everyday ideas were asking for a ***more complex accounting*** of what cells need to grow, rather than a misconceived one. Second, Nadine's continual presses for mechanisms in students' reasoning reflects her recognition of the ***disciplinary legitimacy of mechanistic reasoning*** as important scientific work in and of itself. Finally, we propose

that the fact that their reasoning about water could be ***empirically tested right away*** through the class experiment attenuated any worries about students eventually figuring out the scientifically correct explanation.

Paper 4: "We need to step it up—we are basically the future": Latinx young women doing chemistry

Jasmine Nation, Hosun Kang

This study explores three Mexican American girls' experiences mediated by a 10th grade chemistry curriculum co-designed by researchers and teachers in a long-term research-practice partnership. We show how the curricula and teacher's facilitation expanded students' opportunities to contribute in collective sense-making in a classroom community. Additionally, we uncover how these students constructed stories about themselves and science based on their interactions with peers and the teacher. The research questions that guide the analysis are: 1) In what ways did the Mexican American girls draw from their everyday experiences and ideas in relation to the focal phenomenon in high school chemistry? 2) How were their everyday experiences and ideas taken up and incorporated into the classroom learning context? 3) How were these students positioned by others in the classroom, and how did they position themselves in relation to science?

Framework

We draw upon the notion of 'figured world', a socially and culturally constructed space, that outlines what it means to participate, local definitions of science, and who is considered a science person (Calabrese Barton et al., 2012; Holland et al., 1998). Our analysis is rooted in classroom social encounters since relationships with others shaped learning opportunities, experiences, and perceptions of self for the three girls: Natalie, Juliana, and Briseida. Tuning into interactions helped us consider what experiences and types of knowledge ("history-in-person") were brought to the learning context, and how discourse was shaped by many factors beyond any individual.

Methods

This study employed qualitative case study methods (Merriam, 2009) and narrative analysis (Clandinin et al., 2007), to examine: (a) class session videos, (b) student artifacts (worksheets, models, assessments), student surveys, (c) interviews with the teacher about focal students, and (d) exit interviews with students. We analyzed each class session four times, approaching the video from four lenses (figured worlds of individual, small group, whole group, and intersection of storylines). We created event logs for each class, a unit event map, and interaction logs for each case student, recording every comment or question and whether the teacher or peers ignored, rejected, teased, or validated their experiences and ways of communicating. When we traced individual discourse over time, we paid attention to the interaction between the individual and collective storyline such as when a peer built on their ideas or their discourse shifted the focus of the class discussion.

Findings and Implications

Our analysis revealed how diverse modes of participation and opportunities to leverage cultural ways of being created **porous boundaries between everyday science and chemistry class.** We documented students drawing from *connections to loved ones; previous class knowledge; personal interests; local geographical and climate knowledge;* and *core values* such as climate activism. Additionally, the diverse activities including sharing stories, drawing models, and creating a PSA facilitated self-expression through *sense of humor, imagination/creativity,* and *home languages and informal discourses.* We also found the **students' discourse was taken up and incorporated in three consequential ways:** *1) epistemological recognition 2) cumulative contribution 3) across figured worlds (classroom and beyond)*.

Recognition within the rich disciplinary context, or epistemological recognition, was key to how students' ideas were incorporated into the class storyline. Rather than a general "thanks for sharing" or "great job", experiences were validated for their connection to the science content and how they propelled their unit forward in terms of answering the overall question of "Why are wildfires worse now than 100 years ago?" Contributions also occurred across time, creating a cumulative effect. The teacher referenced students' ideas from previous classes or other small groups, making connections and building out understanding. All three girls made connections based on their "history-in-person" that were sustained across multiple classes. These relevant experiences were almost always shared in their small group first, expanded by peers' ideas, and then presented in front of the whole class, where the teacher provided public validation and connected to previous content. The explanations articulated the importance of these ideas for all students and positioned students as authentic

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contributors through altering the direction or propelling the collective storyline forward. Opportunities to move between the figured worlds of the classroom (i.e. small group to whole class) were essential to formulating and refining complex ideas, and ultimately helped the girls develop agency in science.

Despite starting with different interests in and academic records in science, they all showed meaningful engagement with science and reported the unit as their favorite. Juliana, who was a "high achiever" in conventional science classrooms and expressed confidence in her science abilities, initially appeared uncomfortable with the format of this chemistry class. She did not participate much in either small group or whole class discussions until midway through the unit. In contrast, Natalie and Briseida, who had struggled more with previous science classes, immediately shared their fire stories and models with the whole group and continued to show high involvement throughout the unit based on the opportunities to integrate everyday science. Natalie leveraged her rich experiences from out-of-school science activities and childhood fascination with weather, while Briseida built new connections and interests and a commitment to "step it up" because "we have to-we are basically the future, you know...I think it really impacts me because it has to tell us that we have to step up and make a change to make our place better."

This work provides both practical and theoretical implications on how to support diverse Latinx students in high school science, through equitable enactment of the NGSS and recommendations for educators and policymakers (Cantu, 2012). Specifically, this study expands the knowledge base of culturally relevant pedagogy by articulating two critical dimensions—consequential ways of leveraging students' everyday experiences and recognizing their epistemological contributions. We advocate for more focus on how students leverage their cultural resources and on how teachers facilitate agentic collaborative sensemaking in science.

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Cultivating Critical, Justice-Oriented Data Literacies in a Post-Truth World

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Abstract: What are pathways toward critical and just data literacies? Achieving critical and just data literacies is especially challenging in an ideologically polarizing "post-truth" world in which we confront a rising tide of misinformation and fake news, alongside discourse that denigrates politically conservative perspectives. Although reasoning with data is rooted in epistemic processes, the stances people take are—and should be—influenced by values, concerns about maintaining cultural group membership, and concerns about equity and justice.

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Through a range of approaches, contexts, and age groups, the papers seek to illuminate how to help learners become adept at employing data interpretation conventions, scrutinizing the reliability of data representations, and examining whether data representations render humans and more-than-humans visible or invisible, central, peripheral, unidimensional, or complex. Jointly, the papers examine how to cultivate publics who make use of consequential data representations to negotiate their everyday lives, and who identify and resist datafied injustice.

Keywords: data science education, data literacies, justice, epistemology, axiology, post-truth

Overview and significance

An increasing number of education scholars and practitioners are concerned with how we cope with the rising tide of misinformation (O'Connor & Weatherall, 2019) and fake news in our ideologically polarizing, "post-truth" world (e.g., Barzilai & Chinn, 2020; Kienhues et al., 2020; Lewandowsky et al., 2017; Tabak, 2020; Zummo, 2021). Efforts to address these challenges typically involve focus on epistemic issues and reasoning (Chinn et al. 2020a, 2020b; Kienhues et al., 2020; Sharon & Baram-Tsabari, 2020). Research in this vein often considers the effects of ideological group membership and identity, emphasizing the power of co-construction (Feinstein & Waddington, 2020), or the overshadowing of evidence (Jost et al., 2018). A growing body of research and development, including two sessions from ICLS 2020 that were cancelled due to the COVID-19 pandemic (Arastoopour Irgens et al., 2020; Matuk et al., 2020), focuses on the role that *critical data literacies* can play in creating not only more educated publics, but also a more just world (see also Hardy et al., 2020; Van Wart et al., 2020; Zummo et al., 2021). In this session, we propose examining *how people integrate data, and uses of data, in their reasoning about ideologically-tinged "post-truth" debates, and the stances and positions they take across the lifespan*. Although such reasoning is rooted in epistemic processes, the stances people take are—and should be—influenced by values, concerns about maintaining cultural group membership, and concerns about equity and justice (Arastoopour Irgens et al., 2020; Polman et al., 2020; Walsh & Tsurusaki, 2018).

In this session, we seek to heed the call by Lee, Wilkerson and Lanouette (2021) for a humanistic stance toward data science education. We seek to recognize that multiple ways of knowing and being should ethically be supported. This involves recognizing the problems of Western science's epistemic colonialism while also recognizing its potential; additionally, this involves seeking to avoid the traps of relativism. We therefore aim to recognize the role of power and politics, amid the severe and pressing social and ecological crises and injustices of our times, in which the histories, identities, and flourishing of certain humans and most more-than-humans (1) are marginalized, erased, and eradicated. At the same time, we recognize educational rhetoric focusing on "fake news" and misinformation often ends up denigrating politically conservative perspectives and those who hold them, creating dichotomies and increasing divisions without paving realistic ways forward. Therefore, we seek to answer the question: what are pathways toward critical and just data literacies?

All 9 posters share the grounding assumption that data representations are not simple or direct snapshots of states in the world, rather they are constituted by and they constitute ways of seeing and being in the world. This bi-directional process occurs through narrations of the data (Radinsky, 2020), an explicit or implicit theme in all of the posters. All posters also reflect a commitment to cultivating publics that feel able and entitled to engage in such interpretive processes, and that resist taking data representations at face value, investing instead in deliberative and critical processes (Tabak, 2020). Poster abstracts are listed below alphabetically by first author and referred to here by numbers in this sequence. Some of the posters, especially posters 2, 3, 5, 6, and 9 emphasize epistemic aspects: such as, what are conventions and means for reliable measurement and interpretation, how can alignment and misalignment with such conventions be discerned and assessed in consequential data representations. Some of the posters, especially posters 1, 4, 7, 8, and 9 emphasize axiomatic aspects, such as, how do data representations render humans and more-than-humans visible or invisible, central, peripheral, unidimensional, or complex; and how do representations serve or undermine justice. As a set, the posters integrate these aspects in considering what conventions should be adopted or taught, who should decide, and how can we productively balance conformity with contestation? By building on these shared assumptions and concerns but addressing a range of topics, disciplines, contexts and age groups, the session has potential to inform and appeal to a broad audience.

We propose a 90-minute structured poster session. The session will open with a brief introduction, followed by highlights of each of the posters to orient the audience to the full set. There will be two rounds of free-form time during which the audience can engage with the different posters; in each round, only half of the poster-presenters will be at their posters, to allow presenters to engage with each others' posters as well. The session will conclude with two discussants, both with extensive research experience related to the ideas in the session— one discussant, Clark Chinn, will emphasize epistemic aspects, and another discussant, Thomas Philip,

will emphasize axiomatic aspects. There will be ample opportunity for audience active participation during the free-form segments, and following the commentaries.

1. "School. School. School. Home alone." Promoting students' critical media and data literacy through critique and design of narratives about teen time use.

Anna Amato, Megan Silander, Camillia Matuk, Jill Beale, Kayla DesPortes, Marian Tes, Ralph Vacca, and Peter J. Woods

Youth are often subjects, not producers of public data, which, as a result, can misrepresent their lived experiences (e.g., Lahusen & Kiess, 2020). How can ELA-integrated approaches to data literacy engage students in (1) identifying issues of youth representation in data and (2) in thinking critically about how data are produced and used (Gebre, 2018)? We collaborated with four urban public school teachers to design and implement an 8-day interdisciplinary unit investigating time use. Grade 7 students (N~80) examined arguments from news articles, documentary photography, social media, and the American Time Use Survey, and made inferences about how the (un)availability of time use data impacts representations of youth. Students then collected and analyzed data on their own time use. Qualitative analysis of participant interviews and artifacts showed how students reasoned about data and context, such as by reflecting on the impact of socioeconomic status and location on time use, making comparisons, and asking questions ("one kid might spend their time on the phone, another harvesting crop. Is one more valuable than the other?"). Students reasoned about the value of different data types for communicating meaning ("how would this [photographic] data look different if you presented it as numbers?"). They discussed sampling decisions and representation ("If we want a true and complete representation we would need more pictures"). They designed ways to sample their time use ("We can take photos of a teenager's day every hour and it can tell us a day in the life of a teenager."), attending to who produces data ("photos that teens take themselves") and to describing data patterns ("School.School.School.Home alone"). Findings suggest that integrated ELA-math instruction can expand students' ideas about data, support their critical reflection on data, and help them to generate ideas for representing their own experiences through data.

2. High School Students' Conceptions of Climate Change and COVID-19 Data Presented in Infographics

Daniel R. Pimentel, Emily Reigh, Victor R. Lee, and Bryan A. Brown

Recent concerns about science misinformation (e.g., Barzilai & Chinn, 2020) and the increased use of data infographics in media sources (Polman & Gebre, 2015) indicate a need to understand how young people conceptualize and reason about data presented to them as evidence. Drawing upon Hammer and colleagues' (2005) notion of epistemological frames and conceptual resources, our exploratory study examined the questions: 1) What epistemological frames are involved when students are asked to interpret and critique data from infographics about socioscientific issues? and 2) What conceptual resources do students use to engage in interpretation and critiquing tasks?

We conducted and recorded a think-aloud protocol using videoconferencing software. We observed 15 high school students while they interpreted and critiqued data in four different infographics; two about climate change and two about COVID vaccines. We then engaged in knowledge analysis (diSessa, Sherin, & Levin, 2015) to identify the frames and resources that students used to make sense of the data in each of these tasks. We illustrate that during interpretation tasks, most students primarily viewed data from a *representational* frame, positioning data as fixed and context-independent. When asked to critique, students tended to use a *relational* frame, viewing data as context-dependent and constructed (Leonelli, 2015). We argue that distinct resource sets and partial overlaps in conceptual resources determine whether students see the data represented in the infographics as authoritative or subject to critique. For instance, depending on the frame, students might treat data as correct and self-evident or as subject to error and personal bias. Further research should investigate how these frames might support critical data literacy practices.

3. Establishing trust relationships as a component of critical and just data literacies

Ilana Dubovi, Josh Radinsky, and Iris Tabak

We integrate findings from two studies examining how agency in everyday data practices is evinced not only through numeracy but through interpersonal experiences (Feinstein & Waddington, 2020; Tsatsou, 2018), mediated by trust relationships. These relationships can mitigate barriers to "the emancipatory process of

understanding and critically engaging with one's context" in a datafied society (Jansen, 2021). In highlighting trust as a target for research, we respond to calls for humanistic and relational approaches to data science literacy (Lee et al., 2021; Wilkerson & Polman, 2020).

Both studies focused on COVID19 information practices. One study surveyed 500 diverse (SES, education) Israeli adults; the other interviewed 6 adults (4 Israeli) about their data practices. STEM and social sciences [STEM+] survey participants were more likely than arts and humanities [AH] to reason with data about functional questions (e.g., should schools reopen). Trust (in science) was a significant contributing factor.

Similarly, STEM+ interviewees were versed in epistemic practices for approaching data with an air of "bending the representations to their inquiry will." Despite "following the lead" of the representations, AH interviewees critiqued data and took up new practices (e.g., attending to standardized ratios stating that they did so following the guidance of a trusted person). Trust relationships forged with friends, family and media personalities, who served as brokers of data literacy practices, supported taking up practices and feeling franchised to critique.

We cannot inoculate learners against fake news, but, like other educational responses to post-truth (Feinstein & Waddington, 2020), we suggest that a pathway toward fostering critical and just data literacies lies in helping learners to identify promising knowledge brokers and establish trust relationships.

4. Critical Data Practices within Community Infrastructuring for Survivance and Justice in the COVID-19 Multi-Pandemic

Day Greenberg, Angela Calabrese Barton, and Leslie Herrenkohl

In long-term research-practice partnerships, we investigated: How did youth engage in critical data practices (CDPs) in their out-of-school learning and action-taking related to COVID-19 and its intersections with in/justice?

We combine frameworks of critical data literacies and data justice to explore powered interactions among people and social structures that take shape through data. Data and data practices are never neutral nor independent of human thought systems. CDPs refer to data production, analysis, and sharing (Noble, 2018) to encounter/counter powered interactions and structures of harm (Philip et al., 2016) towards affecting lives, social relations and possibilities.

Using historicized and future-oriented participatory methodologies, we engaged in remote long-form dialogic interviews and experience sampling methods with 23 youth growing up in minoritized communities at three timepoints focused on: COVID-19 information accessed/applied towards decision-making; how efforts were situated within personal/community COVID-19 experiences/networks. We engaged in co-analysis with youth through practices of critical witnessing and being with, and oriented towards conscientization and social transformation of systemic inequities (Villenas, 2019).

We found that youths' CDPs involved efforts to recognize/leverage their intellectual power to engage, within community structures of support co-created in response to urgent shared need, including text and snapchat informational groups, grocery-redistribution networks, and extended family protection strategy sessions. These structures clustered and shifted dynamically in relation to data on the science of COVID-19 and health risks, safety, and social/emotional wellness. Youth also enacted alternative infrastructures for counter data production/aggregation towards community justice, amplifying community wisdom, and necessitating a reimagining of data sets and narratives as sites of struggle over what/who counts in COVID-19 data narratives. Youth navigated contentious spaces as data from different epistemological, social and political origins collided, necessitating new data engagement forms to navigate/transform spaces towards community survivance.

5. Data literacy and social design implications of algorithmic, socio-technical solutions to combating misinformation on social media

Eleni A. Kyza and Christiana Varda

In today's algorithmic-driven world, critical thinking is important for the evaluation of information on social media, where unvetted news abounds and potential misinformation lurks. Therefore, it is important to broaden our realm of inquiry to citizens and older adults and examine data citizenship perceptions and how artificial intelligence is being perceived and used (Hermes, 2006).

We conducted a quasi-experimental study with 80 adult participants to examine whether a socio-technical system — the Co-Inform co-created software browser plugin — supported misinformative-resilient actions, such as avoiding sharing or liking misinformation. We examined how participants reasoned about the big-data-driven interface, and the implications for the design of interventions to support evaluations of online information. We collected data on participants' actions and reflections when faced with misinformation on Twitter.

Analyses examined differences between the control and experimental groups (with/without the plugin) in terms of the participants' misinformation-resilient actions, as well as what prompted trust or distrust in the plugin.

Findings indicate that the experimental group (n=40) engaged in statistically fewer "likes" on misinformation; participants who trusted the software plugin were also less likely to share misinformation. Qualitative data analyses indicated that participants were critical towards the plugin, inquiring about dimensions of trustworthiness, such as transparency and explainability. Findings also point to insufficient understanding of the contemporary online mediascape, with participants overestimating their own abilities to evaluate the credibility of posts. These findings point to epistemic challenges relating to one's understanding of the digital world which should be addressed at multiple levels, and highlight the need for social design for addressing misinformation on social media (Pennycook & Rand, 2021). Such inquiries have implications for the design of sociotechnical systems and for school-based data literacy efforts.

6. Youth and the United Nations Sustainable Development Goals: Can Data Make the Global-Local Connection?

Andee Rubin

The seventeen UN Sustainable Development Goals (SDGs) (United Nations, 2021) are inspiring and far-reaching ambitions for a better world; they include no poverty, zero hunger, good health and well-being, and quality education. Youth (and adults) may feel these international goals are at a level they can't affect, yet middle school students often care deeply about such social issues. Perhaps data about how the countries of the world rate on SDGs can serve as a jumping-off point for youth to delve more deeply into local data around similar measures.

We document the design of NetApp Data Explorers, an out-of-school program whose goal is to support participants to move from a focus on international data on health and education to county-level data to more local and personal data and concerns. We describe both the particular design elements of the program whose purpose was to scaffold this journey and how participants navigated this narrowing and deepening of context. We focus on the influence of students' personal knowledge and experience in their interpretation the data and on the choices they made in "digging deeper" (Rubin, 2020, 2021; Lee & Wilkerson, 2018; Polman & Wilkerson, 2020). We also discuss data reasoning challenges that arose, including understanding how variability may be hidden when a rate is calculated for an entire country (e.g., in data such as "number of doctors per 100,000 people in a country") and untangling correlation and causation.

7. Developing Critical, Contextualized Data Agency through Educational Data Journalism

Stephen Sommer, Cynthia Graville, Joseph L. Polman, Andee Rubin, and Trang C. Tran

During a multi-year research partnership to cultivate data literacy amongst young people our team observed that in the course of doing journalistic work, many youth began to develop a critical consciousness about media, information, and data. Here we develop the concept of critical, contextualized data agency as a promising framework for an equity oriented approach to data education.

The concept of critical, contextualized data agency draws on a broad literature in the learning sciences related to individual and shared epistemic agency (Zimmerman & Weible, 2018) or learning agency (Barton & Tan, 2010; Damşa, et al., 2010). We build upon research related to learners' understanding and use of data actively contextualized and situated in their lives (Gebre & Polman, 2020; Lee & Wilkerson, 2018; Rubin, 2020; Wilkerson & Polman, 2020). We further add to these existing theoretical considerations an attention and emphasis on equity, social justice and critical or feminist data literacies (Arastoopour Irgens et al., 2020; D'Ignazio & Klein, 2020; Tygel & Kirsch, 2016)

We examine the development and manifestation of critical, contextualized data agency through two case studies. In a high school physical science class a student demonstrated a desire to communicate well-justified and actionable concerns to the public regarding growth hormones in livestock. In an after school program case, we document how another student took a global equity stance to argue for an expansive view of happiness beyond economics, and used data acumen to enhance and defend her arguments. Across these cases, we see the importance of cultivating agency to "speak truth to power," and how youth actively used data in contexts that emerged from their lives and contributed to imagining more just futures.

8. Forging Pathways from Computational Complex Systems Models to Current Socioscientific Issues Through Scientific Epistemic Practices

Susan Yoon, Clark Chinn, Amanda Cottone, Thomas Richman, Noora Noushad, and Huma Hussain-Abidi

The DeTECT project examines scientific epistemic practices of data use through computational complex systems models with a focus on transfer of those practices to evaluate controversial socioscientific issues. We are interested in the extent to which teachers and students are able to demonstrate adaptive epistemic practices (Chinn et al., 2020b). These include the ability to determine the veracity of claims based on fit with evidence and deciding which kinds of data are needed to construct accurate decisions in situated contexts. Scholars suggest that an education in epistemic practices requires expanded notions of disciplinary work (Brown, 2017) and highlight challenges in engaging teacher beliefs, improving skills and confidence in content enactments, and implementing pedagogies that afford student epistemic engagement (Buehl & Fives, 2016; Haverly et al., 2020).

We report on teachers' beliefs, enactments, and confidence levels with respect to teaching with curricula to improve student epistemic performance. Students worked with a computational model of gene regulation and examined variables (e.g., feedback loops) and data patterns that enable genes to be turned on and off due to environmental conditions. Students then applied this epistemic framing to current issues such as: data and research on CRISPR gene editing technologies and population disparities exacerbated by unequal access to them; or the intensification of climate change resulting from positive feedback loops and the disproportional impact on vulnerable groups. Preliminary results indicate that teachers hold strong beliefs about the importance of improving students' epistemic practices of data use and making broader connections to socioscientific issues. However, teachers also demonstrated challenges in translating those beliefs into practice, which are discussed in more detail in the presentation.

9. Storytelling with Data: A Syncretic Approach that Brings Together Social Justice with Middle School Science

Xinyu Wei, Cherise McBride, Michael Bakal, Collette Roberto, Emily Reigh, Puneet Bhargava, and Michelle Wilkerson

The Writing Data Stories project engages youth in learning activities that integrate computational data analysis and visualizations with personal testimony, interviews, and journalistic media stories. By facilitating middle school students to think more critically about social justice, the project encourages them to draw on evidence from their lived experience as a *syncretic approach* (Gutiérrez, 2008) whereby dataset exploration is deepened and contextualized through integration with personalized, multimodal "data stories" (Wilkerson et al., 2021).

We present evidence from a summer science camp on the U.S. west coast where grade 7-9 students explored the racially disproportionate impacts of COVID-19 and other health hazards. Reflecting on extended definitions of environmental racism (Holifield, 2001), students generated hypotheses through case studies, news stories, interviews with family members, and then explored publicly available datasets on the Common Online Data Analysis Platform (CODAP), a computational tool that helped them structure, calculate, filter, and transform data for scientific inquiry and argument (Erickson et al., 2019).

Through qualitative inquiry analysis, we found that students constructed oral and written presentations that contextualized data to highlight intersections of race, geography, health, and environment (Gutiérrez & Jurow, 2016). For example, several students reported the relationship between pollution burden and poverty level in the San Francisco Bay Area; others started advocating for social change after identifying particular communities most vulnerable to asthma. These findings illustrate emerging characteristics of sociocritical data literacy and center lived experience as valued sources of truth and axes for change. We propose that students' syncretic literacies enable them to publicly take a stance on urgent social issues by defining and debating environmental racism in and out of their science classrooms.

Endnotes

(1) "More-than-human" is used among others by indigenous communities and scholars to refer to other species and beings in nature with whom humans should be seen as having kinship relations (e.g., Kimmerer, 2013)

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International Society of the Learning Sciences

Storytelling and Storylistening Towards Collective Learning and Relational Becoming

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Abstract: Black, Brown, and Indigenous communities have long drawn upon storywork - the interrelated processes of storytelling and storylistening - as central strategies of wellness and thriving despite histories of dispossession and domination. This collection of papers theorizes with storywork and provides five contexts of storywork-in-praxis, where acts of creating, telling, and listening to stories feature centrally in critically re-designing spaces towards Black life, Indigenous futures, and the mutual flourishing of communities and lands. Through a syncretic approach, we bring together learning sciences research and perspectives from Black and Indigenous studies to further theorize the role that storywork plays within (1) sense-making activities, (2) the lives of communities that we have been a part of, and (3) our own lives as researchers-storylisteners. We consider the multiple roles of stories in research and design, the political/ethical nature of stories, and how storywork can re-organize power relations in ways that support individual and collective life.

Keywords: storywork, becoming collectives, Black and Indigenous studies, nature-culture relations, politics and ethics of learning

Focus of symposium

Throughout human history stories have been an organizing technology in intergenerational strategies of resurgence and coming to know who we are and who we could become together across difference. Building with these histories, this symposium is grounded in the experiences, epistemologies, and story-theories of Black, Brown and Indigenous communities and collectives. We choose to center our symposium on the interrelated processes of storytelling and storylistening, or what Jo-Ann Archibald (2008) has called *storywork*. Reaffirming that stories are central to human learning and becoming (Marin et al., 2020; Brayboy, 2005), we extend lines of thought and forms of inquiry to more robustly understand the forms, places, and processes of storying and restor(y)ing our relationships to each other and who we seek to become as educators, teachers, researchers, relatives, and human people within this vast web of life.

Which stories are told, by whom, and how we listen to stories matters and has consequences for how people experience the ethical, powered, and political dimensions of learning. In many schooling contexts, claims of objectivity permeate and control the permissible bounds of sense-making within disciplines, shaping what counts as science or knowing more broadly (e.g. Bang., et al, 2012; Lee, 2001). The act of living and listening with stories can help with navigating the epistemological and axiological tensions that arise from engaging with settled expectations based in whiteness (Bang et al., 2012). Stories resonate realities and importantly ground-truth and make place for our felt theories (Million, 2008). In this way, stories and storytelling are methods for refusing ongoing ontological erasure and epistemic violence (Marker, 2006). They also provide a representational infrastructure (or conditions, Hall & Jurow, 2015) for continually enacting intergenerational healing, community wellness, and regeneration.

The papers within this symposium hold a broad definition of stories, including songs, *platicas*, *dichos*, proverbs, and other artistic traditions held by humans and more-than-humans. These story-forms engage the

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multiple senses and ways humans come to know the world, our relations, and the peaceful social order, or what is known as *omenàlà* in Igbo society (Penfield & Duru, 1988; Kopano, 2002). As a collective, we theorize with storywork and riff on the personal, collective, ethical, and political possibilities that emerge from participating in storytelling and storylistening. Together, we pay attention to how stories might sensitize us to each other, the relations of others, and provide forms to bear witness to trauma. We also foreground efforts to reclaim stories that have often been stolen from many of our communities and repackaged towards settler aims through hungry listening (Robinson, 2020).

As researchers of human learning and becoming, we are particularly interested in how stories may surface in the (re)membering of felt experiences in our own lives within intergenerational and inter-ontological (e.g. across humans, waters, plants, animals, and other more-than-human beings) thought and ongoing activity. Through this dialogue, we are interested in how the interrelated processes of storytelling and storylistening connect our whole beings to other kin-relations - human, plants, animal, spirits, and ancestors across multiple timescales where the act of listening is also an act of creation, health, and healing. Malian writer Hampaté Bâ (1981) suggests that the health of a community's social relations depends on how well their stories circulate and continue. Given these responsibilities and possibilities, we continue to ask:

- How does storywork ethically guide our processes of knowledge production (as teachers/learners/ researchers)?
- What does storylistening, an under-theorized dimension in the field of learning sciences, teach us about the design of learning environments in which relational knowledge can emerge?
- How are stories learned, taken up, circulated, listened with, and brought forward across human and more-than-human interlocutors in learning environments - and towards what ends?
- What methodological approaches might help us to better understand storywork across human and more-than-human interlocutors?
- What kinds of visions of wellness, joint orientations and collective pursuits are possible with stories?

Relevance and Contribution

The collection of papers within this symposium speaks to the multiplicity of ways that humans make meaning, dream with, and become story-ready with each other and the rest of the living world. This session holds two main threads, theorizing with stories-as-theories and stories-in-praxis. First, we theorize with stories and becoming story-ready as humans. Being story-ready refers to the ways we humans prepare our hearts and spirits to learn and listen with stories and find meaning from that story within our own lives (Archibald, 2008). It signals an openness and vulnerability to allow another being's stories to guide what we ought to do or how we should act. For us, being story-ready is core to supporting relational becoming - the attuning of ourselves to the rhythm and resonance of others and their relations (Meixi, in press; Nzinga, in press). Second, we turn to design and practice-based implications for the building and sustaining of relational or subject-subject focused designs within and across learning environments (e.g. Bang and Vossoughi, 2016; Booker, 2016; 2019; Marin & Bang, 2015).

Across the papers, we make visible the work of stories within five distinct contexts: as professional and emerging artists that became community during the pandemic; as scholars and community members who recognize the capacity of Indigenous intellectual traditions to shape and expand possible futures, particularly during widespread crisis; as mothers and community members on traditional lands and waters, within e-textiles quiltmaking and the strengthening of Black futures; and as educators committed to offering more liberatory mathematical possibilities for children in elementary classrooms, imagining possible selves among elementary mathematics educators through collective storying. Each of the papers comes from within particular contexts of power and historicity at multiple scales - histories of settler colonialism, systemic anti-Blackness, public schooling and institutionalized norms, and narrow notions of mathematics and science. As a field, we need more scholarship on the roles of storywork in critically re-designing spaces of disequilibrium, negation, and harm for Black and Indigenous young people to ones that further our relational responsibilities to each other and a more just and thriving living for all people and lands. We suggest that centering one of human's oldest technologies - our stories as felt theories - (Brayboy, 2005; Million, 2008) can facilitate the conditions necessary for collaboration and educational innovation. This symposium offers a deep dive into stories, with theoretical, methodological, analytical and practice-based implications for our designs and our relational becoming.

Organization of symposium

This symposium will consist of five featured papers and two discussants. We intend to begin with inviting the audience to consider their own forms of storywork, axiologies, and relational becoming. We will then present each paper as a story, with time at the end of the session for a dialogue and discussion among our two discussants.

Paper 1: Wellness Belongs to Us: Reimagining intergenerational knowledge and embodied wisdom through Hip-Hop arts storytelling

Kalonji Nzinga and Marlene Palomar

Researchers in the learning sciences have noted ways in which storytelling and storylistening in communities of color provide ways for youth to build counternarratives to resist mainstream narratives (Delgado, 1989; Solórzano & Yosso 2002). One such mainstream narrative is that wellness practices are lacking within marginalized communities. The current design-based research study was constructed to analyze how a storytelling intervention introducing the essential elements of hip-hop arts (Knowledge, Djing, Breakdancing, Graffiti, Emceeing) could provide space for adolescents to redefine wellness and articulate healing practices endogenous to their own communities. We were rooted in the following questions: (1) how do youth redefine wellness through art and through their senses, and (2) where do narratives live and how do they circulate through the learning environment and in their communities.

Our intervention centered youth from Latinx, African-American, AAPI, and Indigenous communities with deep histories in the Greater Denver area who are vulnerable to cultural displacement and gentrification. The communities we worked with are both underserved by mainstream mental health care institutions and have seen their cultural practices historically marginalized. The intervention took place within a hybrid (remote/in-person) Ethnic Studies classroom at North High School in the midst of global pandemic. A design team consisting of artists, activists, scholars, students, teachers, and emcees engaged in the creation of a hip-hop based education learning environment that nurtured the exploration of wellness and resistance storytelling in digital form. Storytelling and storylistening was conceived of as reactivating knowledge systems that have been rendered useless by colonial and neoliberal conditions (Abebe, 2021). Our online learning environment weaved narrative, song, art, and intergenerational knowledge as a form of cultural preservation through the circulation of stories (Lambert, 2010; Iseke & Moore, 2011; Cunsolo Willox et al., 2013; Kitchenham, 2013) engaging multiple generations in meaningful engagement with storytelling/storylistening (Hausknecht et al., 2021).

We take a case study approach, focusing on 8 learners and their stories (6 youth and 2 instructors). Using multimodal discourse analysis we analyze a single artistic story produced by these 8 individuals (song, visual art, playlist, interactive website) as well as an artist statement that they produced. Using open and closed coding techniques a team of artist-researchers investigated the ways in which each of these community members defined wellness, incorporated their senses, and also how their stories reflected relationships to community members.

Our analysis produced various conclusions about the process by which stories circulated in the learning environment. First, the vulnerable artistic process that the instructors went through (both while designing the curriculum and while presenting it to learners) modeled techniques of healing expression for the youth. There was evidence of storylistening by the youth, elements of the instructors wellness and artistic forms of expression were seen weaved through the artistic element and statement. In their art youth also reconceptualized wellness as something that was already a part of who they were, and their commitment to transformational resistance in the context of their self, community, diaspora. Youth often reimagined everyday cultural practices that they were already engaged in as worthy, valuable, and connected to wellness.

Paper 2: Stories of (Re)creation and (Re)emergence: Engaging land-based approaches to education and wellbeing

Emma Elliott, Sabrina Elliott, Meixi, and Alayna Eagle Shield

Human survival is predicated upon ethical and sustainable relationships with the land and all living beings. The ethical foundations of our intellectual traditions are best understood as a reflection of our deep sense of interconnectedness, characterized by relational reciprocities, both of which informs how we make sense and move about in the world. These axiological commitments shape our identities, our reciprocal relations with plant and animal nations, and natural world relations, as well as our education, health, and political systems. By drawing on Indigenous stories as the crux of theory development and knowledge co-creation, as well as Indigenous concepts

of relationality, this study identifies social and psychological dimensions of wellbeing from a Cowichan perspective.

This study drew on principles of community-based design research (Bang, et al, 2015), and was a part of a larger study that took place within the context of Cowichan Tribes on Vancouver Island, British Columbia. To consider how Indigenous intellectual traditions and related ethical commitments can help illuminate strategies that facilitate overall wellbeing (e.g., education and health) of all peoples, this study engaged the power of Indigenous creation and land-based stories. With the expertise of a community-based research assistant and a graduate student researcher, we conducted 25 land-based interviews with elders and other cultural knowledge keepers. At each site, the researcher engaged each participant in Coast Salish storytelling and storylistening (Archibald, 2008) to document the stories that emerged from each place, and recorded each interview using GoPro cameras to capture land-based methodologies including "walking, reading, and storying the land" (Marin & Bang, 2018). Four researchers, including the community-based research assistant, analyzed each interview using a constant comparative process consistent with grounded theory methodology (Glaser & Strauss, 2017) to identify local social and psychological dimensions of health and wellbeing.

By engaging land-based and Indigenous approaches to research, we found that embedded within local, land-based stories are the frameworks to teach science, technology, engineering, math, medicine, and environmental sustainability, as well as culture, language, and arts. The stories gathered in this study provided considerations about context and conditions, collective and intergenerational contributions, cross-cultural relations, and directions forward toward a just and sustainable future for all. In particular, our study documented stories, both historical and contemporary, that provided Cowichan people with 1) connections to their land and territory, as well as to animal and plant nations; 2) land-based and Indigenous teaching and learning strategies, 3) a deep commitment to Indigenous relationality; and 4) theories and practices that included sustainable frameworks to teach all learners what it means to be a human being and how to "walk in a good way."

Throughout the course of this study, the world experienced (and continues to experience) multiple pandemics, including the novel coronavirus, police violence against Black people and anti-Black racism, and a widespread climate crisis (Ladson-Billings, 2021). As educators, we continue to imagine our contribution to education and wellbeing, and frankly to humanity, throughout this challenging time. As scholars, we recognize that through widespread crisis or chaos, creativity and imagination can emerge. We have the opportunity to recreate and re-imagine another way of educating and caring for our children. As Indigenous peoples, we recognize the strength of our relational onto-epistemologies and axiological commitments, and offer Indigenous relationality as a framework for addressing widespread crises across humans, plant and animal nations, and natural world entities. Indigenous intellectual traditions are rooted in our ancestral territories and expressed as "an ecology of relationships in the absence of coercion, hierarchy, or authoritarian power…, relationships based on deep reciprocity, respect, noninterference, self-determination, and freedom" (Simpson, 2017, p. 8). These systems of relationships have been put in place to ensure human collective survival. We must not only understand the theoretical underpinnings of our stories, we must also strive to engage these theories in the process of re-imagining our collective futures. The answers to the social and psychological predicaments faced by our communities are embedded within the intellectual traditions of each community, and more specifically, within land-based local stories that serve as theories of learning and wellbeing (Brayboy, 2005).

Paper 3: Restorying STEM Learning Communities through E-textiles Quiltmaking

Mia S. Shaw

The purpose of this study was to design an inclusive STEM learning community with minoritized youth from an informal STEM program at a local science museum. I conceptualize youth's STEM learning through this four-year program as "legitimate peripheral participation in communities of practice" (Lave & Wenger, 1991, p. 31). In other words, youth deepen their knowledge of STEM practices and careers through deepening their membership into the STEM community in the form of hands-on workshops, field trips, and internships. However, dominant narratives about who or what are considered "legitimate" STEM identities, practices, and goals have resulted in the historical and institutional exclusion of communities across various social locations (i.e., race/ethnicity, gender, class, and ability). I ask: How do we design for creating inclusive STEM learning communities that reimagine dominant narratives surrounding what STEM is and who belongs? One of the ways the learning sciences have considered reimagining or "restorying" narratives surrounding STEM learning—particularly those endorsing "narrowly defined hegemonic science practices steeped in material culture" (p. 409)—has been to frame the

heterogeneity of cultural practices and experiences as central to learning and designing learning environments (Rahm, 2019).

This study engages in heterogeneity through the sharing of diverse STEM stories and experiences, for exchanging stories can create learning communities through providing a "cohering feeling of shared concerns, values, and investigations" (hooks, 2010, p. 52). In order to design for heterogeneous STEM identities and practices through the sharing and listening to stories, I developed and facilitated a two-part, 45-hour workshop in which youth designed electronic textile (hereafter, e-textiles) quilt patches that "restor(y)ed" dominant narratives about computing technology. An analytical perspective used in narrative and literacy studies, restorying describes how minoritized youth "narrate the word and the world, [analyze] their lived experiences and then [synthesize] and [recontextualize] a multiplicity of stories in order to form new narratives" (Thomas & Stornaiuolo, 2016, p. 318). E-textiles are fabrics embedded with microcomputers, lights, and sensors stitched together with conductive thread and programmed to perform various actions (Buechley, Peppler, Eisenberg, & Kafai, 2013). Furthermore, minoritized groups have used quilting as both an art form and sociopolitical tool to resist oppression and collectively reconstruct their cultural histories through sharing stories of their lived experiences (Cash, 1995; Stull, 2001). Through the integration of historically-feminized practices of crafting (and quilting) with historically-masculinized practices of engineering and design (Buechley, Peppler, Eisenberg, & Kafai, 2013), e-textiles quiltmaking serves as a novel approach for creating inclusive STEM learning communities.

Through analyzing field notes and video observations of community-building activities, participants' exit tickets, and researcher memos, narratives surrounding the culture of STEM learning (particularly in formal schools) emerged. Through collaborating to design a collective quilt including all their patches of restor(y)ed narratives, youth and adults present were able to reimagine and create a STEM learning community rooted in empathy-building and psychological safety, as well as play and authentic friendships. Implications for this study include the design of collective narrative-based artifacts as a context for developing inclusive STEM learning communities.

Paper 4: Co-constructed Anti-Deficit Storytelling in Mathematics Education

Mallika Scott

Justice-oriented teacher preparation programs aim to prepare novice teachers to create more humanizing learning communities in which each student can bring their full selves to learning (e.g. Andrews et al., 2019). Creating these types of caring and rigorous communities in the mathematics classroom requires grappling with and disrupting deficit discourses about students from currently and historically marginalized communities that remain prevalent in K-12 schools (Adiredja & Louie, 2020; McDermott et al., 2006). The stories teachers tell about children often function to reinforce narrow conceptions of ways of knowing and being in the mathematics classroom and to reproduce existing hierarchies (Horn, 2007; Louie, 2019). However, stories also have the potential to support teachers toward more liberatory and expansive views of children and of mathematical learning (Battey & Franke, 2015). Here, I present an analysis of a learning community of beginning teachers who co-constructed a form of storywork – storytelling and storylistening about children that disrupted deficit discourses rampant in their school contexts.

This study was informed by social approaches to design that emphasize designing activity systems intended to afford new forms of activity (Gutiérrez & Jurow, 2016; Gutiérrez & Vossoughi, 2010). The author served as facilitator, co-designer, and researcher of a learning community of six first-year elementary school teachers from the same preparation program. Teachers participated in monthly meetings in which they told stories of successes and dilemmas from their classroom teaching. Data sources include video recordings of meetings and audio recordings of interviews with participants. Data were analyzed to examine how teacher stories from the classroom were co-constructed and functioned to reproduce or disrupt deficit discourse about mathematics teaching and learning.

Findings indicate that participants co-constructed a new joint activity of telling stories about children that reinterpreted student behavior from an anti-deficit perspective. This activity grew out of an emergent need in the community for teachers to support each other to expand their own limited views of the children in their classrooms by collectively investigating why student behavior might be considered sensible within the classroom learning ecology. As teachers listened to each other's stories, examined classroom artifacts, and thought together about the experiences of individual children in their classrooms, they supported each other to open their hearts and spirits to connect with children in the experience of learning mathematics. In describing how this activity supported her learning, first-grade teacher Selina reflected, "I don't think I would have gotten to that point if I

didn't have everybody looking at the same work with me. Because I was such in a box. [...] So asking for an outside perspective and not limiting yourself to a deficit view, like what are they not getting. It's like what are they getting, and what is it about this that is confusing." Through this activity, participants collectively constructed new stories of mathematical learning that pushed back on individual, deficit-oriented interpretations and honored children's dignity as learners and as human beings (Espinoza et al., 2020; Espinoza & Vossoughi, 2014).

Paper 5: Becoming Maestras Matemáticas through Pláticando

Sandra Zuniga-Ruiz

I grew up listening to my abuelita's historias about being raised en el rancho and navigating the struggles of migrating to the United States. I bear witness to her memories, memories that would be intertwined with dichos and consejos of becoming buena gente. I begin with the stories of my abuelita because storytelling is interconnected with who we are in history, intergenerational knowledge and connetion that is passed on, and storytelling provides a groundwork for the future. These stories were of the form of pláticas, critical conversations. In this work, pláticas are a cultural practice of storytelling embedded in the design of transformative learning communities (Gutierrez & Jurow, 2016) that I argue is central to learning and becoming. This paper centers *pláticas* as stories that create opportunities for prospective teachers of color, Mexicanas, to engage with the complexity of issues related to social justice and mathematics.

Becoming a mathematics social justice educator entails understanding and engaging with multiple literacies: racial, critical and mathematical literacy (Freire, 1996; Sealy-Ruiz, 2011; Schoenfeld, 2014). While such literacies are central and never an outcome, very little is known how one grapples and develops such literacies with mathematics while centering the experiences of marginalized communities. One such way to center the experiences of prospective teachers of color (PCTs) is through the creation of a counterspace, a "safe space" created by marginalized people in response to the daily barrage of racial microaggressions (Solorzano, Ceja, & Yosso, 2000). This study merged the need to create spaces for us and with us while paying close attention to designing a transformative learning community.

The purpose of this project was to co-construct a learning community where PTCs had opportunities to grapple with issues of race, justice and mathematics. Such opportunities came from the use of tools and artifacts to spark conversation. The women had all taken the same math content course so they had a shared experience that allowed them to talk with one another about their math experiences. The co-participants in this study are a researcher and 4 PTCs who self-identify as Mexicanas. Even though the participants are in the same ethnic group, there is a lot of diversity within the group. PTCs are all college graduates who attended a Hispanic Serving Institution in a predominantly immigrant Latinx community. At the time of the study, all co-participants had yet to begin a credential program and intended to continue to work in the community they grew up in. The participants were selected by their willingness to engage in conversations about social justice and mathematics. Data sources include video recordings of zoom meetings and interviews with co-participants.

Through analyzing the video data, findings suggest that the stories that the mujeres shared about their families served to both construct new meanings with one another and with mathematics itself. For instance, the developmental stories of parents doing math in their everyday life pushed on the mujeres' understandings of who does math and what is math. The storytelling about family helped build a collective community where they were vulnerable and were able to relate to struggles of their multifaceted identities as women of color. Furthermore, their experiences in the pláticas served as a foundation for the women to co-construct a vision of a mathematics learning community grounded on community, historicity and dignity (Espinoza et. al, 2020; Espinoza & Vossoughi, 2014).

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International Society of the Learning Sciences

Developing Accessible and Sustainable Computational Modeling Tools in Learning Science: What is Next?

Chairs: Tamar Fuhrmann, TC Columbia University; Sharona T Levy, Faculty of Education, University of Haifa
Discussant: Uri Wilensky, Learning Sciences & Computer Science, Northwestern University

Introduction

In this symposium, we address two issues that extend the body of research on students' computational modeling: enabling greater access to computational modeling activities and sustaining such activities within educational settings. Modeling has become an essential part of many scientific disciplines -- a core element in professional scientific practice for formulating and testing hypotheses, justifying new claims, and explaining natural and artificial phenomena (Pluta et al., 2011; Halloun, 2011). The involvement of students in developing a scientific model has been shown to have many pedagogical affordances: models can be used as inquiry tools, creating meaningful learning opportunities (Gilbert et al., 2016; Passmore et al., 2014; Schwarz et al., 2012); additionally, models enhance students' disciplinary knowledge (Passmore et al., 2014) and help develop their understanding of the epistemology behind constructing scientific models (Lehrer et al., 2006; Schwarz et al., 2005). In addition, it has been found that students who engage in designing their models also develop a critical perspective about models and metamodeling knowledge (Wagh et al., 2018; Fuhrmann et al., 2018). The last few years have seen modeling activities gradually take root as part of science education. Incorporating modeling has become a key goal in many countries' national standards in the past decade and a core component of school curricula (Gilbert et al., 2016), as evidenced by the fact that national policy documents have centered modeling activities in the curriculum (National Research Council, 2007; NGSS, 2013) and by the fact that modeling is woven throughout the Next Generation Science Standards (NGSS).

With the realization that constructing models is essential and computational modeling should be learned in schools, new computer modeling environments and designs have proliferated. As a result, today, a wider range of robust, mature, and carefully designed software and hardware tools are available for modeling in K-12. Nevertheless, several issues remain to be addressed before students engage in meaningful modeling activities, create their models based on data, and share them and discuss them with others, thus participating in activities aligned with authentic scientific practices.

The papers in this symposium focus on the big question of what is next in domain-specific computational modeling languages/environments for K-12 students. To this end, we address two relevant issues, namely accessible and sustainable development. Here, we define *accessible* development as development that enables students with different interests, contexts, and abilities to begin interacting with the learning materials. This can be done by lowering the threshold to begin using the tools and/or by catering to different forms of expression to motivate students to begin engaging with the tools. Increasing accessibility to a learning environment is necessary when considering schools with teachers who may or may not have the skills to support a class of students constructing computational models. Students' need for support in constructing a computational model is significant, and learning design needs to consider how to offload some of this responsibility from the teacher to the computational toolkits themselves.

We define *sustainable* development as creating learning materials that can continue generating new activities over time, be it for additional content, for higher ability levels, or for other extensions. Ensuring the sustainability of innovative and expressive activities such as computational modeling in schools is an important endeavor that has been undertaken by several leaders and researchers (Horn et al., 2011; Kelter et al., 2021). Building upon these efforts, there is a need to continue developing and diversifying the strategies for supporting the continued use of computational modeling in science learning. In the process of variation and selection in different contexts, this would advance the broader vision of democratizing people's use of computation as a tool to express their assumptions regarding phenomena in the world and of generating dynamic representations that can be compared with these assumptions.

Paper 1 presents a nuanced framework that differentially integrates divergent data sources with modeling activities and labs. Paper 2 introduces the Much.Matter.in.Motion platform for modeling, which unifies computation across systems in chemistry and physics. It demonstrates the idea with research into learning about electricity through computational modeling. Paper 3 presents research with a novel extension to the Scratch environment that enables topical computational modeling. Further, this paper looks at related research that highlights how students' ideas are expressed visually and evolved through the programs they construct. Paper 4 presents work and research with the StarLogo Nova platform. It looks at how programming blocks might be used for learning a variety of scientific phenomena across the curriculum while enabling the opening of these blocks

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to get a deeper understanding of the computational constructs. Finally, Paper 5 presents a framework for making computational modeling in science a sustainable activity in middle schools.

Each of the papers in the symposium addresses accessibility and sustainability in different ways. Regarding accessibility, common to all the papers is the use of functional computational blocks that are limited to a subset of phenomena and form a library of concepts that students can use to construct their models. By limiting the library of concepts and aligning them with a variety of intuitive concepts, it is made possible for the students to immediately begin constructing with relatively little support. In Paper 4, these blocks can be opened up during the learning process, supporting students as they gradually come to understand the more basic computational constructs the blocks are built from.

As to sustainability, the papers provide an array of strategies. Paper 5 specifically addresses sustainability and presents a framework with several components that could support the continued use of modeling in schools. Papers 1 and 3 both employ Bifocal Modeling, an approach that combines the use of labs and models to facilitate easy comparison. In this way, additional practices common in science education are integrated with modeling, thus strengthening the holding power of those practices.

Similarly, Paper 2 intersperses physical experiments into the learning unit, with the express goal of helping students transition back and forth between experience and representation. Integrating standard science education practices into learning units that engage with modeling can also be seen in Paper 1, where a framework for integrating data practices with modeling is presented. In Paper 4, using the mature StarLogo Nova platform and beginning with a more limited library of blocks enables the gradual transition to a full-blown modeling toolkit by gradually unpacking these blocks, providing for an extended developmental learning process that can continue even over several years. Another strategy used in paper 4 to increase sustainability is creating several libraries, each of which addresses different curriculum topics so that modeling can be integrated into learning throughout the school year. Finally, in Papers 2, 3 and 4, the limited set of blocks enables modeling a broader range of phenomena — systems in chemistry and physics — by capturing the computational similarities among diverse phenomena; this supports the vision of continued use of the same platform as students progress in their studies and learn new topics in these sciences.

The session will open with introductory words. Five paper contributions will then follow. Our discussant, Prof. Uri Wilensky, will draw upon the various strategies developed to increase accessibility and sustainability to interrogate some of their implicit assumptions underlying the learning designs and the related research presented in the papers. The symposium intends to integrate and focus our efforts on furthering scientific computational modeling in schools, streamlining it to the burning issues we have addressed. To summarize, the papers comprising this symposium acknowledge several essential issues regarding computational modeling in science. The more we know about this topic, the more we are driven to further explore and extend our understanding. We hope that the symposium helps democratize this important science learning component by addressing key issues that can make modeling more widely available for all learners and relevant throughout their studies.

Paper 1: Comparing and Contrasting Real-World Data and Models: Cognition, Pedagogy, and Implementation

Engin Bumbacher, Tamar Fuhrmann & Paulo Blikstein

Empirical data plays a crucial role in scientific modeling: scientists use such data to construct, refine or decide between possible models (Passmore et al., 2009), and assess the adequacy of a given model by the degree to which that model is able to explain the data (Passmore & Svoboda, 2012). However, approaches to model-based learning (MBL) have predominantly focused on model-based and data-based practices separately (Bumbacher et al., 2018). While these reductive approaches have helped students improve in the respective practices (Zimmerman, 2000), they have yet to prove successful in helping students develop a deeper grasp of the practices and epistemic understanding of the scientific endeavor (Berland et al., 2016; Chinn & Malhotra, 2002).

Recent technological advances hold the promise to support more integrative approaches that interweave models and data. For example, the Bifocal Modeling framework (Blikstein, 2014, 2016) suggests integrating technologies for real-world data collection with technologies for computational modeling to enable real-time comparisons of simulated and real data. Studies have shown that activities designed according to this framework can develop students' conceptual understanding and meta-modeling competences (Blikstein, 2014; Fuhrmann et al., 2018), but more work is needed to examine the types of learning opportunities that arise from comparing real-world data and computational models, as well as the conditions under which they arise.

Integrating real-world data in the modeling process provides learning opportunities that would not arise if students just focused on the models. For example, real-world data might encourage students to explore more deeply the

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underlying features of a phenomenon (Schwarz, Akcaoglu, Ke, & Zhan, 2013) in order to decide on criteria of model-fit. Similarly, real-world data might also inform the evaluation of models, when students have to decide how well a model fits the data, and what conclusions are justified by the data (Holmes, Wieman, & Bonn, 2015). But there is not just one type of data source, and there is not just one way of comparing models and data. We argue that the type and quality of learning opportunities arising from comparing models and data are dependent on the type of data source being used, and the way models and data are brought together. For example, juxtaposing a model-based simulation of bacterial growth with time lapse recordings of an actual experiment might encourage students to engage differently in the comparison of models and data than merely contrasting the growth curves of the simulated and real bacteria.

Thus, developing technologies and pedagogical approaches that productively integrate data and models necessitates a better understanding of the types of data sources and types of comparisons of models and data. This is particularly relevant today, as the past decade has seen an explosion of novel empirical data sources and means of collecting data (Lee & Wilkerson, 2018). Novel technologies like probeware, wearable sensor technologies or remote laboratories enable individuals to collect quantitative data continuously and in real-time. The internet provides access to large, publicly-available datasets in the form of spatial data, quantitative data tables, or qualitative data such as videos. Further, computer vision algorithms can even turn non-quantitative data like videos and images into quantified datasets (e.g. Hossain et al., 2016). Depending on the data source, real data might be produced and compared to models in real-time or asynchronously. And depending on the data source, real and simulated data can be compared in side-by-side visualizations or overlaid in the same visualizations; they can be compared across multiple dynamically linked visualizations, or quantitatively by means of analysis tools, and so on. Each of the data sources necessitates different data-related skills, and each of the types of comparisons has different implications for what students might focus on and how they might reason when using models and data. In this presentation, we present a taxonomy of these types of data sources and types of comparisons, and elaborate on how they might impact possible learning opportunities. This work is necessary to guide the development of technologies and activities for rich scientific inquiry through the integration of computational models with real-world data.

Paper 2: Eighth-Grade Students Learn Electricity through Constructing Computational Models with Much.Matter.in.Motion

Janan Saba, Elon Langbeheim, Hagit Hel-Or & Sharona T. Levy

This study focuses on students' learning of the concept of electric current through the lens of complex systems by constructing computational models with an iconic interface. We focus on how students develop mental models that associate properties of a circuit at the macro-level, such as the magnitude and direction of the electric current, with entities at the micro-level, such as electrons and their motion (Eylon, & Ganiel, 1990). We examine the students' development of mental models as they construct computational models with an early widget-based version of the Much.Matter.in.Motion platform (MMM; Levy et al., 2018). One of MMM's main affordances is sustainability, which enables modeling of many physics and chemistry phenomena.

Learners rely on cognitive constructs termed "mental models" when explaining the world around them (Norman, 1983). They develop these mental models through interactions with natural or human-made systems; yet, these models are often partial, unstable, and inaccurate. It is important to support students' expression of these mental models and to follow their transformations through learning. This process is facilitated by having this expression take the visual form of drawing, on the one hand, and become animated through the generative power of computation, on the other hand.

Most computational platforms that were designed to support teaching of electricity are based on a macro-level representation of circuits (e.g. Roll et al., 2018), with only a few environments attempting to introduce electric circuits from a micro-level perspective (Sengupta & Wilensky, 2009). In our study, we developed the MMM modeling platform (created with NetLogo [Wilensky, 1999]) for building and running computational models. MMM enables model construction at the micro-level without coding, by using pre-built model features that can be added and modified. To increase the accessibility of MMM, it is set up in such a way that users first draw the boundaries of their model conductor, and then add particles for which they define size, initial speed, heading, and interactions. After constructing the model, students can run the model and observe the resulting behavior. Figure 1 shows a screenshot of the MMM platform with a constructed model. The brown particles represent the atoms, and the red particles represent electrons.

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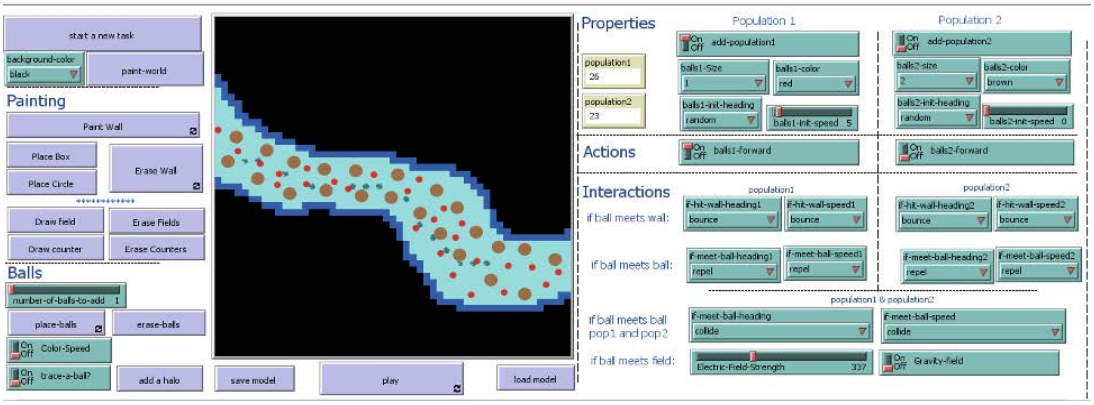

Figure 1. The Much.Matter.in.Motion (MMM) interface

Thirty-three eighth-grade students' learning by constructing models is compared with 23 students' learning with a normative curriculum, during six 1.5-hour sessions. The learning process included physical experiments and modeling activities. Students completed pre-and-post-test questionnaires and four students were interviewed. Activities were logged and screen-captured.

The interaction between time and group ($F(1,54)=6.67$, $p<0.05$) shows the superior learning of the experimental group. The specific component that contributes to this significance is the micro-level reasoning on the systems. A two-step cluster analysis was conducted on the students' responses to the open-ended items in the questionnaires regarding simple electric circuits. Five mental models were revealed that differed across several features: the balance between physical macro-level components and micro-level descriptions and the degree of integration between the micro and macro levels. Comparing the magnitude of the transitions between mental models across the two groups shows a significant transition magnitude for the experimental group between pre- and post-testing compared to the comparison group.

Our study shows that constructing micro-level models of electric conductors advances micro-level conceptualization of the electric circuit, and does not diminish the overall macro-level understanding. In addition, cluster analysis is an important methodological advancement compared to prior studies that examined individual responses without an integrated approach that combines all of the knowledge elements expressed by each student. Results indicate that enabling students to construct computational models using MMM promotes progress in thinking about electric circuits: from simpler mental models that are focused at the macro-level in the beginning of the learning process to more sophisticated ones at the end that include the micro-level entities and interactions. This approach to learning science is now being extended to additional topics. We are now studying the sustainability of these ideas over time and across topics.

Paper 3: Unpacking Students' Reasoning Using Computational Models With Domain-Specific Blocks

Cassia Fernandez, Tamar Fuhrmann, Paulo Blikstein & Roseli de Deus Lopes

Engaging students in modeling practices to make sense of scientific phenomena and the nature of science is the focus of recent reforms in science education (NGSS, 2013; NRC, 2012). Creating a computational model can be a valuable way for students to create and test their own hypotheses and refine their understanding of natural phenomena (Gilbert et al., 2016; Passmore et al., 2014; Schwarz et al., 2012). Although the constructivist idea that students are not "blank slates" but rather possess a wide range of previous knowledge on natural phenomena is well established (diSessa, 2018), there is, still, less research than needed about what students already know in specific domains of science. Thus, often, educators and designers (by no fault of their own) are not completely aware of preconceptions that students might bring to classrooms, what they are confused about, or how their ideas about the world fit with what they are attempting to learn. This paper aims to analyze students' conceptual trajectories while programming a computational model, in order to understand their initial, nonstandard, ideas about diffusion and how those ideas evolve. We are interested in learning how interaction with a constrained model can reveal students' thinking and, thus, inform designers on how to design tools and languages that acknowledge students' ideas and sensemaking (Wilkerson-Jerde et al., 2010; Wagh et al., 2017).

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Our preliminary findings are drawn from a pilot study conducted through individual online sessions with seven 5th-grade students. Each session lasted one hour and involved model creating and comparison with data (Fuhrmann et al., 2018). Students observed a diffusion experiment and designed a model to explain the phenomenon at the particle level, using their experimental observations to validate and refine the model. For these sessions, we designed an initial version of nine domain-specific programming blocks integrated into Scratch as an extension. By combining our blocks with the original Scratch blocks, we expected students to test and refine their own ideas about diffusion, using scaffolding tasks and questions from the researchers.

The use of block-based modeling tools has many affordances for young students. For example, it allows them to develop their own scientific models without being overwhelmed by text programming in a dynamic process (Gouvea et al., 2017). By doing so, students can revise their ideas and make changes through many iterations. According to our findings (see Figure 2), designing computational models in this way helped students externalize scientific ideas that would otherwise remain tacit. Through coding their models, students revealed unexpected concepts such as molecule "transmutation," atoms that would simply disappear or "melt," and particles with volition. Being able to express those ideas in code was crucial for students to be able to then reflect on those ideas, understand their possible flaws, and refine their initial ideas.

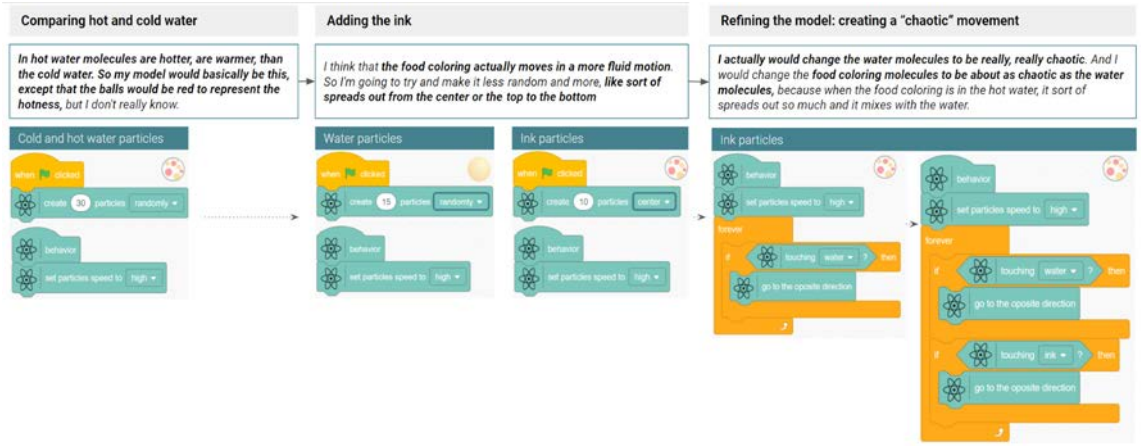

Figure 2. An example of student initial ideas and the evolvement process illustrated with blocks

The use of blocks can be a valuable strategy to explore students' reasoning processes: the translation of ideas into code unpacks students' thinking. It reveals inadequate conceptions since it forces students to make their thinking visible. By being aware of students' prior knowledge and identifying possible sources of confusion, science educators can mediate the scientific knowledge-building process for learners; help them make sense of how scientific models are generated and validated; and scaffold learners' conceptual understandings rather than merely giving them the "correct answer." While learning how students reason about a phenomenon, designers and researchers can create more domain-specific blocks that acknowledge students' initial ideas and sensemaking processes.

Paper 4: Custom Blocks in StarLogo Nova: Lowering Barriers and Providing Pathways to Further Learning

Daniel Wendel & Eric Klopfer

Agent-based computational modeling (ABM) has been shown to help students reason about the parts and interactions in systems that give rise to observed scientific phenomena at the system level (Klopfer, 2003; Resnick, 1994; Sengupta & Wilensky, 2009; Wilensky, 1999). Using models has shown some benefit (Yoon et al., 2016), and modifying and creating models provides a rich opportunity to engage in both the practice of modeling and in computational thinking (Sengupta et al., 2013; Wagh, Cook-Whitt, & Wilensky, 2017; Weintrop et al., 2016), both of which are essential skills for modern scientists (Foster, 2006). However, our experience and the experience of many other researchers in computational modeling is that teachers are often reluctant to incorporate modeling due to its high startup costs, particularly the cost of learning to "code" (Ertmer & Ottenbreit-Leftwich, 2013; Guzdial 1994; Hsiao et al. 2019).

In a current research project, working with our partners at NYU, we found that students — including English language learners — in a 5th grade classroom were able to use our online ABM tool, StarLogo Nova (www.slnova.org), to create models of microbes breaking down solid food into waste products and gas, conserving the overall mass of the system to match their "landfill bottle" physical models. In post interviews, these students demonstrated systems thinking as they explained the process of modeling the phenomena. They were able to reason more effectively about aspects included in their models than about hypothetical scenarios they had not modeled (Haas et al., 2020), which underscores how important having created the model is to students' ability to make sense of the phenomenon. In this full-year curriculum, the costs can be amortized across a whole year, but many teachers need activities that can be integrated into existing curricula within a more constrained time frame.

We have reconciled the need to address particulars of the curriculum with the desire to build student modeling skills across the year by making changes to the StarLogo Nova platform in the form of "custom blocks." We developed StarLogo Nova to be beginner-friendly, using a blocks-based programming language to reduce the barriers of syntax faced by novices (Klopfer et al., 2009). However, the process of modeling concepts or phenomena from a set of domain-general programming primitives remains challenging (Anderson & Wendel, 2020). Recently, domain-specific modeling languages/environments (DSMLs/DSMEs) have attempted to narrow the conceptual gap between programming language semantics and scientific phenomena (Hasan & Biswas, 2017). For example, whereas StarLogo Nova's modeling language may represent a predator's "hunt" behavior as "face toward nearest prey agent; move forward 1 space; on collision, delete prey and increase my energy trait," a DSML for ecosystems may simply use "chase prey; if I catch prey, eat it".

In science education, these DSMLs are typically implemented as sets of "custom blocks" layered on top of existing primitives in a modeling environment. These blocks are carefully designed by educators to be beginner-friendly, but are typically treated as "black boxes" to shield students from the underlying implementation (e.g. Basu et al., 2013; Wilkerson-Jerde, Wagh et al., 2015). In contrast, in computational thinking/computer science education, blocks-based programming environments engage learners themselves in the process of creating and modifying custom blocks as an introduction to procedural abstraction; Snap!'s previous version was even named "BYOB: Build Your Own Blocks" (Harvey, 2020).

StarLogo Nova's new custom blocks feature aims to combine these ideas. Rather than viewing the custom blocks of a DSML as black boxes to hide underlying complexity, we have intentionally designed StarLogo Nova's new custom blocks feature to capitalize on StarLogo Nova's "blocks all the way down" language architecture, hoping to transform a custom block's underlying implementation from a liability into an opportunity. Because custom blocks can themselves contain custom blocks, we envision and are beginning to investigate a layered abstraction approach, with DSML blocks providing not only a seamless introduction to computational modeling, but also a path to deeper understanding by allowing students to "look inside," reading and modifying code at successively more domain-general (and therefore more flexible and powerful) layers of abstraction as their computational modeling skill grows.

Paper 5: Towards Sustained Computational Modeling: Exploring Strategies to Support Extended Investigations in Middle School Classrooms

Aditi Wagh, Tamar Fuhrmann, Michelle Wilkerson, Engin Bumbacher & Paulo Blikstein

There is now a considerable amount of research exploring how, through design and pedagogy, educators can lower the barrier to computational modeling for young learners. For example, modeling environments that make use of accessible media like block-based (e.g., Klopfer, Yoon & Um, 2005) and/or domain-specific (e.g., Repenning & Summer, 2005; Wilkerson, Wagh & Wilensky, 2017) toolkits ease the technical aspects of programming, whilst pedagogical approaches such as embodied (e.g., Wilensky & Reisman, 2006) and bifocal modeling (Blikstein et al., 2016; Fuhrmann et al., 2018) support conceptual aspects of computational modeling. This research has contributed to our understanding of how to make computational modeling an accessible practice in science classrooms. However, less is known about how to make computational modeling a *sustained* practice in classrooms. By "sustained", we mean engaging in extended investigations using computational modeling.

In this paper, we will describe how our research aims to foster sustained engagement in modeling using data from co-design sessions with teachers and classroom implementations. We draw on two design strategies from the broader scientific modeling literature (Lehrer & Schauble, 2012; Manz, 2015) in which extended investigations with modeling and iterative refinement are part of what students do. We use these strategies in the design of the computational modeling toolkit and the curriculum. The first strategy involves building uncertainty into student investigations through experimental data to create resistances for students to consider, tackle, and

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possibly resolve (Manz, 2015). Tackling such uncertainties together with the use of data can amplify disciplinary ideas while supporting progress along a modeling trajectory. In related work, the authors of this paper have integrated computational modeling with data in order to highlight — rather than dismiss — discrepancies between models and data, bringing noise, uncertainty, and intrinsic differences between them to the forefront (Blikstein et al., 2016). This bifocal modeling approach has been successful in several domains, but for relatively shorter interventions (Fuhrmann et al., 2020). The second strategy we draw on is repeatedly revisiting a small set of disciplinary ideas from multiple perspectives to pursue extended investigations (Lehrer & Schauble, 2012). We envision this as enabling students to construct, deconstruct, and recombine models of related phenomena as well as unpacking blocks and chunking them in ways that can be meaningful for students. We see this as a way to deepen engagement in modeling so as to develop an epistemologically rich perspective on the role of computational modeling in understanding a phenomenon.

In our paper, we report on co-design sessions with three middle school science teachers as they provide feedback on the computational modeling toolkit and refine two curricular activities. Our analysis describes the role that teachers expect the data to play in supporting students' computational modeling activities, and how to support students in coordinating data analysis and model refinement. We also describe how teachers suggest linking across curricular topics, particularly through model construction, deconstruction, and recombination. Finally, we share challenges teachers anticipate in this work.

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International Society of the Learning Sciences

Seeing Histories in Bodies, Places, and Disciplinary Learning: Historicizing Methodologies

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Abstract: In this symposium, we will reconceptualize our methodologies and research design centering histories in places, bodies, and disciplinary learning. We re-engage in qualitative methodologies that guided us so far yet limited us in fully accounting for the sociopolitical and sociohistorical nature of our research and analyses. This symposium challenges individualized knowledge production and invites the field of the learning sciences to bring forth collective and dialogic figuring and refiguring, co-thinking, and community/solidarity building. Four sets of paired dialogues will defamiliarize familiar methodologies in the learning sciences (e.g., video-based research, interaction analysis, ethnography) toward fuller consideration of power and radical transformation. These paired dialogues will also open new horizons on the role of arts and affect in research from the perspectives of histories in places and in bodies. Collectively, we will revisit the epistemological assumptions that shaped what were rendered visible and invisible in our research process.

The overall focus of the symposium: Historicizing methodologies

Background

The International Society of the Learning Sciences Annual Meeting in 2022 will be held in Hiroshima, Japan – where histories of militarism, war, and colonial violence are still vividly inscribed within people, buildings, and ecosystems even after 76 years since the atomic bomb was dropped. Disciplinary learning, which is at the core of our inquiry in the learning sciences field, is never in a historical vacuum. Learning is "fundamentally cultural, unfolding through multiple pathways that occur in relation to shifting social and contextual conditions, to which humans are constantly adapting" (Lee, et al., 2020, p. xvii). STEM disciplines carry histories of colonialism and militarism and have directly contributed to destroying bodies and places (Philip et al., 2018; Takeuchi et al., 2020; Vossoughi & Vakil, 2018). As we center historicity in our conceptualization of disciplinary learning, we are grappling with a question: How can we account for the ghosts that haunt our historic present (Gordon, 1997). What will the ghosts in Hiroshima speak to us as we reconfigure the portraits of learning, learners, and disciplines in the post-pandemic world?

In our recent scholarship and panel discussions, we have collectively been pushing the field of the learning sciences to interrogate ahistorical epistemological assumptions on bodies, places, and disciplinary learning and calling for fuller accounts on historicity, coloniality and power (Ali, 2018, 2019; Avraamidou, 2020; Davis & Schaeffer, 2019; Marin, 2020; Martins, 2020, Philip et al., 2018, Philip & Sengupta, 2021; Takeuchi, 2021; Vossoughi et al., 2021). Our ISLS 2021 panel, *Expanding Conceptions of Learning: Colonialism, Social Movements, and Possible Futures*, identified some of the edges in our field: a) colonial histories and materiality/notability, b) racialization and discipline across countries (beyond the US), c) learning, freedom and agency, and d) criticality, ethical relations and possible worlds. In one of our dialogues, Audrey Msimanga reminded us of colonial narratives around learning and learners perpetuated upon people in the Global South:

> This local, national, continental and even global narrative that "something is not there" in the African child is often what shapes thinking about education in the Sub-Saharan Africa contexts that I have worked in. It is not unusual for a whole systemic reform or a review of the curriculum, a rethink of pedagogical approaches and/or assessment practices to be framed around just addressing "what is missing" in the learner. What is more, this broader narrative then filters

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> down and bears nasty stubborn babies in the heads of teachers and learners themselves (A. Msimanga, Personal Communication, May, 2021).

How can we, as the field of the learning sciences, shift away from this damaging narrative of deficiency, incompleteness, and insufficiency imposed upon learners under the guise of development and learning?

The field of the learning sciences is dynamically shifting to center learning that happens in the forms of collective resistance and protest (e.g., Special Issue organized by Curnow & Jurow, 2021), of prefigurative relationship-building processes (Uttamchandani, 2021), of multigenerational alliances (Tivaringe & Kirshner, 2021). Despite these shifts, the methodologies we draw from in our field remain largely devoid of full consideration of histories of places and bodies. The taken-for-granted White gaze (Toni Morrison quoted in Paris, 2019) assumed in "ethnography" has largely remained unquestioned. Colonial assumptions that separate human and more-than-human behind interactional analysis (Jordan & Henderson, 1995) have just recently begun to be questioned (Krishnamoorthy et al., 2021; Marin, 2020). How can we reimagine histories of surveillance and inherent power (Ali, 2018) reproduced through video-based fieldworks? Taking account of what is shifting and what remains unchallenged in the field, in our symposium, we aim for critical accounts of histories inscribed in places and bodies by reimagining our methodology. We will collectively re-figure ways in which we might reconceptualize our methodologies and research design as we take histories in places, bodies, and disciplinary learning seriously. Through our symposium, we pose questions to ourselves and to the field of the learning sciences: What kinds of questions do we have to ask for (and of) ourselves to deeply engage in historicity through our analyses and design? How do we re-engage in classic qualitative methodologies that have guided us so far, yet limited us in other ways? How could we reconceptualize our methodologies while accounting for sociopoliticalness and sociohistoricalness in our research and analyses?

In line with learning sciences scholarship focused on communality, justice and design (e.g., Davis & Schaeffer, 2019; Gutiérrez, & Vossoughi, 2010; Special Issue organized by Curnow & Jurow, 2021), we propose this symposium as an intentional shift away from methodological approaches that privilege individualized knowledge production and those that treat disciplines and methods in the field of the learning sciences as settled. In our call to deepen and historicize methodologies, we are drawn to interrogate the meaning and purposes of researcher reflexivity. Traditionally, the notion of researcher reflexivity calls for scholars to name intersectional identities and describe what we see as proximal histories (e.g., to characterize recent interactions and relationships to places and participants). Positionality statements, now a gold standard of qualitative research, may be contextualized by entries in fieldwork journals that are seldom (and never fully) represented in reports of research findings. While this attention to reflexivity represents an important departure from the positivist research stance, this notion of reflexivity does not necessarily invite or demand inquiries into collective histories of experience. Our methodologies may demonstrate an awareness of inter-subjectivity but inadvertently obscure the long and complicated histories that stretch across places, bodies, and time. At the same time, we recognize that important forms of reflection and insights into the relationships cultivated between learning scientists and research participants are sometimes intentionally withheld. We question what counts as disclosable and relevant to the study of learning, when and for whom accounts of identities and methodologies may fall short in capturing the richness of human experience (Bang & Vossoughi, 2016; Philip et al, 2018). Consequently, we seek to analyze, together, methodological efforts to "resist and navigate potentially disempowering social systems" (Lee, 2017, p.x) to include reflections on how our own vulnerabilities (Behar, 1996; Howard, 2020), knowledge, histories (Gutiérrez et al, 2017) and commitments inform what we notice and interpret.

Our ISLS 2021 symposium challenged individualized knowledge production and moved us to collective and dialogic refiguring of the field of the learning sciences. Unlike a traditional symposium that is formed by a set of related yet independent research papers, our symposium will result from our ongoing dialogues as pairs and as a whole group. In preparation for this symposium, we will continue this process of co-thinking and co-figuring by engaging in shared textual reading and paired and group analyses of data. During the symposium, we will extend this co-thinking and co-figuring to the audiences and participants by sharing our unfinished thoughts, our embodied tensions and dilemmas as learning sciences researchers, and inviting contemplations and questions from the audiences.

Description of Each Paired Paper

The first paper critically reflects on the collection and analysis of video data from an ongoing project on land-based disciplinary learning with refugee children. Highlighting moments of youth agentic selection (Ali, 2018), authors explore the subtle agentic moves that children use to communicate what should not or cannot be captured by the camera, in light of the geopolitical configuration of identities (Takeuchi, 2021). Paper two pursues questions about Interaction Analysis (IA) and ethnography by co-analyzing key moments from a community-

based summer program and a collective of improvisational jazz artists and musicians. Findings consider if/how IA can function as a tool for radical transformation and facilitate generative forms of relational praxis (Gutiérrez & Vossoughi, 2010) and accountability. Paper 3 invites a reimagining of the study of affect in the Learning Sciences that includes attention to emotional configurations (Vea, 2020) that emerge over time. Drawing examples from two projects that investigated students' layered sensemaking in STEM, the authors analyze how the felt dimensions of learning can also be viewed as embedded within longer, racialized histories of power. Finally, Paper 4 considers the role of arts-based methods as tools for disrupting narrow, exclusionary conceptualizations of science. Taking examples from projects situated in Brazil and the Netherlands, the authors describe the relationship between the methodological design, youth participation and longstanding issues of colonialism and power in science.

Format of the Symposium

For the symposium, each pair will present methodological insights developed through analyzing empirical data to explore histories in bodies, in places, and in disciplines. Each pair will share portions of their shared analyses salient for rethinking social research methodologies from sociohistorical and sociopolitical perspectives. Each pair will analyze (or reanalyze) data from our ongoing and previous works. In this process, we will defamiliarize familiar methodologies and methods of analyses, and revisit some of the epistemological assumptions that shaped what were rendered visible and invisible in our research process. As a group, we collectively identify some areas where our field may further develop its tools and insights in order to account for histories in places, bodies and disciplines — through research methodology. This session will last ninety minutes, beginning with a five-minute introduction by the session co-chairs. Following, four papers will be presented (15 minutes each). The co-chairs will then facilitate a conversation across the papers for five to ten minutes. We will conclude this session with a fifteen-minute reflection and response on audience comments on the digital white board. We will also allow participants to engage in reflection or ask questions during these concluding fifteen minutes. Recognizing the limitations and opportunities of an online conference symposium, we have decided to utilize a digital white board to allow participants to engage in reflection and response, in real time. A digital white board allows for multiple streams of conversation to happen parallel, as opposed to utilizing a chat window. The whiteboard will include a guiding question developed for each paper as well as an overall guiding question. An example question is: 1) how we might more fully account for, and attend to, what constitutes post-Cartesian "rigor" in data collection and analysis as we attempt to shift away from Eurocentric, Western epistemologies? Over the course of the symposium, participants will be reminded to engage in conversation and response on the digital white board.

Off camera scripts in video research: Histories and politics of visibility

Arshad Ali, Miwa Aoki Takeuchi

Video-based research has been one of the primary research methods being used in the learning sciences (Derry et al., 2010). Video cameras are never neutral records of human activity. Rather, cameras are directed in particular directions to capture specific events, and more importantly, to not capture activity beyond the frame. Be it human, motion detection or algorithmic, the directionality of cameras is not without context, meaning and purpose (Ferguson, 2019). Beyond directionality, cameras themselves often represent a manifestation of the carceral state in the lives and experiences of poor and youth of color (Gregory, 2020). This is especially true for the communities that are under the threat of police surveillance. The presence of video cameras can inscribe traumatic relationships and panopticonic gazes (Foucault, 1980, p. 39) of being seen in public spaces (Ali, 2019). The field of the learning sciences has not fully articulated the histories of construction of Other (Said, 1978) through video-based research, and explored the material and epistemological limitations of this tool. Our dialogue critically reflects on what our research tools, including video cameras, produce and reproduce in the process of the learning sciences research.

We engaged in collective viewing of video data collected by an ongoing research project with refugee families and children's intergenerational wisdom sharing and land-based disciplinary learning in urban farms. The project was conducted in urban farms in the land of Treaty 7 regions during the COVID-19 pandemic and we analyzed video data and fieldnotes collected over 11 visits from August 2020 to September 2021 (each visit lasted 60 to 150 minutes). Video data were collected using a hand-held camera (worn by a researcher and participants), a wearable camera (worn by a researcher and participants), and a smartphone camera of a researcher. In this paper, the authors engage in shared analyses of what becomes visible and invisible in the video data and fieldnotes to each of us, who come with different histories and ontologies.

Our dialogue highlights moments of youth's agentic selection (Ali, 2018) of what should be presented and erased as data in the presence of a video camera. Recognizing the right and potential of participant refusal (Tuck & Yang, 2014), we, together, unpacked subtle agentic moves by young children to show what should and should not be documented in the video data, as well as what cannot be documented, in light of the geopolitical configuration of identities (Takeuchi, 2021). Our dialogue directed us to comparatively look at what was unveiled and hidden between when a video camera was on and off. For example, in the face of racism experienced on historically predominantly white farmlands after colonization, a refugee child from Syria only shared their experiences of racism and verbal and physical attack in the process of shared walks (Lee & Ingold, 2006; Marin & Bang, 2018), without a video camera. Children used a still camera to take photos that euphemistically reflect their racialized experiences, without explicitly explaining them verbally. In contrast, when the video camera was on, children shared the experiences partially, without explicitly naming the details of their experiences. We interpreted these moments of youth's agentic selection as key to interpreting macro carceral contexts and panoptical white gazes (Morrison, in Paris, 2019) and refusal (Tuck & Yang, 2014) for dignity (Espinoza et al, 2020).

Our dialogue through shared analyses raises questions to the field about the role of the learning sciences research in reproduction of surveillance and racialized gaze through video-based research. Our dialogue also identifies moments of youth's reappropriation of video and still cameras to challenge hierarchical relationships on seeing and being seen.

We will conclude our presentation by engaging the panelists and audience in a conversation exploring the significance of off-the-record (Ali, 2018) scripts for learning, and ask how we might more fully account for, and attend to, what constitutes post-Cartesian "rigor" in data collection and analysis as we attempt to shift away from Eurocentric, Western epistemologies.

Relational Ethics, Researchers as Learners and Methodological Futurities

Ananda Marin, Shirin Vossoughi

In what ways can Interaction Analysis (IA) and related ethnographic methodologies seed radical transformation? What role does deep engagement with the histories of bodies, places and disciplines play in such possibilities? We pursue these questions through close engagement with two settings where we participated in co-design relations that preceded and spilled out beyond "researcher" in ways that matter for how we understand the roles of research. We co-analyze key moments from one another's settings to consider how our training in IA and ethnography served as axiologies that shape everyday relations, particularly when shared political and educational work are leading activities and research is reconfigured as a form of learning towards those evolving ends.

In the first setting, ethnographic and interactional methodologies (McDermott & Raley, 2011) were utilized to scaffold teacher learning through careful attunement to pedagogical interactions. Within a teacher residency program that combined university courses on learning and educational justice with guided participation in a community-based summer program serving Black and Latinx middle school youth, the broader study considers the pedagogies and forms of co-teaching that supported teachers to attune to the histories of bodies, places and disciplines in ways that nurtured deep shifts in their ways of being with children. We draw on teacher fieldnotes as well as the dialogic feedback they received from researchers/teacher educators to examine how a novice teacher shifted their own talk and embodied interaction with a student in ways that reached towards an ethic of relationality, racial justice and holistic personhood. This empirical story helps us consider how criticality becomes necessary but insufficient for supporting educators to perceive and construct possible futures in here and now activity (Bang, 2020; Bang & Vossoughi, 2016).

In the second setting, co-design (Ishimaru et al., 2018) and conversational methods (Kovach, 2010; Wilson, 2008) were used as tools to explore how collaborative and improvisational performances become contexts for the microgenetic and ontogenetic development of skills, knowledge, and capacities across time, space, and social relationships. This project invited a collective of five Chicago-based improvisational jazz artists and musicians that routinely perform together and apart in various combinations of ensembles to use the tools of research to engage in and reflect upon their routine activities (i.e., designing and enacting a conversational concert and listening session). We draw on video and transcript data from co-design sessions to examine how genealogy and kinship (Janke & Gilles, 2012) were evoked to create contexts for participants to mobilize research toward their own desired ends — engaging in processes of relationship building through historicizing their own embodied and geographical stories of artistic creation. We consider how material relations (i.e., instruments and artistic tools) not present in the scene are made relevant through processes of remembering and storying, troubling tendencies towards relational dehistoricizing in IA.

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Both studies consider what it can mean to understand researchers as learners who observe to participate and participate to observe in ways that can facilitate a relational praxis (Gutiérrez & Vossoughi, 2010). We consider interactional and ethnographic sensibilities as both scaffolded and endogenous to life (people are always already reading bodies, place, race, gender etc.) in ways that highlight the complex, sedimented layers of everyday activity. We work together to articulate how the growing attention to criticality in the learning sciences might reimagine and reorganize research towards transformative ends, raising questions about anchoring a critical politic (only) in the deconstruction of research as power. Here we draw on Indigenous and Māori centered work on the centrality of kinship and genealogy (Jahnke & Gillies, 2012), as well as ideas of "worthy witnessing" (Winn & Ubiles, 2011) to support relational accountabilities and the co-creation of possible futures.

Studying Affect and Learning through Lenses of Collective Memory, Histories, and Imagination

Natalie R. Davis, Thomas Philip

Research on teaching and learning has long focused on the role of emotions and affect (Boler, 1999; Fredricks et al, 2004; Vygotsky, 1987). Much of this work has explored how emotions serve as a conduit for learning by shaping motivations to learn and participate within communities of practice (Vea, 2020). More recently, scholars have advanced research that (re)considers emotion as a target of learning, and that recognizes the collective, political and ideological understandings represented through affective stancetaking (e.g. Boler & Zembylas, 2016; Curnow et al, 2021; Vea, 2020). While the Learning Sciences has demonstrated a growing interest in examining the affective dimensions of learning, there has been less focus on the methodological frameworks and tools needed to deepen understandings of emotion as situated in collective memory, histories, and imagination.

One of our primary concerns lies in the methodological tendency to overemphasize researcher-observed, individualized, universal and/or discrete constructs for emotion. An exclusive focus on an individual's affective experiences through this lens may obscure the complex relationships between affect, sociopolitical histories and contexts. For example, traditional ethnographic methods and discourse analysis are less likely to provide insight into affective experiences of learning that are not overtly expressed in the body at present or articulated aloud (Parks, 2020). Outbursts are documented but more subtle felt understandings tied to histories of power and race often drop out of our analyses. This may inadvertently suggest that learning only carries emotional valence at particular moments in time and in direct response to recent stimuli. Classical methodological approaches may also de-emphasize the racialized, gendered and/or aged experiences of learning to negotiate, subdue or internalize emotions in educational contexts. How do we account for the felt dimensions of learning that may be discerned in interaction while also interrogating if/how/when full emotional expression is constrained or otherwise less visible? As an alternative to decontextualized and individual assessments, the lens of emotional configurations helps us name and study the "situated and reciprocal interrelationships between feeling, conceptual sense-making, and practice that give emotion social meaning in the learning of individuals and collectives" over time (Vea, 2020).

In this paper, we revisit comparative cases from our individual work focused on ethics, historicity, politics and STEM learning. The first case draws data from a project that investigated Black children's layered meaning making during a classroom unit on water (Davis & Schaeffer, 2019). This work centered analyses of the socioscientific and felt dimensions of learning about water justice, a topic which can also be viewed as layered and embedded in longer, racialized histories of power. The second case explores undergraduate students' sensemaking in an engineering ethics class focused on militarized drones (Philip et al., 2018). The re-analysis presented here situates the localized manifestations of affect within the broader historical memories and ideologies of colonialism, imperialism, and nationalism. Looking across our own research, we consider the methodological openings and tensions inherent to work focused on affect, learning and justice. Applying the lens of emotional configurations and Gordon's (1997) notion of haunting, we look closely at textual and visual data to determine if/how they might serve as a window into collective histories of sociopolitical striving and human suffering.

Our findings raise questions about how we represent and study affective experiences in spaces of learning. Where the learning sciences has in large part focused on how individuals feel, our analyses suggest that collective longings for justice, imagination and shared felt experiences also co-construct learning in important ways. In the case of the water justice example, Black children's strong emotional responses to and learning about the Flint water crisis were also connected to their layered understandings and awareness of racism. We conclude with ideas for how researchers might become more methodologically attuned to collectivity and histories while also attending to the nuances of affect in moment-to-moment activity.

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Arts-based methods in exploring issues related to power and colonialism in science participation

Lucy Avraamidou, Isabel Martins

Our purpose in this paper is to argue about both the need and the value for disrupting specific conceptualizations of the nature of science (i.e., white, heterosexual, middle-class men with superior intellect producing absolute knowledge in an isolated, culture-free, and methodical way) through capitalizing on ethos: scientific knowledge should be accessible to all members of the scientific and social communities to use. Toward this goal, we will engage with the following questions: a) How have understandings of the nature of science contributed to conceptualizations of who can be a scientist and who is recognized as a scientist? b) How are these understandings tied to issues related to power and colonialism in science education, c) How have these conceptualizations contributed to producing exclusionary narratives and perpetuating inequalities in science? d) How might arts-based methods be used to explore issues related to power and colonialism in science participation?

In exploring these questions, we draw from research projects carried out in the context of the Netherlands and Brazil and provide empirical evidence of how various arts-based methods (e.g., narrative production, life stories, photovoice products, writing and poetry) were used to explore issues related to power and colonialism in science participation in the context of after-school science programs with young children.

The first research project is situated in the Netherlands and examines the ways in which out-of-school, STEM community-based programs might serve as a means for disrupting monolithic conceptualizations of the nature of science and existing exclusionary narratives of who is considered a legitimate producer of scientific knowledge (Avraamidou, 2021). This is especially important in former colonial contexts, such as the Netherlands, which, unlike other European countries lags behind in processing its colonial past across educational institutions (Wekker, 2016). Hence, the out-of-school program, theoretically framed in Culturally-Relevant/Sustaining Pedagogies, aims to serve a group of young children with a migration background. The project comes as a response to the urgency and value of engaging with a set of underexplored questions that relate to issues of colonialism, power, and racism, in science education in the Netherlands.

The Netherlands is used as an example of a country with a colonial past, in order to make the case for the urgency and value of addressing goals related to social justice in education. This interest is rooted within the fact that the community of educational researchers, especially in the area of STEM education, have remained largely uninvolved with research that examines issues related to access, inequality, colonization and equity.

The second research project is set in Brazil, a country where race relations have been shaped along almost four centuries of slavery of Black populations who were brought by force from Africa. For Gomes (2003), one of the challenges faced by Black populations in Brazil is "to build a positive Black identity in a society that, historically, has taught black people from very early on that in order to be [socially] accepted, it's necessary to deny their own identity" (p. 171). In 2003, following years of claims by social movements, a federal bill made the teaching of Afro-Brazilian and African History and Culture compulsory in Brazilian Basic Education. Although authors like Santos and Neto (2011) acknowledge that the school alone will not be capable of reversing years of disqualification of the black population and consequent social injustices, several efforts have been made to reinforce the role of schooling in fighting against racism and overcoming prejudice (Verrangia 2014). The project analyses the efforts of a community of learning which gathers university researchers, pre-service and in-service teachers, and research students in order to develop contents for a website that explore approaches to racism in the science curriculum. Contents are organized as Questions & Answers which address issues such as: social media algorithms that select and erase images of people according to phenotypic aspects; ways through which structural racism in Brazil shapes social and professional relations in science; expressions of scientific racism concerning health rights of the Black population, amongst others. Analyses explore transdisciplinary contributions to the understanding of racism and its curriculum representations as well as ways to fight it.

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International Society of the Learning Sciences

Expansive Learning and Transformative Agency for Equity and Sustainability: Formative Interventions in Six Continents

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Abstract: This double symposium brings together activity-theoretical formative intervention research conducted in six continents. The aim is to illuminate and examine the common threads, important differences, and new challenges of formative intervention studies to address "wicked problems" in different cultural, political, and economic contexts. Formative interventions facilitate expansive learning and systemic transformation led by local stakeholders in organizations and social movements. The formative intervention methodology is based on the principles of double stimulation and ascending from the abstract to the concrete. Its most well-known application is the Change Laboratory method. Formative interventions generate and support expansive learning and transformative agency. The current global crises of climate change, poverty and deepening inequalities are giving rise to what is called fourth generation activity theory for tackling fateful challenges by building heterogenous multi-activity coalitions. The symposium will present the theoretical and pedagogical challenges and possibilities in Change Laboratories and other formative interventions to develop just and sustainable solutions to global crises.

Symposium Overview

This double symposium brings together activity-theoretical formative intervention research conducted in six continents. The aim is to illuminate and examine the common threads, important differences, and new challenges of formative intervention studies in different cultural, political, and economic contexts. The methodology of formative interventions is based on the principles of double stimulation and ascending from the abstract to the concrete (Engeström, Sannino & Virkkunen, 2014; Sannino, Engeström & Lemos, 2016). Its most well-known application is the Change Laboratory method that has been used in more than 30 countries since its inception in Finland in the 1990s (Engeström & al., 1996; Sannino & Engeström, 2017; Virkkunen & Newnham, 2013). Formative interventions generate and support expansive learning (Engeström, 2015) and transformative agency (Sannino, 2020b). The current global crises of climate change, poverty, and racial inequality are giving rise to what is called fourth generation activity theory for tackling fateful challenges by building heterogenous multi-activity coalitions. This is reflected in recent developments in Change Laboratories and other formative interventions. The symposium will present and discuss these developments and seek ways to conceptualize them.

In learning sciences, it has been suggested that formative interventions might be a way to overcome the limitations of the linear interventions and expand design-based research regarding engaging local stakeholders in the design, implementation, and analysis of interventions (Gutierrez, Engeström, & Sannino, 2016; Penuel, 2014; Sannino & Engeström, 2017). Change Laboratories and other formative interventions offer new possibilities for rigorous analyses of intensive processes of collective learning, agency formation and design. Methods developed for systematic analyses of formative intervention processes allow for comparisons between interventions conducted in different circumstances. The symposium presentations will examine a range of methods used in such analyses.

The six papers of the double symposium are those of (1) Yrjö Engeström (Europe), (2) Annalisa Sannino (Europe), (3) Aydin Bal (North America), (4) Marco Pereira Querol (South America), (5) Heila Lotz-Sisitka (Africa), (6) Ge Wei (Asia), and (7) Nick Hopwood (Australia). Together the papers offer a rich set of detailed case analyses of Change Laboratories and other formative interventions from the six continents.

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The authors of the papers will elaborate specifically on the following questions from the perspective of their own continents:

- What are the challenges and needs for which formative interventions pursuing fourth generation activity theory might be particularly useful and relevant?
- What theoretical and pedagogical challenges and possible new developments might be identified in the methodology of formative interventions?

Paper 1: Formative Interventions in Theory and Practice: Change Laboratories across the Globe

Yrjö Engeström, University of Helsinki, Finland

This introductory paper of the symposium reviews and discusses the basic theoretical and methodological tenets of formative interventions. It presents the preliminary results of a comprehensive literature review of studies on Change Laboratory interventions conducted in different parts of the world. The Change Laboratory is a formative intervention method based on cultural-historical activity theory and the theory of expansive learning. Committed to serving struggles for equity, social justice and sustainability, the Change Laboratory was developed and first implemented in 1995 in Finland. Grounded in dialectics and the Vygotskian theoretical tradition, its uptake has been demanding and only quite recently it has reached the point of accelerated international adoption. By now the Change Laboratory has been used in over 30 countries in educational institutions, workplaces, and communities to generate bottom-up solutions to challenging problems and complex transformations. At this point, about 250 publications on Change Laboratories have been identified. This growing body of research s warrants a careful and comprehensive review.

Paper 2: Change Laboratories of the Fourth Generation: Interconnected Interventions for Eradicating Homelessness in Finland

Annalisa Sannino, Tampere University, Finland

Fourth generation activity theory (Engeström & Sannino, 2021) emerges largely through formative interventions that support the creation and development of heterogenous coalitions focused on critical societal challenges and "wicked problems." Whereas the early implementations of the Change Laboratory method were focused on contradictions and transformations in single relatively well-bounded activity systems (Engeström et al., 1996), fourth generation Change Laboratories bring together actors from different activity systems, from grassroots practitioners and activists to administrators and decision-makers across sectors and levels of governance.

The first full-scale effort at this type of Change Laboratory intervention was conducted in 2018 and 2019 in Finland, to support the effort to eradicate homelessness in the country. Three interconnected Change Laboratories were conducted, the first one in a supported housing unit for formerly homeless young people, the second one in the city of Tampere, and the third one at the national level. A large number of NGOs, public sector service providers and agencies, cities, and ministries participated in the city level and national level Change Laboratories. However, the first intervention in the housing unit became a reference point and source of energy for the subsequent city level and national level laboratories (Sannino, 2020a; 2020b).

In fourth generation activity theory studies, multiple coalescing expansive learning cycles need to be nurtured and analyzed. In this paper, we will examine connections and interactions between the expansive learning cycles of three Change Laboratories. All the six sessions of each Change Laboratory were video-recorded and transcribed. We also recorded a number of interviews with participants and homelessness experts. In addition, each Change Laboratory produced a document detailing the solutions and suggestions designed in the intervention. This extensive dataset will be analyzed to answer the following questions:

1. What kinds of connections and interactions may be identified between the expansive learning cycles induced by the three Change Laboratories?
2. How were these connections and interactions related to the different expansive learning actions (Engeström, Rantavuori & Kerosuo, 2013) and to the different steps in the formation of transformative agency by double stimulation (Sannino, 2015; 2020a; 2020b; Morselli & Sannino, 2021)?

Paper 3: Inclusive Future Making to Address the Racialization of Behavioral Problems in Schools

Aydin Bal, University of Wisconsin-Madison, USA

This paper presents the Culturally Responsive Behavioral Interventions and Supports (CRPBIS) Project and a multisite longitudinal formative intervention study, Learning Lab, that aims to examine and disrupt the

racialization of behavioral problems with local stakeholders, especially those from racially minoritized communities who have been historically excluded from schools' knowledge-production and decision-making activities.

Disproportionality in behavioral outcomes is a historically accumulated systemic contradiction that requires systemic solutions led and owned by local stakeholders (Bal, 2018). The CRPBIS Project was initiated in 2011 in the state of Wisconsin as a strategic family-school-community-university coalition and funded by the state's education agency, districts, civic organizations. An inclusive knowledge-production and systemic design process, Learning Lab, has been implemented in public schools in the United States (U.S.) and Brazil facing racial disparities in school discipline. Learning Lab is informed by Cultural-Historical Activity Theory (CHAT), critical pedagogies, and decolonizing epistemologies (Cole, 1996; Engeström, 2016; Freire, 2000; Ladson-Billings & Tate, 2006; Smith, 2021). Learning Lab is a formative intervention in which local stakeholders work collectively to transform their systems through articulation, examination, and resolution of contradictions. The role of the interventionists in formative interventions is to stimulate a transformation process (Gutierrez et al., 2016).

Learning Lab has been implemented at 12 schools: Two elementary, seven middle, and two high schools in four districts in Florida and Wisconsin in U.S. and one K-12 special education school in Rio, Brazil (Bal, 2016; Bal et al., 2018; Bal et al., 2021). Leaning Labs informed each other. Learning Labs included 10-15 stakeholders, especially those who were historically excluded from schools' problem solving and decision-making activities. Learning Lab united students, parents, community members, teachers, support staff (e.g., social workers, and playground attendants), administrators, representatives of civic organizations (e.g., Urban League, Centro Hispano) and the university researchers. Following a cycle of expansive actions (Engeström, 2016), members started identifying daily manifestations of the contradictions in their schools related to discipline and analyzed their existing discipline systems and its outcomes. Then, they designed new behavioral support systems to address those contradictions. The new systems were culturally responsive to their school communities' diverse experiences, resources, interests, and goals. The new systems are implemented in the next academic year.

Data were generated through video recordings of meetings, interviews, and document analysis. The method of analysis of expansive actions (Engeström et al., 2013) and the emergence of transformative agency (Sannino, 2015) were utilized.

This paper presents the design principles of the Learning Lab as an example of fourth generation CHAT (Engeström & Sannino, 2021). The session will contribute to the learning sciences by demonstrating how local stakeholders and organizations with diverse and often opposing interests and histories built heterogenous coalitions that collectively generated knowledge about racial disproportionality and designed the future of their schools for justice, joy, and expansive learning for *all*.

Paper 4: Formative Interventions for Re-integration of Adolescents in Conflict with the Law

Luciana Pena Morgado, Rodolfo Andrade de Gouveia Vilela, Marco Antonio Pereira Querol

Change Laboratory has been increasingly used in Brazil as a method for developing work in multiple activities (Vilela et al. 2020). For instance, it has been applied in developing the activity of children labor prevention (Donatelli et al. 2020), public health (Masiero, 2018), education (Cenci et al. 2016; Silva-Macaia et al. 2020), railway transport (Lopes et al. 2020), urban cleaning service (Bobadilha, 2020), waste management (Cassandre et al. 2018), agroforestry (Francisco Junior, 2018), airport construction (Lopes et al. 2018), and labor inspection (Vilela et al. 2018) among others.

The study presents a Change Laboratory intervention implemented for developing activities involved in the re-integration of Adolescents in conflict with the law (Morgado, 2018; Morgado et al. 2020). The initial problem that led to the demand of the intervention presented in this study was the recurring episodes of violence in which security guards and adolescents were involved in a cycle of violence. The intervention took place in a Re-integration Center located in Campinas, Sao Paulo State, Brazil. In the study, we will present how the method of double stimulation was used to produce transformative agency and expansive learning. The data is composed by 30 hours of transcription of videos of 14 sessions, lasting two hours each, which took place between August 30, 2018, and April 30, 2019. During the sessions, with the use of double stimulation, practitioners expanded their conception of the problem and causes of violence, formulating a hypothesis of the main contradiction between the object of social workers (to re-integrate by education and psychological assistance) and the object of the security guards (to imprison using violence). With the help of models as second

stimulus, workers designed, tested, and implemented a germ-cell - a new model for the activity that integrated both objects. They developed a boundary crossing tool, what they called an "Qualified Case Discussion", in which the family of the adolescent, the security guard, the social workers, psychologists and pedagogues jointly constructed the trajectory of a young. The main developmental challenge now is how to expand the new model to other units of the institutions and to the high management.

Paper 5: @River Commons Formative Intervention: Scaling Citizen-based Water Quality Monitoring in South Africa

Heila Lotz-Sisitka, Rhodes University, South Africa

Fourth generation CHAT research and its concern for poverty and climate change responsiveness via expansive learning and transformative agency (Engeström & Sannino, in Yamazumi, 2020) is immanently necessary in South Africa, the 30th driest country in the world where we are experiencing a persistent crisis in water resources supply and quality management which affect the poor most severely. This crisis intersects with a historicity of apartheid state infrastructure marginalization, and contemporary mass failure of wastewater treatment plants and associated monitoring capacity. Coupled with regular climate change induced droughts, this manifests as a cultural-historical-ecological wicked '@RiverCommons' problem of long durée. It induces an urgency to learn and act in and for equity and sustainability in a context where a history of racism and exclusion has left up to 60% young people unemployed. Involved in the '@River Commons' 4th generation CHAT inspired formative intervention processes (Engeström & Sannino, 2021) are policy actors, intermediary institutions, and citizen-based water quality monitoring (CBWQM) groups operating in an intersecting, multi-levelled system of heterogeneous coalitions (HCs). Currently this is involving the following HCs:

A tertiary form of heterogenous coalition (HC) involving: the Department of Science and Innovation, the Water Research Commission, Ecological Infrastructure for Water Security coalitions, business partners, major NGOs, national educational institutions, and the Presidential Employment Stimulus Programme

Secondary form HCs - Hosting organizations and graduates: River Rovers (supporting the Enviro-Champs) and Data Detectives (translating the data from the mobile data monitoring application into tools for 'management into action' and 'agency for river health' activity, amongst others), all working in support of CBWQM river monitoring activity.

Primary HCs involving unemployed youth and their communities, community organizations, traditional leaders and local government partners who monitor and report on river health at local levels in and across catchments.

All are engaged in expansive learning cycles that seek to address a pernicious policy-praxis contradiction that promotes CBWQM, but which fails to support it pro-actively on all fronts.

The '@RiverCommons' formative intervention is taking place as we speak – to date over the past four years, continuing into the present. Led by a coalition of active partner organizations operating within and between diverse HCs; expansive learning cycle(s) and transformative agency via double stimulation processes have been catalyzed along HC learning pathways that focus on different aspects of generatively 'scaling' CBWQM activity along a differentiated CBWQM value chain. Mirror data and double stimulation tools have been generated through historical and ethnographic data that includes reviews of CBWQM practice, survey data involving 60 CBWQM HCs, analysis of research and evaluation reports, questionnaire data, and in-depth policy contradictions analysis as well as workshop data.

Four adapted change laboratory interventions or 'national workshops', involving intersecting actors from the 3 HCs, with smaller scale less formal Change Laboratories involving multi-actors (at times online due to COVID-19) in-between the 3 main CLs, were catalyzed and documented, with more emerging. Diverse aspects of generative forms of 'scaling' CBWQM activity have, so far, been advanced with different HCs along expansive learning pathways, and via cross over Change Laboratories involving all HCs. The 'old' activity of voluntary CBWQM using a limited scope of tools has been extended to a youth employment initiative developing a 'work for the common good and learn for the future' approach to CBWQM that embraces equity and sustainability principles *at the same time*, using a wider range of tools, but which still needs to be more fully institutionalized and embedded in national systems of education, training and work. The '@RiverCommons' formative intervention work is therefore still in progress but is shaping emergence of ethico-politically inspired emancipatory agency from below for scaling of CBWQM '@River Commons' in settings where equity and sustainability must be engaged at the same time. Elaboration of the focus on emergent ethico-political emancipatory agency across HCs offers a new perspective on CHAT research, especially in its emergent fourth generation.

Paper 6: Developing Pre-service Teachers' Practical Knowledge through Formative Interventions

Ge Wei, Capital Normal University, Beijing, China

Practical knowledge is critical for the professional development of teachers, and the development of such knowledge in advance is important in initial teacher education (ITE). However, very little research has so far been undertaken to uncover the evolutionary process through which the components of such practical knowledge are acquired. By conducting a longitudinal interventionist study in a Chinese Normal university during the 2017-2018 academic year, this paper helps improve the understanding of how pre-service teachers (PSTs) develop their practical knowledge through interventions made by more experienced external parties (e.g., school and university mentors). Through the 13-month period of formative interventions, we examined a series of changes in PSTs' practical knowledge through their performance in a mandatory learning module, *Curriculum and Instruction* (which includes two courses and seven credits), in a bachelor-level ITE program.

Drawing on expansive learning theory (Engeström, 2015), we explored a multi-cyclical learning trajectory of theory and practice during the interventions. The results showed that the seven expansive learning actions functioned as analytical tools to map the PSTs' learning, while several deviations, disruptions, and practical actions of design during the process were revealed as well. Moreover, knowledge components of PSTs' practical knowledge have various manifestations in different sessions of intervention.

This study is a response to the historical crisis of the theory–practice schism in teacher education. In contrast to a linear input-output teacher training method, formative interventions facilitate the development of PSTs' practical knowledge through active engagement, self-inquiry, and a 'heterogeneous coalition' (Engeström & Sannino, 2020) between PSTs, teacher educators, and potential knowledgeable others. This study proposes a new research agenda for the transformation of ITE program through the activation of PSTs' professional agency in formative interventions. Meanwhile, it contributes Asian experiences and reflection to the methodology of interventionist studies in an uncertain times.

Paper 7: Developing Equitable and Engaging Pedagogies in Nepalese Classrooms through a Cross-national Pragmatic Formative Intervention

Nick Hopwood, University of Technology Sydney, Australia

This paper addresses the questions of this symposium with reference to a collaboration between education researchers in Australia and teachers and teacher educators in Nepal. What are the current challenges and needs for which Change Laboratories and other formative interventions pursuing fourth generation activity theory might be particularly useful and relevant? What theoretical and pedagogical challenges and possible new developments might be identified in the methodology of formative interventions? In this case, challenges related to (1) aiming to deliver long-term change but having only limited time for direct collaboration; and (2) constraints in the Nepali education system that created contradictions between participants' desired pedagogies and those that seemed possible. The formative intervention needed to develop means to enact high quality pedagogies that cost little or nothing in money and time. The paper reveals how pragmatic variations to Change Laboratories can uphold foundational principles while also adapting to contingencies of complex international collaborations and challenging pedagogical environments.

Starting points: frustrated pedagogical ideals

Many teachers and teacher educators share a common frustration: that the pedagogies that wish to see enacted in classrooms do not materialize. We need to identify historically accumulated contradictions in activity systems that lie at the roots of these difficulties. In countries such as Nepal, these contradictions originate in colonial influences on formal education, and continued inequalities of wealth. Today, teachers are charged with delivering a curriculum that is heavy with content, often in crowded classrooms, often in a language (English) that is not the language students speak at home. Cultural values and norms also shape what teachers do in the classroom, and thus may contribute both to the development of contradictions, but also ways of breaking away from them.

The intervention

A formative intervention study was conducted that resulted in a significant change in pedagogies across a whole school in Kathmandu. It was part of a collaboration between the University of Technology Sydney, Kathmandu University and Tribhuvan University in Nepal, The Royal University of Bhutan, a Nepalese

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educational NGO, and teachers from schools in Nepal and Bhutan. A group of 14 teacher educators and teachers spent two weeks in Sydney, and then continued the process of change upon return home. Inspired by the Change Laboratory (Engeström et al., 2014), mirror data were collected to enable participants to gain reflective distance and see themselves as agentic actors (Virkkunen & Newnham, 2013): closely discussing practice and using artefacts to identify problems and question the status quo (Bal et al., 2021; Morris et al., 2021). A key contradiction was identified: a desire to engage learners more, more interactively with each other, and more equitably (particularly concerning female and less high-achieving students) vs didactic approaches that became a default for teachers concerned to deliver content in a short amount of time (where student engagement tended to be limited to higher-achieving boys who would volunteer to answer teacher questions, and there was otherwise little student-student interaction).

The outcomes

Participants developed a suite of eight principles: new mediating artefacts to reshape classroom practice. Crucially these were viewed as being low-or-no cost materially and in terms of time. These were: growth, playfulness, liveliness, designing for praise and appreciation, setting up for success, inclusiveness, journeys between concrete and abstract, and stories. Two teacher educators from Kathmandu University applied these principles through the idea of micro-projects. They took this idea back and worked over several years with a nearby school – Creative Academy. Micro-projects began as a germ cell, a compressed idea that ascended and expanded into diverse concrete forms (Engeström, 2020). It was a practical idea that could embody the eight principles. Over time, a micro-projects group formed in the school, and their use spread across curriculum areas and grades, first across the primary school and then into the secondary school.

Insights

Micro-projects became firmly embedded in pedagogies in Creative Academy, representing a significant transformation. This became possible through expansive learning, prompted by the formative intervention. However, tracing ways in which the object expanded reveals how this process relied on principles that have long underpinned Change Laboratories, but which diverge significantly in their concrete, pragmatic manifestation. This suggests a helpful openness in CHAT-inspired formative interventions, showing their adaptability in the face of distinctive challenges presented by contextual needs and constraints.

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Moving toward dignity-affirming invitations to embodied participation in the design of learning environments

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Abstract: This symposium questions a basic assumption in the research and design of embodied learning environments: that the embodied forms of participation we design for will always be taken up as good and desired by participants. Across five papers, we reflect on our own design work across various contexts to think about how embodied learning spaces have and can invite embodied forms of participation that engage learners in meaningful participation while also affirming their dignity and human becoming. Across our work we seek to understand how learners' dignity intersects with embodiment. Together our research offers new directions in embodied methodologies and the design of embodied technologies and activities.

In the last decade, researchers and practitioners in the Learning Sciences have championed the embodied foundations of learning (e.g., McDermott & Pea, 2020; Nathan, 2022), leading to improved understandings of the role of embodiment in various settings (e.g., Vossoughi et al., 2020), the development of frameworks and technology-mediated learning environments that leverage learners' embodied actions to foster new learning (Abrahamson & Lindgren, 2014; Danish et al., 2020), and the description of embodied pedagogies that can broaden learners' pathways for understanding complicated concepts, particularly topics in STEM (DeSutter & Stieff, 2017). However, a tacit assumption in the majority of this work is that learners are willing and desire to participate in such physical and visible ways. While the affordances of leveraging embodied resources for sense-making are well documented, designing embodied learning environments without attending to the lived embodied experiences of learners and their "linguistic and cultural-historical repertoires" (Gutiérrez & Rogoff, 2003, p. 22) can reiterate deficit perspectives of learning and diminish opportunities for dignity affirming educational experiences. By dignity affirming educational experiences we are referring to the ways we position learners to have meaningful and substantive interactions with learning materials that also affirm their personal identity and cultural and moral sensibilities (Espinoza et al., 2020). Dignity and learning are inextricably linked. The ways that educational environments sanction certain forms of participation within them can either legitimize or delegitimize learners' sense of worth. This is particularly important to attend to in embodied learning environments because the body is not just a source of intellectual activity, the humanizing and dehumanizing experiences of the lived body also impact cognition (Bustamante et al., 2019). Therefore, as educators designing for embodiment, we must attend to learners' repertoires of practice in order to honor learners' participation rights and affirm their educational dignity (Espinoza et al., 2020).

The goal of this symposium is to initiate dialogue on how we currently create embodied learning environments, and how we might do so in ways that increasingly honor learners' repertoires of practice and offer them dignity-affirming educational experiences. To explore this issue, this symposium brings together researchers involved in designing embodied learning environments to present a range of examples in which they have asked the following question of their work: *How can we invite learners to participate in embodied learning experiences in dignity-affirming ways?*

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The first two papers discuss the use of embodied pedagogies in classrooms showing ways to honor learner dignity through movement. The next two papers discuss the design and implementation of embodied Mixed Reality platforms providing methodological guidance for future designs. The fifth paper draws from trauma-sensitive instruction and offers principles for developing inclusive instruction in embodied activity. Taken together, these papers take a critical look at embodied learning and offer suggestions for revising research methodologies and technology design that can move us forward toward building dignity affirming embodied learning environments.

The symposium will be organized as follows: (1) Co-chairs will share a brief introduction introducing the themes and issues to be discussed (3 min); (2) each project will present (10 min); (3) the discussant Molly Kelton will examine themes and juxtapositions across the papers with an eye toward how affirmations of dignity require us to re-consider common assumptions made in the field about learners' bodies and their experiences of embodied designs; (12 min); (4) we will take questions from the audience (10 min).

The Relationality of Theatre Games: How Undergraduates "Warm-Up" to Embodied Learning

Lindsay Lindberg, Ananda Marin, Andrea Kern, Marjorie Faulstich Orellana

Despite movement being beneficial for learning (Nathan, 2021), the majority of learning experiences in the academy are sedentary (Barbour, 2004). In order to combat this sedentary bias, learning activities must be designed carefully to accomplish engaging embodied learning practices. This paper describes the importance of allowing university students the opportunity to physically engage with "warm-up" activities as preparation for the physical and cognitive practices of embodied learning.

Leading work in the Learning Sciences has called for research that values new forms of relationality as outcomes of learning (DiGiacomo & Gutiérrez, 2016; Vossoughi et al., 2020), expanding what it means to take changes in participation as evidence of learning (Lave & Wenger, 1991). Warm-up activities provide an analytic opportunity in which this change in participation is visible over a short period of time as participants move from seated and still, to moving and active. Warm-ups in the performing arts are often used for participants to attune to both themselves and to the rest of the group. A warm-up invites participants to attend to themselves and move in a way that is safe and comfortable for them, and also begin to shift their attention to a learning community that is larger than themselves. As learners gain an intrinsic perspective of the group they constitute together, we are able to see the ways that moving becomes consequential for their learning (Hall & Jurrow, 2015). This shift in attention is both conceptual and physical, and can be brought about in part through a series of warm-up exercises.

We present data from one multi-year ethnographic project attending to undergraduates in a college course and a student-centered after school program for K-5th grade students. Using video data from three lessons in which a theatre artist guided a group of 30 undergraduates through warm-up exercises, we highlight one warm-up activity: "pass the clap." This activity consists of participants working together to "pass" a "clap" around a circle (person 1 makes eye contact with person 2 on their left before clapping simultaneously; person 2 then turns to their left and claps with person 3, and so on). We present examples of how a theatre warm-up provided the opportunity to guide participants from an "I" centric view to a "we" experience of a learning environment.

Within "pass the clap," new relations emerged as participants learned the rules and played the game. Empathy and trust are important sensibilities to cultivate in learning environments, and are commonly absent from traditional learning contexts (Cooper, 2010), but are deemed essential and normative in theatre and arts classes (Cummings, 2016). A sense of empathy can be developed through warm-up activities, including "pass the clap." When the claps were not completely synchronized (1 beat), but were syncopated (2 beats), the theatre artist introduced a concept she called "oops - ta da!" which celebrated "mistakes" (like a syncopated or "dropped" clap) and turned them into cause for celebration. If a clap was "dropped" the rest of the class would theatrically say, "oops". The two people clapping would say "Ta Da!" and everyone would clap to celebrate the moment. This practice provided new forms of relationality for students to engage with, and allowed mistakes to be viewed as positive opportunities for growth, empathy, and resilience. In this analysis, empathy is important in that the theatre artist guided the participants to express empathy for themselves as well as for their peers. By taking a group of undergraduates in an educational theory class from seated desks to standing up, clapping, laughing, and making eye contact, the theatre artist used warm-up games to develop new relations and build empathy between participants through a warm-up activity.

These viewpoints-inspired (Bogart & Landau, 2005) theatre workshops supported the development of intercorporeality (Meyer et al., 2017), or a sense of *withness*. Hahn and Jordan (2020) argue that evidence of intercorporeality is a change in participants' identities from "I" to "we". Embodied anticipations begin to stabilize as reciprocal responsibility develops, which also supports empathy and intercorporeal trust. We see this in the

analysis of "pass the clap" as over time, participants shifted their participation strategies - they leaned forward to "catch" the clap, and collectively worked to build a community. Analysis of the students' movements through the space and physical participation in the warm-up showed a developed sense of *withness*, and a substantial repertoire of language and body practices for engaging with this undergraduate course. This broadens conceptualizations of what embodied learning can look like and result in with young adult learners.

This attention to embodied learning and the role of warm-up practices on learning communities signifies "an epistemological and pedagogical shift and draw[s] attention to bodies as agents of knowledge production (Wilcox 2009, 105)," (Wagner & Shahajhan, 2015). Expanding possibilities in higher education through studying physical warm-ups from an interactionist and embodied perspective highlights how individuals' movements can be understood in relation to the whole group activities. Designing embodied practices that are physically and socially accessible to participants is one important way to work towards pedagogy that addresses questions of power, oppression, and privilege (Wagner & Shahjahan, 2015).

Pedagogical challenges raised from science teachers about inviting adolescents in mixed classes to experience full body exercises

Roni Zohar

I developed and investigated an *Embodied Pedagogy for Teaching and Learning Physics* in doctoral research carried out under the guidance of Abrahamson and Eylon (Zohar, 2018). (https://www.youtube.com/watch?v=oLCTJQ-GCLQ). This pedagogy coheres with the embodiment paradigm which impacted educational research (Nathan, 2021). The central principle of this approach is to enable the learners to *physically experience* before using definitions or verbal explanations. "Experience first, signify later." (Abrahamson & Lindgren, 2014). Our assumption is that actual physical experience can be used as a unique resource for learning complex concepts in physics by associating them with daily body activities. The pedagogy involves physical-dynamical engagement such as directed bodily experiences (informed movements); improvisation in movement mediating between imagination and reasoning, body actions and feelings; techniques combining walking and talking; selected aspects of the Feldenkrais method and relaxation (Zohar et al., 2017). In this pedagogy, students work either in pairs or collectively on a choreographic task that gives rise to difficulties of coordinating movements. We argue that solving the coordination problems and expressing explicitly these solutions create significant learning opportunities.

The research was done in a 10^{th}-grade high school for female students (two dance classes and one physics class). We conducted the lessons in the school dance studio using *embodied pedagogy*. Through two case studies, We explored the potential of this pedagogy for learning two complex physics concepts: balance and angular velocity. We found that the students exhibited creativity and a profound understanding of the abstract concepts taught. They linked the ideas to concrete representations, to their personal world and to their private interests. The depth and insight of physics understanding that the students manifested in their summative projects were much beyond what can be achieved in regular instruction (Zohar et al., 2017).

After the doctorate research, I conducted a professional development workshop for science teachers and supported them to implement the *Embodied Pedagogy* in middle and high school classrooms. The following paragraphs depict different ways science teachers responded to the *Embodied Pedagogy* in the context of certain exercises and topics unrelated to the concepts of balance or angular velocity.

Teachers raised issues regarding the implementation of certain full-body exercises among students. For example, in one of the movement exercises for release and concentration, we raised our arms and, in the summer, where there are odors from the armpit area, students asked the teacher not to do the particular exercise. In addition, some female teachers decided not to do other movement exercises involving tapping on the armpit.

Another example is the embarrassment that some students had in pairs or group exercises that require physical closeness or touch. We should be aware that the students will naturally stand next to their friends or next to whom they are attracted to. Science teachers raised this issue in the context of teaching the concepts of attraction and rejection in chemistry and electric current in physics in which students resemble particles.

Adolescents are in a challenging time in many ways and body image and appearance are very important to them, especially when they learn in mixed classes of males and females. There is considerable debate in the literature concerning the issue of teaching adolescents in single-sex classes (Frances, 2011). As illustrated in the examples above this may be a central issue in learning that is carried out in embodied learning environments (especially with full-body). From my experience as a researcher, educator and dance & improvisation instructor, it is important for instructional designers to be sensitive to students' age and cultural settings and conduct such learning in a single-sex classes. My recommendation for the mixed classes is to ask a group of students to demonstrate and if possible, to choose a group with the same gender.

Regarding the personal movement exercises, the teacher should consider recommending to those who do not do the exercises in class to watch the demonstrating students and to try to do it at home after class. This recommendation coheres with research on brain patterns that indicates the potential of learning from watching others (Flanagan & Johansson, 2003). From teachers' reports and from my personal experience some students who decline from participating in class will try to do the movement exercises at home when they are alone.

In conclusion, although according to the *Embodied Pedagogy* approach it is better to experience with our own body and although embodied learning environments can promote understanding of scientific concepts (Zohar et al., 2018), we as researchers, educators, and teacher trainers need to be aware of dignity affirming experiences in integrating embodiment-based experiences in our practice.

Designing Mixed Reality with Indigenous embodied knowledges

Meixi, Sean Dorr, Daniel Keefe, Vicente Diaz

For many Indigenous peoples, coming to know oneself and relations has been an endeavor actualized through whole-bodied intelligences (Simpson, 2017). Learning and knowing through collective embodied experiences with lands and waters is fundamental to cultivating generations of loving, interdependent young people who learn to uphold and advance Indigenous laws and ethics. The growing scholarship on embodiment in the learning or "learning on the move" (Marin et al., 2020), is concerned with how people's mobility between and through places is both the content and the processes of learning (Gutierrez, 2008; Ma, 2017; Marin, 2020; Taylor & Hall, 2013). Interfacing this with Indigenous understandings of mobility and knowing, Indigenous knowledges exist and are advanced through the living and material engagements across human bodies and place (Marin, 2020). In fact, Diaz's scholarship on seafaring (2019) illustrates "how native roots and routes are not mutually exclusive but mutually and powerfully constitutive and generative" (p. 33). In this paper, we focus on the conceptual intersections of embodied participation, Indigenous knowledge systems, and the design of Mixed Reality experiences that begin from Indigenous embodied knowledges (Back to Indigenous Futures, 2019). Additionally, we provide examples of how grounding the design of Mixed Reality technologies can expand intergenerational participation in computer science and Mixed Reality technologies and support the revitalization of seafaring practices in two Indigenous communities in Minnesota.

This paper is based in the Back to Indigenous Futures project partnership with Dakota and Micronesian communities in Minnesota, a community-engaged project purposed towards cultural revitalization and shared learning of their traditional ecological knowledge systems. We view dignity-affirming contexts within the design of Mixed Reality developments in computer science as beginning from the intellectual grounds of Indigenous knowledge systems, specifically, *Paafu*. We target Mixed Reality as the medium specifically because this technology lends itself to embodied experiences.

Designing effective Mixed Reality, embodied experiences is challenging, in part, because the technology can take many forms; these are often described as existing along the Reality-Virtuality Continuum (Milgram et al. 1994). Immersion and presence vary across the continuum and affect the degree of embodiment that is experienced within each. Embodiment in the technological sense refers to what degree one feels the body they are inhabiting is their own, the location of the body is consistent with the mental representation of location, and there is a sense of agency in one's movements (Borrego et. al, 2019). When this definition is juxtaposed with the working definition of embodiment we've used thus far, the question then is not simply how well the technology affords advancing embodied Indigenous knowledge, but also how whole-bodied Indigenous intelligences might advance our conceptions of place, design, and mobility.

Paafu: Indigenous embodied knowledge to support mixed reality development

Paafu, from navigators of the Central Carolines, is a way of organizing the rising and setting of stars for teaching directionality - or simply put, to determine where one is in relation to other markers in seafaring (Diaz, 2019). In the following sections, we highlight the ways in which *Paafu* is conceptually and mathematically advancing the community-based Mixed Reality experiences. Specifically, we highlight using two concepts: (1) wave swells and (2) moving islands, and discuss the ways we are engaging these ideas to create a platform that Micronesian and Dakota families can engage with to tell, listen, and embody their stories of lands, canoes, and journeying across place.

Indigenous design 1: Wave swells In *Paafu*, the outrigger of the canoe faces in the direction of *Tan Mailap* (Altair rising), from whence also flows a major swell from due east of the island of Polowat, for in traditional Carolinian seafaring knowledge, stars and sets of swells serve as proxies for each other in their respective domains (Diaz, 2021), rendering both especially effective instruments for reckoning direction, as well as timing. Moreover, being attuned to the particular and idiosyncratic rhythm and tempo of a particular

swell/rising or setting star, as experienced bodily in the pitch and roll and sonics of a canoe, can also indicate location, direction, and time. Recognizing these embodied skills and knowledges as a set of inherently mathematically dense activity, our design of Mixed Reality experience also acknowledges and builds upon the rigor~~ous~~ of Indigenous design that is embodied in this knowledge set.

Indigenous design 2: Moving islands Likewise, we build upon the traditional Carolinian seafaring concept of etak, or "moving islands," an ancient technique for calculating distance traveled, or position at sea, by triangulating the speed of the islands of departure and destination with that of a third reference island, as these are further "plotted" at sea and in the sky (through the aforementioned reflexivity and indexicality between sea and sky as illustrated in the correlative status between certain swells and certain rising and setting stars. (Diaz, 2011; 2021). Recognizing the sky and the sea as mutual markers and time keepers for directional and navigational purposes is also another way to recognize how Indigenous personhood is reckoned through mirroring relationships with the natural elements through their instrumentalized usage for the purposes of travel in both geographic and ontological terms: relating to the relationships that exist between swells and stars, sea and sky, in nature, is also an example of how Indigenous people "plot" selfhood relationally, in time/space. for the purposes of efficacious travel and for defining one's sense of self historically and culturally. How might this concept, or better yet, technology of moving islands challenge the temporal, spatial, ontological, and bodily-assumptions and norms that inform and underwrite computer graphic design and production? In what ways might Mixed Reality technology help explain as well as benefit from these radically different instruments of time/space imaging?

This paper traces the generative tensions and possibilities of refusing colonial assimilation (Diaz, 2019; Back to Indigenous Futures, 2019) into dominant ideas of the development of Mixed Reality and experiences, by centering the particular knowledge systems of a community and using that as the grounds for digital technology development. Instead of discourses of technological access that presume deficit-orientations common in STEM, we are interested in how first, Indigenous knowledges can advance our understandings of technology, design, and embodiment, and secondly, how these Mixed Reality tools can also further Indigenous knowledge and futures for Indigenous young people, families, and communities.

Building meaningful participation using embodied Mixed Reality technologies

Nitasha Mathayas, Xintian Tu, Joshua Danish, Lauren Vogelstein, and Lana Cosic

We represent a larger team of researchers who developed an embodied Mixed Reality (MR) learning environment that blends elementary grade students' movement through play with a virtual interface depicting various scientific phenomena (Danish et al., 2020). Designed for classrooms, we use motion tracking technology to track the movement of up to 10 students at a time while remaining students make observations and mediate their peers' activity. Our environment focuses on coordinated, collective activity amongst participants, and thus *meaningful embodied participation* occurs when students work collectively, using their bodies and adapting their actions in response to their peers, to explore scientific phenomena.

Although our previous studies show that creating embodied learning opportunities for young children supported complex scientific modeling (Danish et al., 2020), our design has implicitly assumed that all children wanted to participate in this physical way. Their "willingness" to participate in embodied activity over time was never questioned. Espinoza et al. (2020) explain that meaningful participation is deeply intertwined with students' educational dignity influencing how they act in educational environments. This led us to question how meaningful embodied participation through our environment affirmed or did not affirm the dignity of students. In this paper, we revisited a past study to interrogate moments where the lack of focus on dignity affirming designs may have inadvertently led to problematic experiences for our participants. We examined multiple interactions before settling on two episodes for further analysis in which first and second grade students were exploring states of matter. We then utilized methods of Interaction Analysis, IA, (Jordan & Henderson, 1995) to explore how some students' meaningful embodied participation did not appear to elicit a potentially desired response from peers, and yet which upon further reflection in our IA sessions may have thus been disappointing or frustrating for the participants. We discussed how student participation was meaningful, what student interactions were missed by the facilitators (us), or peers during each moment, and questioned how we could have better supported students in dignity-affirming ways. The following case descriptions include the main observations from each case followed by some general implications for embodied technology design.

In the first episode, the class was divided into three groups and each group took turns modeling states of matter using our MR platform. One student, Mary, did not join her modeling group when it was their turn to embody a state of matter. She quietly observed from the back of the class while her group constructed a model of gas particles with their bodies, and other groups shared observations from the sidelines. After the round ended, the classroom teacher asked Mary if she wanted to participate in the embodied activity which she declined. The

teacher then offered Mary an alternative role as an observer and annotator which she accepted. In this way, Mary was provided an alternative way to engage in the modeling without having to physically work with her peers in the moment raising the questions: (1) What methods could we have used to learn why Mary did not want to participate in the embodied activity? (2) As the embodied activity unfolded and Mary's personal goal changed, how could we have made space for Mary to express her changed goals? (3) Might we have benefited from asking Mary and the other students how they'd like to participate in the first place?

In the second episode, the instructors had half the students modeling states of matter by moving while the other half of students gestured to give students-as-particles energy from the outside. As this activity unfolded, the screen depicted particles changing states of matter which caused modeling students to move faster but the gesturing students to stop and watch the screen. We also found that modeling students then dominated the following discussion, even though gesturing students raised their hands to share their ideas. This made us question whether our platform, which is designed to track the modeling students' movement in the center of the room, may have inadvertently privileged their embodied activity over the gesturing students' activity. Since the MR environment is limited by the number of students it can reliably track in a classroom space, how might we adapt the environment to involve the observing students' embodied activity? How might we better support observers in taking as active a role in discussing their peers' embodied activity as they'd like?

Ultimately, these cases suggest the need for pedagogical measures and tools that regularly check for student willingness to participate. Also, designers of embodied classroom technologies need to carefully examine how the different forms of participation might privilege certain students' conceptual contributions over others.

Every Body Belongs: Principles for Inclusive Instruction in Embodied Learning Activities

Morgan Vickery

Often student participation in embodied activities relies on a set of normative ideals that students' bodies look, function, and respond in a particular way. These ideals are grounded in the valuation of mesomorphic, masculine, motor-competent, and 'able' bodies as worthy of attention and praise whereas expressions of difference (in activity participation, in setting, or in degree of physicality) often fails to activate the same level of social capital within peer groups (Fitzgerald, 2005) and is treated as noncompliance by instructors (Goodwin, 2020). I draw upon scholarship related to trauma, disability, physical education, yoga, and dance in learning to consider how principles for inclusive instruction in these domains might provide insights for designing embodied activities where all bodies are welcomed, respected, and valued. Here, I propose a 3-faceted framework for designing embodied learning environments as trauma-sensitive, body-positive, and disability-inclusive.

There is a breadth of work which has been conducted to research and implement trauma-informed practices in schools at the interaction, classroom, school, and system levels. The 'trauma-sensitive' facet of this framework expands on Goodwin's (2020) 'graduated instructional prompts' framework which offers principles for trauma-sensitivity during embodied activities: (a) the avoidance of language which might be interpreted as a demonstration of dominance or function as microaggression (for example "everyone can see you," "stop being disruptive," or the use of condescending/infantilizing tones), (b) respecting bodily autonomy, sanctity, and ownership and thus avoiding physical contact/coercion, (c) recognition that student non-cooperation or resistance to participation may indicate that triggers may be present, and (d) respecting students' refusal to participate.

The second facet refers to dance, yoga, and body-image scholarship to inform principles for constructing body-positive and dysphoria/morphia-sensitive embodied learning environments. Considering how such environments frequently require the collection of video movement tracking data, I raise concerns regarding the use of tools which make depictions of one's body visible to students (i.e. mirrors, projected camera views, etc). The ongoing use of mirrors and self-views in performance arts spaces has been shown to lead to students' use of self-objectifying language, comparison of bodies to their peers, and increased distress resulting from self-focused attention (particularly for students experiencing body dysphoria/morphia) (Radell et al., 2020). Picket and Cunningham (2017) also convey the importance of diverse representation of bodies in embodied learning spaces, acknowledgement of body nonconformity and authenticity by instructors (for example, sharing when a pose is difficult or impossible), the removal of hierarchical and evaluative language to refer to movements (i.e. not referring to certain poses as "beginner" poses), and normalizing asking questions, admitting limitations, approaching discussion of bodies from a holistic perspective (as opposed addressing appearance / size).

The third component for this framework draws on disability and physical education literatures' emphasis on attending to the social dynamics that exist between students; the use of competitive games where students may be excluded or activities in which students may feel the need to "blend in" are cited as problematic in disability-inclusive physical education spaces (Bertills et al., 2019). Furthermore, the explicit teaching and reinforcement

of cooperative learning practices (i.e. shared negotiation of goals, shared decision-making, constructive feedback, approaching individual accountability, etc) in peer groups has been shown to promote inclusion of students with both physical and cognitive disabilities (Grenier, 2006). Grenier (2006) also notes how 'inclusion' is not synonymous with "the same experience for all students in the same setting" but that instructions should work to identify, remove, and/or provide accommodations for barriers that students may encounter in activity.

Together these fields suggest that student experiences in embodied learning environments are multifaceted and cannot always be recognized or explained solely through observable actions and talk. Thus, I argue that we must embrace an expanded version of the 'universal trauma' principle (Goodwin, 2020) to teaching; we must presume that all students have experiences which lead to vulnerability in non-trauma sensitive, non-body-positive, and non-disability-inclusive environments. By making this assumption and over-compensating for these assumptions in our work, we ensure that students do not fall through the cracks regardless of how their trauma, mental health, and disability manifest externally. To conclude, I refer to Fitzgerald's (2005) recognition that the normative ideals that (re)enforce these barriers for students are deep-seated in the habitus of modern-day schooling and thus cannot be resolved exclusively with such instructional "superficial remedies." I acknowledge that the above categorizations should not be treated as comprehensive but rather a vehicle to facilitate discussions about expanding our notions of inclusion in embodied learning activities.

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Examining Equity in Facilitation of Tinkering and Making in STEAM

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Abstract: This symposium brings together research that examines equity as it relates to facilitation across a diverse set of tinkering and making activities and settings. Drawing on an equity framework for out-of-school learning, we focus on the potential for facilitation to create transformative learning opportunities for learners who have been historically marginalized in making and tinkering activities, including communities of color; note the complexity of equitable facilitation across settings and contexts; and highlight the importance of facilitator reflection to acknowledge and challenge hegemonic approaches in STEAM. Taken collectively, these papers highlight not only how facilitation is essential for making productive connections between making and tinkering and the sociopolitical issues at play in our world, but how those pedagogical practices themselves are sociopolitical, connected with histories and disciplines in ways that can either reify existing inequities in STEAM or create new, more equitable futures for learners and facilitators.

Symposium Focus and Framing

Tinkering and making activities draw upon constructionist traditions of learning which promote knowledge as something that is constructed through experience and gained while building something that is personally meaningful (Papert, 1980). These activities can offer new opportunities for youth to playfully engage in science, technology, engineering, arts, and mathematics (STEAM) – especially for those learners who have been historically marginalized in formal education settings (Calabrese Barton et al., 2017; Halverson & Peppler, 2018). Thus, tinkering and making spaces and activities are viewed as providing more equitable approaches to informal STEAM education than those in traditional classrooms.

Previous research has examined the ways in which equity can be located in learner agency and engagement in their chosen projects (Calabrese Barton et al., 2017), connections to knowledge not typically prioritised in such spaces, such as e-textiles and crafting (Beuchley et al., 2008), and in the power structures inherent in tools and programs offered by such spaces (Melo & Nichols, 2020). However, only a few studies (e.g., Ryoo et al., 2016; Vossoughi et al., 2021) have focused on equity and *facilitation* in making and tinkering activities - that is, how equity is enacted in the moment-to-moment decisions and actions of adults and youth who support learners in those spaces. Vossoughi et al. (2016) have argued that attending to these pedagogical practices is critical for advancing equity in making and tinkering. Focusing on equity and facilitation can push the discussion beyond considerations of access (which, by itself, is not enough to transform educational inequities; Vossoughi,

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2017) to deeply consider what equity *looks* and *feels like* for both facilitators and learners in these informal education settings.

To that end, this symposium brings together research that examines equity as it relates to facilitation across a diverse set of tinkering and making activities and settings. The goal is to examine how equity may be defined or imagined by facilitators in these spaces, what tensions may exist between those definitions and the moment-to-moment interactions between people in each setting, and what implications attending to equity in this way will have for both research and practice. In order to facilitate the beginnings of a shared understanding of equity across each paper, we draw from an equity framework for out-of-school learning first articulated by Vossoughi (2017). She argues for research that is "animated by an equity framework [which] treats all learning as a cultural and sociopolitical process and foregrounds questions of epistemology, power, and justice" (Vossoughi, 2017, p. 2). Specifically, she highlights the questions of "Access to what?" "For whom" "Based on whose values?" and "Towards what ends?" as critical tools for reflection and action in the equity framework. These questions assist researchers in illuminating "the dynamic histories of practice, ways of knowing, forms of joint activity, and value systems present," (p. 4) aspects of the cultural contexts that we believe are critical to understanding equitable facilitation in tinkering and making environments. We have expanded the framework to specify the "how?" and "why?" We believe that this expanded framework can deepen facilitator and researcher reflection on equitable facilitation in making and tinkering activities.

Major Issues Addressed in the Symposium

Firstly, our collective work showcases the ways in which facilitation is a key part of creating space for transformative learning experiences with making and tinkering, especially for communities of color and other communities who have been historically marginalized in STEAM education, by connecting activities with both current and historical sociopolitical contexts, and creating space for new possible futures. Our second point notes that equitable facilitation is a complex practice: it involves values (personal, institutional, disciplinary, etc.) which then come into contact with different learners, facilitators, materials, and informal education settings. These complex human-material and human-human relations can lead to tensions between how facilitators and learners *think* about equity versus how it is enacted (or felt) in the space. For this reason, reflecting on equitable practice in making and tinkering activities is key in surfacing histories, tacit values, and moments of discomfort, all of which can then be used to create space for intergenerational learning and pedagogies of care.

Scope and Significance of Contributions

The papers included in this session consider the facilitation of making and tinkering activities across a wide variety of settings, including online after-school programs, public computing environments, summer programs, science classrooms, library makerspaces, and museum spaces. Additionally, these papers acknowledge that there are many different roles in which one can act as a facilitator for making and tinkering, each with their own tensions and complexities as they negotiate their own positionalities, values, institutional requirements, and disciplinary norms as they intersect with notions of equity. Taken collectively, these papers highlight not only how facilitation is essential for making productive connections between making and tinkering and the sociopolitical issues at play in our world, but how those pedagogical practices and the facilitators themselves are sociopolitical, connected with histories and disciplines in ways that can either reify existing inequities in STEAM or create new, more equitable futures for learners and facilitators.

Equity as a Moving Target: Engaging Informal Learning Educators' Differing Visions of Equity

Ricarose Roque, Ronni Hayden, Celeste Moreno, & Stephanie Hladik

Science museums, libraries, and other informal STEM learning organizations are increasingly incorporating concepts from computer science alongside other STEM activities and spaces. As these efforts are still relatively new, there's an opportunity to interrupt dominant scripts of what "counts" as computing, who participates, and how someone engages with computing to more meaningfully support groups who have been marginalized from traditional computing spaces. Informal learning educators or facilitators in these spaces make key decisions at the micro (moment to moment interactions) to meso (how space is designed, how they recruit people, how they curate activities) (e.g. Vossoughi et al., 2021). Without careful and consistent effort towards equity, these decisions can influence who and how people can participate risking the reproduction of existing inequalities. As facilitators incorporate computing into their spaces, we wanted to examine how educators are engaging youth and families in equitable learning experiences. Our initial research question was: What challenges and barriers do informal

learning educators, or facilitators, face to engage their learners in design-based activities with computing? As we discussed computing activities with educators, we noticed the ways that educators were talking about and applying equity in implicit and explicit ways into their practice.

We interviewed 15 facilitators from three informal learning organizations that included a science museum, a network of makerspaces in a library system, and network of community-based technology centers for youth. All facilitators were based in the United States and represented 5 states. During 90-minute virtual interviews, we asked participants to share a computing-based activity that they had implemented in their space. We also asked questions about their background, goals, and how they considered equity in their practice. In the first round of thematic analysis, we noticed the ways that equity was emerging implicitly and explicitly in how they designed activities. To focus our analysis, we used a framework of questions inspired by an article by Shirin Voussoughi (2017), where she argues that out-of-school spaces committed to addressing issues of equity must ask: "Access to what? For whom? Towards what ends? And based on whose values?" We added the question of "How?" After conducting preliminary analysis, our research team conducted 60-90 minute, virtual "share-backs" where we shared and discussed what we learned with interviewees and their colleagues. In addition, we focused sharebacks on how facilitators were considering equity in their work and added "Why?" as a question for them to consider.

Each of the spaces had different stances on their equity work. The network of library makerspaces focused on providing free and open access to their resources. The science museum focused on examining how their equity work manifested in their pedagogy. Facilitators at the community based tech centers focused on being culturally responsive to the communities they serve. In share-backs with educators, we highlighted different tensions within their stances. For example, when considering "for whom," most library educators focused on "for all" which risks continuing to only serve dominant groups who take up these activities and misses opportunities to really focus on engaging some who would benefit the most from meaningful engagement with their resources. While we initially imagined these "share-backs" as member checks on our data, we saw potential for collective reflection and questioning in our discussions with educators around their equity work. By reflecting on "Why?" as it related to their decisions regarding materials, pedagogies, and goals, facilitators began to question and trouble current assumptions around facilitating computing experiences. Future work will continue these conversations with facilitators and incorporate their shifting visions of equity in the co-design of new computing education activities.

Speculative Fabulation: Narrating Fabulous Possible Futures through Remote Making and Tinkering

José R. Lizárraga

This paper presents findings from a study that examined the learning of student teachers in a teacher education course and youth from non-dominant communities who were linked via a remote Making and Tinkering club called the Speculative Fabulation Lab. As part of this remote after-school club, youth and teachers received take-home maker kits (with simple circuits and other craft supplies) and had remote access to a 3D printer. In this work, we consider how *speculative fabulation* is a type of digital fabrication that is "about worlding 'naturaltechnical' worlds [...], worlds needy for care and response" (Haraway, 2014, p. 242). The work presented in here builds on previous projects that have sought to examine how *everyda*y cultural practices (Gutiérrez & Rogoff, 2003) can mediate meaningful and consequential learning that is, at its core, socio-political and transformative for communities of color (Gutiérrez, Becker, et al., 2019). The following argues that designing making & tinkering learning environments for the *everyday cyborg* (Lizárraga & Cortez, 2020), in this case novice teachers and middle schoolers in a Latinx-serving after school program, fosters an engagement with everyday dilemmas in ways that serve as catalysts for further learning (Engeström, 2006) and the new world-making or *speculative fabulation* (Haraway, 2014).

Participants of this Social Design-based study (Gutiérrez, 2018) included 14 undergraduate novice teachers from diverse cultural, linguistic, and socioeconomic backgrounds, as well as majors including cognitive science, engineering, business, and computer science. Participants also included 10 elementary and middle school students from schools that served a Latinx community. The study draws from 75 hours of after-school program video data (recorded from zoom sessions), 15 hours of interviews, and 112 digital artifacts produced by 24 participants. Data also included data analytics from a custom-designed digitized learning management system. Video and audio were logged on a variety of metadata, interviews transcribed, and digital artifacts analyzed using multimodal analysis (Hull & Nelson, 2005). Codes were developed inductively (Bogdan & Biklen, 1997). Through these analyses, micro-moments were examined to gain an understanding of how meaning-making mediated in virtual making and tinkering interactions. Through remote making and tinkering (with the use of take-

home kits and remote 3D printing), expertise emerged as a distributed phenomenon which novice teachers and young people collectively examined and developed models for engaging with everyday socio-political issues and designing for new possible futures. I specifically highlight what I have coined as *cyborg sociopolitical technical reconfigurations* (CSTR), where learners assembled ideational and material tools to craft objects of learning activity that went beyond those established by teachers and schooling.

From Players to Hackers: Intergenerational Tinkering with the Socio-political in Video Game Play

Arturo Cortez, Kate Baca, & Ashieda McKoy

In this paper, we examine young peoples' and educators' learning and development in the context of a video gaming ecology. Online video-game play has gained traction as a site of digital activism, where young people collaborate with others across the world as they respond to anti-Blackness, capitalism, and other systems of oppression (Cortez, McKoy & Lizárraga, under review). In particular, we examine how young people's valued everyday practices can serve as resources for academic learning, with a specific focus on sociopolitical action, as a making and tinkering activity. Given this previous work, our project designs a learning ecology that centers distributed expertise, where young people, undergraduates, researchers, and in-service teachers learn to build together within the context of video-game play. In this regard, this study offers new theoretical insights for examining the development of relational agency (Edwards, 2017; Gutiérrez, et al., 2019), methodological affordances for studying how young people and adults build together, and pedagogical openings (Cortez & Gutiérrez, 2019) for designing learning environments that center young people's everyday cultural and making and tinkering practices. The focus of our study explores the emergence of distributed expertise as young people and educators tinker with and re-imagine racism, gender-based violence, and other forms of oppression in video games and video gaming practices. In this work, we examine the affordances and constraints of leveraging digital technology and new media to open up emerging forms of agency, activism, socio-political critique, and resistance practices for educators and young people (Lizárraga & Cortez, 2019). Broadly, our project seeks to understand how to design for expansive forms of learning in an intergenerational and interdisciplinary learning context, with specific emphasis on how and if young people and adults can identify and collaborate together, using and sharing valued tools and practices, on shared dilemmas that they experience across their everyday lives.

In this social design-based experiment (Gutiérrez, 2018) we centered the iterative process of designing and studying the naturalistic processes that emerge in gameplay. Our study draws from 115 hours of audio and video recordings and participant-generated field notes by 14 (11 undergraduates and 4 high school students). Video and audio data were transcribed. All data were reduced and coded across themes and using inductive processes (Bogdan and Bilken, 1997). Video analysis processes (Erickson, 2006) were used in order to examine the specific micro interactional moments of collaborative inquiry and distribution of expertise. Findings from our study reveal that young people and educators often contribute differently as they examine video game play. However, by examining the moment-to-moment interactions, our study illuminates how educators and young people leverage each other's expertise to jointly tinker with and re-imagine possibilities in game play and video gaming practices. We seek to identify a learner-centered approach, such that adults and young people are positioned as co-learners. The design of such learning environments are rare in formal K-12 classrooms, and, of importance, we have found that these collaborations open up new possibilities for sustained collective inquiry. In particular, our project examines how adults and young people develop critical civic literacies (Mirra and Garcia, 2020); that is, the disciplinary content that is developed over the course of the identification and resolution of a shared project, as well as the relational expertise that emerges when people learn how to collaborate together. Our study has implications for how to design for the development of critical civics and how it is attuned to social and political interrogations and re-imaginings of injustice in our institutional and everyday relational practices.

Facilitating "Reading" Code in the Context of Symbolic Violence

Simren Trehin, Apoorve Chokshi, & Pratim Sengupta

Our study offers an investigation of facilitation in the context of visitors' experiences of symbolic violence (Bourdieu, 1991; Burawoy, 2019) during their interactions with computational models and maps of racial segregation and ethnocentrism (Axelrod & Hammond, 2003; Sengupta et al., 2021). Our work arises from concerns along two dimensions: a) the paucity of scholarship on facilitation of computational models in informal spaces, with only a few exceptions (Hladik et al., 2021; Ozacar et al., 2020); and b) the entrenchment of computational models of racial segregation in White Innocence (Gutiérrez, 2005; Gotanda, 2004), which reframes

racial segregation in US and Canada as inevitable and emergent while ignoring the role of intentional, institutional and systemic racism (Sengupta et al., in press). Specifically, we ask the following research question: What roles does facilitation play in engaging ethically with visitors/learners of color as they are engaging in experiences that may result in symbolic violence?

The context of this study is a public computing environment (Sengupta & Shanahan, 2017) located in a busy walkway at a large university in Canada. The three large touch screens hold a place of prominence, displaying a multi-agent simulation based on Hammond and Axelrod's (2006) ethnocentrism model and a Racial Dot Map of Toronto, based on the Canadian census data. Visitors can interact with the simulation through manipulating sliders that (among other variables) can adjust world size, immigration rates, birth/death rates, with effects visually presented through changes in populations of different colours of agent over time. The Racial Dot Map illustrates the neighborhood-wise racial segregation in Toronto (Clark, 2011), while the simulation positions racial segregation as an inevitable and emergent phenomenon that arises through prisoner's dilemma-like interactions of co-operation and non-cooperation between individuals belonging to different racial groups, even when there is no initial bias toward segregation in the system (Hammond & Axelrod, 2006). The participant in our study, Sapna, is an advanced graduate student in the social sciences whose parents immigrated to Canada from the Global South. Sapna's interaction with the simulation was facilitated by a member of our research team (Apoorve), while another member (Pratim) video-recorded the interaction, which was also transcribed for analysis. Using a constant comparative approach (Glaser & Strauss, 2017), we identify key vignettes in the interaction between Sapna and Apoorve. Based on Espinoza et al. (2020)'s framework of educational dignity, our analysis of these vignettes focuses on the use of first, second and third person accounts of both the facilitator and the visitor, and we identify salient themes in the nature of experiences of symbolic violence when apparently neutral computational representations are "read" through the use of interpretive explanations and queries, only to reveal dissonances, ambiguities and erasures of experiences of immigrants of color, and the facilitator's responses in these moments.

A key finding is that both learning and facilitation involves simultaneous layering of various forms of work, including both emotional and ethical work in contexts of symbolic violence. These labours are interwoven with both the syntactic and semantic ambiguities inherent in explaining and interpreting code. For example, interpreting the different strategies of cooperation in Hammond & Axelrod's (2006) model involved Sapna recognizing the violence of the term "traitorous" as a strategy that immigrants must use in order to assimilate based on first person accounts, while Apoorve offering a similar first-person account in solidarity. We will present the heterogeneity within such ethical and emotional encounters with code that are essential for recognizing the complexity of both learning and facilitation of computational models of race in informal spaces.

The What, How, To What Ends of (Re)Making of Selves, STEM, and Futures, Understood through the Lens of Equitable Facilitation

Jrène Rahm, Ferdous Touioui, & Delphine Tremblay-Gagnon

In this paper, we focus on emergent relations among facilitators and youth in two very different maker activities. Case 1 implies maker activities inside a four-week summer youth entrepreneurship program offered for free to urban youth by a community organization (CO). Case 2 entails a maker project inside a science classroom in a public high school that adheres to the International Baccalaureate (IB) intermediary program, offering enrichment activities in all subject areas. The same CO mediated that extra learning activity in the classroom, working closely together with the science teacher. We bring to the analysis a critical lens to center voices historically ignored. In doing so, we pay attention to first, how structural and political dimensions sneak up on emergent human-material relations, posing a threat to equity and creativity in ways often promised by maker space projects (Marsh, Arnseth, & Kumpulainen, 2018), but also wished for by teachers and facilitators who care deeply for youth of color given their own histories of marginalization. In doing so, we also pay attention to problems of intersectional marginalization (Crenshaw, 2021). Second, we attend to the manner a vision of STEM education as indispensable, objective, and settled truth sneaked up on the emergent relations, despite intentions to center youth voices and multiple STEM perspectives (Vakil & Ayers, 2019). Third, playing with a materialist and posthuman approach to analysis, we will focus in on "material-discursive entanglements constituted through human, non-human, and more-than-human relationships" (Sheridan et al., 2020, p. 1278), and as captured by Barad's materialist notion of *inter-action* (Barad, 2007). Together, these three different lenses will point to tensions that at least in part undermine the equity driven STEM practices the CO aims to support.

The two cases come from a larger video ethnography, conducted in collaboration with the CO over time and part of a five-year partnership and co-design project (2015 to 2020). For each case study, we rely on data that emerged from interaction analysis among the research team, supplemented by thematic analysis of interview data and fieldnotes. Case 1 relates the story of Burak, one of the youth involved in the young entrepreneur program

and participant in the activities by that CO over four years shared with us how he "participated for real" in the program only the year we documented it. He felt respected by his peers who consulted him every time they needed help, as for instance when they made soap together and struggled with chemicals. Participation in the program "helped me to get to know myself better… and know what I like to do with my future…", after a challenging beginning in the school system in Quebec, where he had to repeat his fourth year in the elementary school, upon arrival with his family from Haïti. Case 2 speaks to interesting parallels in relations that stood out from our analysis of the maker project - parallels between the science teacher and some students, who were both entangled in complex ways with subject positions marked by histories of immigration, deep interest in and expertise in science and technology yet unrecognized locally and othered, despite a deep commitment to becoming somebody in science and entanglement with the maker project. The two cases make evident in what ways taking "a more expansive lens to human learning and political possibilities" (Philip & Sengupta, 2021, p. 331), helps center tensions but also new possibilities of being/becoming in STEM, especially if emergent from equitable facilitation.

Supporting Educators Exploration of Making through Intergenerational Professional Development

Stephanie T. Jones, Sarah P. Lee, Sydney Simmons, I. Mallwitz, Marc Jiang, Megan Butler, & Marcelo Worsley

Since 2017, the MAJIC (Making A Just Inclusive Community) team has collaborated with K-8 teachers in the suburbs of a large midwestern city. These teachers were interested in bringing hands-on making into their classrooms and afterschool programs, but found limited opportunities within their district. In summer 2019, we invited five teachers to participate in a professional development (PD) program to design, test, and discuss hands-on making activities alongside their family members. We intentionally curated this intergenerational environment to surface and emphasize making practices situated within culturally sustaining pedagogies and pedagogies of care (Alim & Paris, 2017; Ladson-Billings, 2014).

We continued this PD virtually in the summer of 2020 to assist three teachers in curating intergenerational experiences for students who were now learning from "home," and in environments surrounded by siblings, cousins, elders, and parents. Given the pandemic, we recognized an urgency to continue centering pedagogies of care and educational dignity for both students and teachers (Worsley et al., 2021; hooks, 1994; Espinoza and Vossoughi, 2014). Thus in this paper we explore: what are opportunities to shift the way we imagine what is possible for facilitating making activities virtually and at home?

In this paper, we draw from video recordings of the 2019 and 2020 summers, synthesizing across 9 and 7 synchronous hours respectively and 45-60 minute long interviews with each of the teachers. As a team we open coded each interview for themes, which we then used to review the video data and iterate on the PD program. Themes included challenges of online pedagogy, pandemic constraints, and family engagement.

During PD, teachers engaged in readings and discussion that drew on and expanded their prior experiences making across lab and home settings with family members (Perez et al., 2020; Worsley et al., 2021). Teachers highlighted challenges such as zoom fatigue, material constraints, and availability of help, while recognizing practices from their existing expertise that they could develop. They identified new concepts from literature which led to incorporating pedagogies of care within intergenerational contexts. This deepened their sensemaking around hands-on making.

Teachers then wanted to create an environment to allow young people to explore literacy and making alongside family members as an additional community. We see this as a way teachers challenged ideas around participation and knowledge and opened opportunities for intergenerational making at-home. This culminated in a virtual Family Maker Night where teachers designed and mailed several book themed hands-on activity kits that students could choose to work on with siblings or adult guardians. The selected book was read in both English and Spanish. Families could incorporate other materials that they had at home and the activities could be worked on in several stages or beyond the synchronous time together. Since then, students that participate in the literacy and making program are selected on a rotating roster with optional family involvement. The ways teachers distributed materials, reduced language barriers, and created an ongoing literacy community highlight how teachers can support equitable intergenerational making.

Future considerations respond to tensions that teachers faced to fulfill district STEM requirements alongside invitations to hold and value other forms of knowledge and experience. As such, we see our role as a team to work with teachers to continue to develop ways that we can make outside of the constraints of schooling and model alternative facilitation for classroom settings. Finally, from holding space for teachers' multiple identities as family members, to the shifting vulnerabilities unique to video calls, we continue to wrestle with how this work looks in different home contexts and what that means for access to materials and support within making.

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When, Where, and at What Pace? Space and Time in Equitable Learning and Design

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Abstract: Educators and designers of learning experiences must make critical decisions not only about the *what*, *why*, *to what ends* and *for whom* of learning (Philip et al., 2018), but also *when*, *where* and *at what pace*. This symposium is organized around the conjecture that by more explicitly and systematically considering the time-space dimensions of learning and design processes, we can more reliably surface differences in how we understand learning as well as inequities that result from how it is conceptualized and designed for, helping make progress towards more just educational futures. Collectively, this symposium shows the progress that one group of learning scientists assembled in the ISLS 2021 Early Career Workshop has made in bringing careful attention, useful theory, and systematic approaches to understanding equity issues related to space and time, while also working out ways to attend to these issues in our temporally and spatially distributed design processes.

Introduction

Educators, learners, and designers of learning experiences must make critical decisions not only about the *what*, *why*, *to what ends* and *for whom* of learning (Philip et al., 2018), but also *when*, *where* and *at what pace*. Space and time demand consideration not only as objective dimensions of learning and design unfolding in the real world, but also as subjective perceptions and culturally constructed understandings of our experience that pattern activity. Indeed, different assumptions about and perceptions of learning rate, space and time influence our very understanding of what counts as good, effective, diverse, equitable, inclusive and just learning and design. Many vexing and familiar tensions and failures in designing for equity, for instance, can be traced to differences in the speed with which equity is pursued, or to lack of attention to when and where learners are put into interaction for more equitable outcomes. As a field, the learning sciences must continue to develop new ways of seeing, analyzing and responding to the implications of space and time in learning both *in* and *through* design.

This symposium is organized around the general conjecture that by more explicitly and systematically considering the time-space dimensions of learning and design processes, we can more reliably surface differences in the way we understand learning as well as urgent inequities that result from how it is conceptualized and designed for, thereby helping us make progress towards more just educational futures.

Overview of Structure and Content

Collectively, this symposium shows progress that one group of learning scientists, assembled in the International Society of the Learning Sciences (ISLS) 2021 Early Career Workshop, has made in bringing careful attention, useful theory and systematic approaches to understanding equity issues related to space and time, while also working out ways to attend to these issues in our temporally and spatially distributed design processes. In the first two papers, design processes themselves are examined in terms of the "narratives" that pattern innovation and the "trajectories" of experience and identity development that play out over the course of design. These pieces deal with how the dynamic and distributed arrangements of educational design unfold in ways that prioritize some "protagonists" over others, for instance, and act immediately and explicitly on some goals and measures of equity while tacitly deferring others. The third and fourth papers focus on spatial-temporal dynamics within specific designed learning environments. These papers deal with how individual learners move across and link virtual and real spaces in different configurations at different moments. The studies bring attention to how learners assemble and disassemble in spatial-temporal contexts and emphasize the importance of attending to these dynamics in designing for inclusive and equitable experiences.

The symposium organizers will engage ISLS participants in a discussion of paradigmatic, methodological and practical perspectives that help us grapple with critical questions like the following: (1) Where

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and when is equity being foregrounded and prioritized through learning and design? (2) How does design for equity at one rate, scale or place reinforce, disrupt, or stand in tension with its pursuit at others? (3) How do we make abstract notions of space and time more technical and tractable for the design of contemporary learning in, for instance, virtual and online spaces? (4) And, how do we work across different, culturally- and contextually-specific understandings and experiences of space-time for more equitable and just outcomes?

Time, Space and Equity in EdTech Crisis-Innovation Narratives

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While technology in education is often taken up in the work of designing for more equitable and just futures, scholarship on educational innovation has shown how public narratives and broadly shared assumptions about school and schooling tend to pattern technological integration in ultimate service of status quo goals, beneficiaries and ways of doing things (Cuban, 2013; Sims, 2017; Tyack & Tobin, 1994). Designing for substantive technology innovation in education, in other words, requires *values innovation*. In this study, the case of the EdTech Network, an urban innovation hub, is examined to show how the very spatial and temporal configurations of the stories that these innovators tell about educational change reflect and pattern how they organize and design for more equitable futures.

This study draws upon the concept of *chronotope*—Bakhtin's (1981) way of theorizing how space-time works in novels—to examine narratives of crisis and innovation told by ed-tech innovators. Space and time are treated not (just) as separate, objective dimensions of an independent real world, but more importantly, as interdependent sociocultural constructions that pattern human experience (Ritella et al., 2016), narrative sensemaking (Boje, 2011; Bruner, 1986; Weick, 1995) and the organization of work and learning (Orr, 1996). For the purposes of this study, *technology* is treated as a social-material process of development suspended among different possibilities (Feenberg, 2004). Technology *innovation* is an abductive (Cross, 1999) process of organizing for specific possible futures, and *critical innovation* is a contradiction-driven material-discursive process (Foot, 2002; Miettinen, 1999) that both critiques and works to repattern a persistent, unjust, inequitable orthodoxy.

Method

This analysis was undertaken as part of a larger multimodal narrative case study of the pseudonymous EdTech Network, an open, urban innovation network that meets online and in a downtown coworking space called TechAssembly. Overall, the approach involved collecting and comparing different stories of innovation work from teachers, entrepreneurs, educators, administrators, tech professionals in the EdTech Network. A snowball sample and high-level structural representation of the EdTech Network and its various subnetworks was developed using a name-generator instrument, systematic interviewing and standard community detection algorithms for network analysis. Employing a minimal definition of narrative as a passage from one state of equilibrium to another (Czarniawska, 1998), *crisis-innovation narratives* were identified in the sample of interviews, abstracted and compared. A crisis-innovation narrative was defined as a genre of innovation story that combines (1) some disruptive event or transition that results in a state of educational crisis (i.e., narrative disequilibrium) with (2) some kind of innovative or abductive move or plan to resolve the crisis (i.e., achieve an equilibrium). These narratives were then examined with particular attention to how their chronotopes patterned and reflected the *logic*, *pace, practice, protagonists* and *ends* of equity- and justice-oriented changemaking.

Findings

Two general chronotopes organized many of the crisis-innovation narratives reviewed in this study. First, crisis-innovation narratives patterned by an *institutional chronotope* played out relatively gradually, within and across separate but linked and interdependent organizational spaces. Innovation is both supported and constrained by a complex network of persistent, hierarchical, bureaucratic actors and stakeholders. One inter-institutional group of computer science education champions, for instance, relayed stories of how their work addressed a crisis of "coding skills" (interview transcript) by gradually collaborating across schools, educational institutions, and state and federal funding agencies to develop new curricula, teacher preparation programs, and support networks. The innovational *end*—that is, the resolution of the crisis and establishment of a new, more equitable equilibrium where coding skills are taught and learned system-wide—was seen and acted upon as a decades-long story of concerted, coordinating planning and action in relatively compartmentalized domains by often isolated actors, including individual teachers in classrooms and educational researchers in universities. The abductive *logic* of these narratives promised impact through collective, collaborative, and coordinated action of a relatively complex set of stakeholders.

Other crisis-innovation narratives were patterned by a very different understanding of and distribution across space and time, a *market chronotope*. Within this second chronotope, innovation stories play out more quickly as innovators from different environments "rub shoulders" (interview transcript) in a densely populated, frenetic market, working opportunistically around the TechAssembly innovation hub, their social-material "center of gravity" (artifact text). One entrepreneur, for instance, "pitched" (interview transcript) a story to other innovators at TechAssembly about how virtual reality tools could be deployed to immediately address crises of equitable access to quality curriculum, rapidly scaling virtual project-based learning experiences to a broad network (and market) of schools. The urgency and speed of innovation that characterized stories in this chronotope seems to be related at least in part to the way that innovators experience and value space and time itself in the urban market. Unlike the institutional chronotope, the market chronotope is a shifting, hectic, precarious, and commodified space-time, within which innovators must organize quickly and efficiently to demonstrate both valuable progress on equity goals as well as market value. The abductive logic of an effective crisis-innovation narrative in the market can often be crystallized in the form of a curt "value-proposition" or a promising "return on investment." The *ends* of these crisis narratives are often described in terms of "multiple bottom lines," one of which is new market value and another is a more equitable equilibrium (fieldnotes). At the same time, the urban and social infrastructure that constitutes the center of gravity around which these stories are developed (i.e., TechAssembly) is not particularly accessible to innovators who cannot pay to play by traveling regularly to the urban center or afford to spend time and materials on projects that may not last or immediately pay off. The general chronotopic conditions of openness and precarity favor those who are well-positioned and resourced to act as first movers.

Significance

Without inappropriately confusing what innovators say they do with what they actually do, it seems reasonable that these chronotropic configurations likely also help us understand how and why innovation plays out in practice. For instance, we can see how space-time influences the abductive rationale behind design and innovation by establishing different meaningful *ends* of innovation as well as what amounts to compelling evidence of *pace* and progress towards those ends. Entrepreneurs developing innovations in a frenetic, urban chronotope characterized by precarity and the urgent need to make equity technical (e.g., as an issue of scaled access to curriculum) and demonstrate immediate progress (e.g., through sales or user metrics) may not align with equity innovation patterned per a longer term, cyclical, institutional chronotope, where change is a complex, halting, non-linear, collective journey that may not have an immediate end in sight. Furthermore, we see how chronotope as a material-discursive construction can feed into the maintenance of exclusive innovation *practices and infrastructures*, for instance, by making innovation something that happens in urban centers by those who can afford to pay for heavily commodified space and time. Going forward, careful chronotopic analysis of innovation stories and practices could generate new useful typologies of innovators, innovative practices, and abductive goals of innovation, and contribute to a more sophisticated and inclusive understanding of what counts as innovative and who counts as innovative.

Accounting for Spatial-Temporal Identity Trajectories in Student Co-Design

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Teacher preparation traditionally follows a model in which teacher candidates complete prerequisites prior to entering into a credential program, then, once in the credential program, participate in a series of siloed courses taught by different instructors, while simultaneously completing field work with a master teacher. This siloed model of learning is similar to other contexts in formal and informal education. Despite efforts to create coherence within teacher education programs and a recognition of teacher education as a moment of identity transition for beginning teachers, the connections between prerequisite coursework, coursework within the credential programs, fieldwork, and future teaching are often unclear (Nolen et al., 2011). One significant detriment of this model is that it does not purposefully or equitably support teacher candidates' developmental trajectories as they navigate multiple courses and new experiences, while also making sense of their developing and new identities as teachers. Courses and experiences tend to lack connections or systematic supports for candidates' developmental trajectories. Within this model of teacher education, success is often defined as completion of course assignments, external measures of teaching, and teaching observations, without a systematic view of development as a professional. For this work, I instead look at teacher candidates' development as professionals who learn and, ideally, enact equitable teaching practices. Nasir and Hand (2008) introduced the concept of practice-linked identities, in which, with the support of different identity resources, learners will be more engaged and develop identities that are linked to specific disciplinary practices. By supporting teacher candidates' identities in and

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across learning contexts, I seek to support their spatial-temporal linkages to specific teaching practices, specifically practices connected to just, equitable, and inclusive education. Researchers have argued that without explicitly and purposefully supporting learners' identity development, learning environments run the risk of perpetuating inequities, focusing too narrowly on measures and content over learners' experiences and development (Banks et al., 2007; Nasir et al., 2006). Focusing on teacher education specifically, without naming and supporting all novice teachers' development perpetuates inequities around whose identities are supported and how identities are supported. As such, a premise of this work is that the onus of identity development falls not just on individual learners, in this case teacher candidates, but that designers of learning environments need to equitably support learners' identities and developmental trajectories over time and space.

Method

This study draws upon perspectives in the Learning Sciences that focus on designing to equitably support learners' identity (Nasir, 2012; Tierney, 2020), student co-design of learning environments (Pitt et al., 2019; Tierney et al., 2021), and the design of digital badge systems to represent learning and development in and across contexts and timescales (Bakhtin, 1981; Davis & Singh, 2015; Horstman et al., 2020; Pinkard et al., 2008) by identifying and supporting teacher candidates' developmental trajectories into and through the Single-Subject Credential Program. Candidates' developmental trajectories were mapped through students co-design of digital badge systems to identify learning and supports for identity development within and across courses and experiences in the program. As opposed to content-centric perspectives of courses, such as curriculum maps or backwards planning, the digital badge systems focus on candidates' experiences and development in specific courses into and through the Credential Program. Built upon the ideas of badges from Boy Scouts and Girl Scouts, digital badge systems are used as the underlying design framework to map out valued learning accomplishments and identity pathways for learners, creating a trajectory for professional development in the program. In essence, the badges serve as a map for what it means to demonstrate professional identity development into and throughout the teacher education program. However, through co-design, the badge systems represent candidates' perspectives and experiences, highlighting how candidates interacted with course content and developed over time.

Findings

Results from the study show what identity trajectories for individual students look like in a classroom co-design context, and how they can be mapped out to inform more equitable co-design processes and outcomes. Specifically, when looking at designing for equity across different learning contexts, it is valuable to orient to not only where learning and development occurred, but also when. By centering on learners' experiences through co-design, the designers negotiated what should be included in the badge systems by also situating the content and learning within their developmental trajectories. This was particularly salient when looking at the discourse of co-designers who were at different points in the credential program.

Significance

Designing for equity across space and time requires an element of narrative. In doing so, it is important to consider who or what becomes the protagonist in that narrative (Iversen et al., 2017). Put another way, what is the organizational framework for thinking about space and time? This study presents one model, in which learners' experience is centered to map out, and then design for, learning and development in and across learning contexts over time.

Charting Learner Experiences of Immersion Across Digital Space and Time

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Extended reality (XR) technologies hold great promise for engaging and immersive learning experiences. Yet, issues of equity and access related to the use of such advanced technologies for learning are of significant concern. In XR environments, students can experience challenging interactions with content, peers, and instructors. For instance, students may encounter Internet connectivity problems or even have adverse physical reactions such as nausea, hampering their ability to fully participate. Additionally, because XR technologies allow for the creation of highly realistic and immersive scenarios and contexts, there is the potential for students to experience difficult emotional reactions such as fear and anxiety, which could also be a detriment to their learning. Designers of learning environments that include XR technologies have an opportunity to positively shape learners' experiences by carefully attending to a range of design elements that promote equitable access. As XR technologies become increasingly prevalent in educational contexts, it will be especially important to understand how arrangements of

space (e.g., levels of immersion in a learning context) and time (e.g., course structure and sequence) can play a role in advancing equity-focused design goals.

Method

To make progress on these design goals, we investigated the extent to which an online, graduate level XR for Learning course fostered an equitable and immersive experience for students. The course aimed to interrogate claims that are made about the educational value of XR technologies in support of learning. To explore these themes experientially, students borrowed virtual reality (VR) headsets from the university library. Over the course of each class session, students experienced both low-immersion spaces (e.g., a web-based, interactive classroom) and high-immersion spaces (e.g., the university campus recreated in VR). Each class session was carefully structured, creating intentional opportunities for students to "dwell in and step out" (Ackerman, 2004) of these spaces, according to the learning goals for the class and students' comfort with technology and course topics. Instructors offered alternatives for high immersion activities (e.g., watching a video screencast or using a VR application). Instructors' design choices were motivated by efforts to ensure that all students would be supported pragmatically in their use of XR technologies and upheld emotionally in their explorations of sometimes difficult topics and subject matter.

We created visual timelines (Quintana & Slotta, 2017) to portray all pedagogical design elements from each class session. These timelines emphasized two important dimensions of engagement: space (i.e., level of immersion, ranging from viewing non-immersive digital artifacts to interaction in a 3D world through a VR headset) and time (i.e., lesson structure and sequence). We used the Simulation Experience Design Framework (Raybourn, 2007)—a framework to facilitate the design of connected, immersive, and equitable learning experiences— to analyze and reflect on the visual timelines.

Findings

Our analysis and findings are structured according to the four dimensions of the Simulation experience Design Framework: interaction, narrative, place, and emerging culture.

- Interaction: The course design allowed for *co-present action* and *co-present reflection* (Raybourn, 2007). Various XR technologies allowed students to be co-present, engaging in collaborative problem-solving using shared artifacts. In one class session, students met together in the university's central meeting place in virtual reality. For some students, this was their first time "on campus" due to pandemic restrictions. In this setting, students joined a live networking event as part of an XR Summit, meeting with conference attendees including researchers, academics, and industry professionals. Each class session also included opportunities for *co-present reflection*, with structured and facilitated discussion opportunities in small groups, occurring in both low- or high-immersion spaces.
- Narrative: The course design achieved *co-created immersion with and through interactivity* in an immersive and information-rich problem space (Raybourn, 2007). In a low-immersion space (GatherTown), students engaged with various knowledge artifacts connected to the session's topic, such as short lecture videos, digital posters, and interactive whiteboards, together with their peers. Students participated in "fireside chats" around a digital fireplace, which underscored the communal nature of the experience. In high-immersion spaces, students participated in a variety of educational narratives, such as sitting alongside peers in a futuristic lecture hall and co-viewing a movie clip in an "art house" environment. While these experiences all connected to learning goals for the course, they were experienced in a narrative context, with students "taking on the role" of a student or critic.
- Place: The course design allowed for *active immersion through contextual cues* (Raybourn, 2007). In a high-immersion space (e.g., virtual chemotherapy scenario), students interacted with textual overlays, audio cues, and wayfinding symbols. Students were also provided low-immersion alternatives to experience this medical setting through narrated walkthrough videos of the treatment scenario. This allowed students to select the level of immersion that made them most comfortable, while still exploring the contextual cues provided through representations visible in the digital pace.
- Emerging culture: One criticism of XR environments is that they promote single points of view (Raybourn, 2019). An opportunity exists to support multiple points of view and perceptions across multiple spaces. Using this approach allows for a *socially-constructed culture of learning* to emerge (Raybourn, 2007). The visual timelines revealed that the course structure allowed for both homogenous experiences (e.g., students could come together in the same virtual space) and multiple divergent opportunities, such as choice of spatial modality (low or high immersion) and even choice of XR application. To explore the topic of empathy, students chose from applications that highlighted the lived

experience of individuals from a range of social identities. Students had multiple opportunities to share their reflections and reactions through digital workbook entries and small group discussions, contributing to a shared, emerging culture of learning.

Significance

The analysis revealed how arrangements of space (i.e., levels of immersion) and time (i.e., course structure and sequence) contributed to an equitable and immersive experience. Intentional pairing of high-immersion experiences with low-immersion alternatives created options for students who experienced barriers to engagement. Interleaving low- and high-immersion experiences in one class session helped mitigate the "intensity" of XR experiences, while creating a connected experience for students. This study shines a light on arrangements of space and time that contribute to equitable and immersive XR experiences. While findings are promising, we are just beginning to understand how instructors can advance equity-focus design goals in XR.

Integrating Academic and Professional Space-Time with Technology

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Experiential learning is "the process whereby knowledge is created through the transformation of experience" (Kolb, 1984, pp. 38). In higher education, experiential learning pedagogy is used to assist learners with the process of transferring knowledge from the classroom into a real-world professional setting (James et al., 2020). In a capstone project, students are physically immersed in the classroom with the instructor integrating a real-world context through the introduction of an industry project. In an internship or co-op, students are physically immersed in a professional setting with the internship coordinator integrating a learning context through reflective writing and discussion. Despite which physical context is centered, these pedagogical practices introduce an industry professional into the learning environment, increasing the complexity of delivery and can impact the willingness of instructors to make this pedagogical choice (Jona & James, 2021).

Distance and online learning is often attributed with the role of democratizing and opening up access to education through its ability to mediate the transfer of learning remotely and asynchronously. Despite its benefits, it is not without its shadow sides when it comes to engagement and learning retention. If distance and online learning make access to education equitable and accessible, and experiential learning help learners transfer their learning to real-world contexts, then in order to to broaden participation in experiential learning distance and online options are required. However, combining experiential learning with online learning also combines the complexities they bring. In this new space-time configuration, the learner, instructor, and industry professional are in their own physical space and time making facilitation of the learning experience infinitely more complex.

Framing & Context

Bakhtin's notion of chronotopes (1981) is used in learning science as an analytical tool to examine the changes in space-time relations, particularly as learning adapts as a result of technology innovation and educational reform (Ritella et al., 2016). This study leveraged chronotopes to reflexively examine virtual internships, a technology-mediated learning intervention (hereafter referred to as virtual internship) developed specifically to broaden participation in experiential learning for students who are unable to access place-based and time-bound opportunities like internships that align with more traditional learning environments.

The virtual internship emerged over a three-year design-based research project. Over several design iterations the intervention designers focused on reducing the complexity of online experiential learning so that participation in a virtual internship was feasible for the learner, the instructor, and the industry professional.

Findings

In discussion with colleagues while preparing this symposium it became apparent that our research team was using instructional technology to reconfigure the space-time relationships between the learner, instructor, and industry professional. Moreover, the reconfiguration as opposed to the technology itself enabled a more accessible and scalable model of experiential learning that held its pedagogical integrity for individual students. The virtual internship intervention used technology to pass the work the learner was producing and the feedback the industry professional was providing back and forth between the learner and the industry professional while giving the instructor a birds eye view of the interactions and the ability to intervene in the exchange if required. Using the technology in this way folded the space-time distance between the classroom and professional space.

Significance

A reflexive examination of the 'new' space-time relations between the learner, teacher, and industry partner that the model illuminates two roles the technology was playing:

1. To uphold the operating rhythm and momentum of the virtual internship
2. To clarify and reinforce the agreed roles and responsibilities of the learner, teacher and industry partner.

The technology playing these two roles allowed the learner, teacher, and industry partner to 'sync' with the virtual internship itself. In a time-bound, place based experience the human actors would 'sync' with each other in a team meeting to clarify tasks, align expectations and check project status. Intentionally designing the role of the student, teacher and industry partner upfront and structuring the technology to capture and pass information back and forth enabled them to stay in sync and aligned despite the physical space-time difference.

During the initial phases of the research project the research team identified multiple different configurations of roles and responsibilities used at different research sites. Moreover, multiple different perceptions of the roles and responsibilities between the learner, teacher and industry partner in one virtual internship. Despite these perceptions of the roles and responsibilities having a significant impact on the expected actions of the learner, teacher and industry partner these expectations were implicit, leaving it up to chance whether the student, teacher and industry partner were engaging in the virtual internship with expectations aligned. By using the technology to layout and uphold the roles and responsibilities of the learner, teacher and industry partner the roles and responsibilities within the virtual internship were made explicit upfront and constantly realigned throughout the learning experience. Making the roles and responsibilities explicit up front and leveraging the technology to enforce them enabled the learner, teacher, and industry partner to align and consistently re-align their expectations of each other and stay in sync despite the physical space-time difference.

The key outcome of this reflective examination of the virtual internship through the lens of space-time highlights the need for intentionally considering the role of the technology when designing remote and distance models of experiential learning that are accessible to all learners.

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Agents, Models, and Ethics: Importance of Interdisciplinary Explorations in AI Education

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Abstract: Artificial Intelligence (AI) is proliferating in both visible and invisible ways across our society. It is imperative for our new generation to gain a fundamental understanding of how intelligence is created, applied, and also its potential to perpetuate biases and unfairness. Because of the nature of AI, it is important that we take an interdisciplinary approach in order to ground the systems and models in real and meaningful contexts for learner exploration. This symposium explores these approaches with a multi-disciplinary group of researchers presenting empirical studies on designing and studying AI learning environments. These studies provide unique insights towards design recommendations, challenges, and opportunities in the rapidly emerging area of study in K-12 education.

Symposium Overview

Artificial Intelligence (AI) has become essential in daily technology usage, decision-making, and the STEM workforce (Long & Magerko, 2020). More traditional methods in scientific research and STEM occupations are being replaced with AI-based modeling and problem solving. The need to prepare the future workforce for advances in AI, and its potential to perpetuate bias and unfairness, has spurred the integration of AI into K-12 learning settings (Carney et al., 2020; Druga et al., 2017; Forsyth et al., 2021; Touretzky et al., 2019).

An emerging theme and emphasis on K-12 AI education is promoting its interdisciplinarity. The public tends to believe that AI-related work is all about programming. Thus, teachers may avoid introducing AI concepts in non-CS (computer science) classes, and students might view AI narrowly as an advanced CS topic (Long & Magerko, 2020). An emphasis on AI's interdisciplinary applications can help broaden access to AI (Akram et al., 2021). The interdisciplinary view would help students draw connections between application areas of interest and CS, broadening the range of students to whom such AI learning environments can appeal. Despite the many calls to promote AI's interdisciplinarity (e.g., Kusters et al., 2020), there remains a knowledge gap of how to develop meaningful experiences for students and teachers in K-12 settings.

Our contributors are from different disciplines and backgrounds (e.g., learning sciences, literacy education, science education, computer science, and human-computer interaction) and explore interdisciplinary K-12 AI education from different perspectives. Specifically, Zhang et al. investigated teacher learning in integrating AI concepts across disciplines; Walsh et al. explored using AI ethics as an interdisciplinary topic for classroom teaching; Akram and Yoder draw on the perspective of computational thinking to show students' learning in AI modeling of science phenomena; Jiang et al. examined students' data modeling practices that require an interdisciplinary understanding of AI; Payne et al. illustrated unique affordances of embodied learning

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through dancing in helping students to reason about capabilities and ethics of AI systems. Together, these contributions shed light on strategies in promoting AI's interdisciplinarity, teacher learning in integrating AI in different disciplines, and how students explore AI models and technologies (e.g., what students engage with, what their interactions are, and how do these interactions relate to learning of AI and other disciplines). This symposium will be a landmark in the development of our understanding of learning in the rapidly emerging area of study in K-12 AI education.

We will structure a panel discussion following these steps: co-chairs introducing the contributors, contributors briefly presenting their research in a sequence, contributors engaging in a panel discussion facilitated by the co-chairs (discussion topics will be prepared by co-chairs and also selected from attendees), co-chairs summarizing the discussed topics and presenting future directions.

Individual Contributions

1. Integrating AI Education Activities into Middle and High School Classrooms

Helen Zhang, Irene Lee, Katherine Moore, Yihong Cheng, & Beatriz Perret

The rapid expansion of AI is having unprecedented industrial and social impact and necessitates educating a generation of AI literate citizens who are familiar with AI technologies and can work with AI tools in various job tasks in the future. Yet, AI education is in its infancy and early findings on AI Literacy are just beginning to shed light on which topics are appropriate to teach at various grade bands and how learners gain an understanding of AI concepts and processes (e.g., Lee et al., 2021). Further despite the fact that AI itself is an interdisciplinary field, many students believe that only computer scientists or programmers work with AI. Such stereotyped views prevent them from recognizing the interdisciplinary nature of AI or their own capability of interacting with AI tools outside of computer science contexts. More research is needed to explore how AI education activities can raise students' awareness and foster their understanding of the interdisciplinarity of AI.

This exploratory study aims to address this issue by investigating whether/how AI activities can be infused into classrooms across domains and how the integrated AI learning experiences can impact students, particularly those who have been historically underrepresented in STEM and CS education. This study employs a multiple case study approach (Stake, 2013) and reports four cases of teachers who embedded AI into their teaching of the core subject area. The cases were selected from educators who participated in a year-long PD program that prepared them for implementation of an AI education curriculum called Developing AI Literacy (DAILy). The PD program consisted of (1) an online Book Club where educators read an AI book, learned the DAILy activities as a learner, and discussed their experiences and thoughts of AI and the DAILy activities; (2) a practicum where educators co-taught the DAILy curriculum in summer camps to middle school students; and (3) monthly webinars to share classroom implementation plans and experience during the school year. We utilized purposive sampling (Tongco, 2007) to select the four cases to represent the extremes on a continuum (Rubin & Rubin, 2011) and to allow for maximal variation sampling within the PD program. The selection criteria included subject area taught by the teachers (e.g., science, library, technology, math, and communication), teaching structure (co-teaching or teaching individually), and the age group of students (middle or high school students). All the teachers taught in schools with a high percentage of underrepresented students (i.e., at least 80% of the students were from low-income families and/or racial and ethnic minority groups). Multiple sources of data were collected such as interviews with teachers, observations of classroom instruction, and student work.

Preliminary findings demonstrate that teachers in various disciplines are able to find places to integrate AI lessons within the school day. A closer examination revealed differences in teachers' integration: in one case the AI activities were interwoven with the science content whereas in the other cases AI was taught as a stand-alone curricular component that meets the overarching goals of the course (e.g., developing students' information or technology literacy). For instance, in a science class, Ms. P developed an activity that asks students to use Google's Teachable Machine to train supervised models to distinguish between eukaryotic and prokaryotic cells. Students curated a dataset of pictures of both types of cells, labelled the pictures to train the models, and troubleshot and tested the AI model. Their understanding of the science and AI concepts was found to be reinforced through this activity. In the communication/debate class, Mr. D focused on utilizing the AI-generated Deepfakes and misinformation that appear in social media as a motivational hook to engage students. His students learned to use generative AI tools to create stories and art and debated/discussed who should own the copyright of the generated art. Such activities raised students' awareness of AI in media and sharpened their 21st century skills of debating, communicating, and critical thinking. Another finding is that co-teaching is a potentially powerful approach to demonstrate the connections between AI and other fields. In one case, three teachers (who

teach math, technology, and library respectively) chose to co-teach the DAILy activities so that each teacher could contribute examples of how AI is connected to the different fields.

These findings contribute to the AI education field by providing concrete examples of teaching AI across disciplines to help students realize the interdisciplinarity of AI. They also inform the design of PD programs by revealing guidelines on how to support teachers in reorganizing and revamping the learning experiences to make AI a valued and integral part of the schooling for all learners.

2. Adapting and Reinventing Interdisciplinary AI Ethics Curriculum: Co-design with Computer Science, Cybersecurity and English Language Arts Teachers

Benjamin Walsh, Aaron Guggenheim, Bridget Dalton, Stacey Forsyth, & Tom Yeh

The Imagine AI Project team is in its 3rd year of designing, implementing and analyzing Artificial Intelligence Ethics curriculum for middle and high school students. With AI's potential to solve significant social problems (Abebe et al., 2020), while simultaneously playing a role in the widespread violation of human rights (United Nations Human Rights Council, 2021), AI and AI ethics are urgent topics that belong in schools (Touretzky et al., 2019). Our team of Computer Science, STEM and Literacy educators and researchers is dedicated to helping youth become ethical consumers and creators of AI.

We view AI Ethics as an inherently interdisciplinary topic, which can be effectively taught by integrating CS, Ethics and Literacy instruction. We have designed and studied project-based instructional modules that combine original short stories with youth protagonists at the center of AI ethical dilemmas with non-fiction media, and immersive CS tool and simulation experiences (Alverman & Wilson, 2011). Together these modules help students develop a technical and intuitive understanding of how AI systems work, how these systems are affecting individuals and communities in positive and negative ways, and ask them to consider what it might take to design more ethical and empathetic AI. Our modules address topics such as algorithmic bias, the ethics of self-driving cars, recommendation algorithms and social media, and AI art and music. Each module culminates in a digital design task (such as creating a digital comic, an empathetic chatbot, or a creative computing artifact) that asks students to express their own stance on an AI ethics dilemma. We tested these modules in online summer camps and in two 9th grade ELA classes and found that students developed better understandings of how AI systems work, and more nuanced views on AI ethics issues (Forsyth et al., 2021).

We are currently partnering with CS, Cybersecurity, and ELA teachers to bring AI Ethics projects to their classrooms. We believe the best project-based units are customized to fit the needs of a specific group of students, and that teachers are vital co-design partners in making this possible (Penuel et al., 2007). An essential component of project-based learning is striving to provide students with authentic learning experiences (Polman, 2012). Our work has focused closely on ensuring that projects are authentic to the academic disciplines, and that students experience projects as authentic to their own interest, experiences and communities.

Using the Imagine AI modules that we tested in year 2 as a starting point, we have worked with teachers to adapt, extend and reinvent our curriculum to fit their classroom contexts. For example, based on recommendations by a 9th grade Cybersecurity teacher partner, we made a number of small shifts to highlight security concerns related to self-driving cars, facial recognition systems and recommendation algorithms, and added digital design tasks to challenge students with more extensive coding experience, including a new ethical app design challenge as a culminating product. Similarly, a 9th grade ELA teacher took the lead in integrating our materials into a project which examines how AI can reproduce and amplify social inequality. This project incorporates a graphic novel version of the classic text "Frankenstein," and asks students to create evidence-rich multimodal texts (Dalton, 2012) to answer questions such as, "Can AI be monstrous?" This ELA teacher's reinvention of the modules has maintained an interdisciplinary scope appropriate for AI Ethics, while also firmly situating the project within the teacher's primary discipline and academic standards.

Teachers have also played a vital role in helping to ensure that students will experience the AI ethics projects as authentic to themselves and their communities. For example, each partner teacher has shared very specific reasons why they believe particular examples of algorithmic bias are likely to resonate with their students more than others. Furthermore, teachers' co-design and enactment has been essential in helping us live up to Universal Design for Learning principles (Meyers et al., 2014), which help ensure that projects are accessible and challenging for all students. This includes scaffolded design challenges that are appropriate for students with extensive programming experience, and also those who will be writing code for the first time, and providing audio versions of AI ethics stories to support students' learning and language needs.

The various curriculum adaptations and reinventions that are emerging from these partnerships are informing our larger development and dissemination efforts. As we prepare to publish more of our AI Ethics stories and modules (https://www.colorado.edu/project/imagine-ai/resources), we are including alternate texts,

activities and design tools as well as strategies for customizing our curriculum so that teachers across a range of subject areas classes and contexts can implement projects that will better serve the interests and needs of their own unique groups of students and their academic disciplines. Preliminary data suggests that this approach can help the topic of AI ethics resonate with students in and across multiple subject areas classes.

3. Enhancing Computational Thinking Skills in Middle-school Students' Computational Modeling

Bita Akram & Spencer Yoder

Computational Thinking (CT) skills are becoming the new form of literacy. As a result, efforts for integrating CT in the K-12 curriculum have become the subject of increasing focus (Sengupta et al., 2015). One particularly effective approach is integrating CT skills within the mainstream K-12 science curriculum through computational modeling. Many researchers have argued that learning scientific concepts in the context of computational modeling facilitates and strengthens learning across both domains (Weintrop et al., 2016; Sengupta et al., 2015). In this work, we discuss activities for integrating one of the domineering aspects of CT, Artificial Intelligence, with a middle-school science curriculum (Akram et al., 2021) in the form of a computational modeling perspective and propose future directions for improving these activities.

Our activity design focused on two CT frameworks proposed by Sengupta et al. (2015) and Weintrop et al. (2016). Sengupta et al. (2015) argue that CT consists of practices that are essential to computing, computer science, and modeling scientific and mathematical concepts. These practices include problem representation, abstraction, decomposition, simulation, verification, and prediction. Following this framework, Clark and Sengupta (2015) proposed a computational modeling framework that incorporates three scientific modeling practices: model building, ramification, and deployment. This modeling framework shares similarities with Weintrop et al. 's (2016) CT framework that introduces four primary practices for CT: data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices.

Specifically, we are developing a block-based simulation environment that models the spread of epidemic diseases through a contact-tracing app. Epidemic diseases and their effects on the ecosystem are among the core disciplinary ideas mentioned in the NGSS (Lead States, 2013). In these activities, middle school students engaged with the model building and model ramification of Clark and Sengupta's framework while practicing problem representation, abstraction, decomposition, simulation, and verification. We will extend our activities to incorporate model deployment and, thus, validation and prediction by providing students with empirical data about the spread of epidemic diseases. Through our proposed activities, students will be engaged in an iterative computational modeling approach where they build a model based on evidence and observations, observe interactions among different variables in their model, and evaluate its effectiveness by comparing the results generated from their models against empirical data. From this comparison, they identify the source of mismatch and revise their model to accommodate for that. This work will spur much-needed research on designing effective block-based programming environments that help students to build a comprehensive view of computational modeling, specifically AI modeling, for science-centered applications.

4. High School Students' Data Modeling Practices: From Modeling Unstructured Data to Evaluating Automated Decisions

Shiyan Jiang, William Finzer, Jie Chao, & Carolyn P. Rosé

Efforts to incorporate data literacy and analytics throughout K-16 education are on the rise (Lee & Wilkerson, 2018). In this paper, we argue that a neglected area of data literacy is dealing with unstructured data as well as the restructuring of structured data to prepare for effective modeling. The unstructured data this paper focuses on is text and building machine learning (i.e., a subfield of AI) models with texts from real-world datasets. This study aims to fill the gap of current research on understanding student modeling unstructured data and evaluating automated decisions from these models.

Through interaction analysis (Jordan & Henderson, 1995) of 28-hours screen recordings of high school students' AI modeling activities, we identified ten data modeling practices: drawing on experiences to create features, making hypotheses about patterns, analyzing confusion matrix, identifying patterns in training data, noticing gap between hypotheses and patterns, pursuing feature surprises, generating "thoughtful" testing data, reasoning about model decision making, describing models in social contexts, and engineering features.

Specifically, *drawing on experiences to create features* refers to the practice of creating features based on students' understanding of the way humans describe positive and negative experiences. For example, students created a feature, "delicious", as from their experiences, humans would use the word "delicious" to describe

positive experiences. In this practice, students leveraged their own experiences and knowledge to create different kinds of features, such as generating a feature "service" while describing how important services were for one's family to select restaurants. *Making hypotheses about patterns* represents the practice of explaining obvious patterns before exploring AI models, such as "if a review has feature 'love', most likely it's a positive review." In the practice of *analyzing confusion matrix*, students examined correctly and incorrectly classified reviews systematically. Through systematically analyzing reviews, students engaged in the practice of *identifying patterns in training data*. After identifying patterns, they noticed that some patterns were different from their hypotheses in the practice of *noticing gap between hypotheses and patterns*. For example, they considered "like" as a good feature for positive reviews (i.e., if a review has feature "like", most likely it's a positive review), but the model showed that almost half the reviews having feature"like" were negative reviews. When reading the negative reviews, they found that "like" could be used in negative reviews such as "don't like" and "taste like soap." To further explore models, students picked features that showed unexpected patterns in the practice of *pursuing surprising features*, such as exploring why feature "die" had a big weight for positive reviews. When testing the model with self-generated reviews, students wrote reviews that the model could classify correctly after realizing that the model only used single words and could not understand contexts when classifying reviews. We described this practice as *generating "thoughtful" testing data*. In the practices of *reasoning about model decision making*, *describing models in social contexts*, and *engineering features*, students explained multiple features driving decision making, discussed humans and social contexts behind data and data modeling (e.g., who would benefit from the model and who would be excluded), and iteratively revised the feature space for better model accuracy respectively.

Our analysis demonstrated that students engaged in a variety of data modeling practices when modeling texts and analyzing model decision making. These practices require an interdisciplinary understanding of AI (e.g., mathematical understanding for analyzing confusion matrix, literacy learning for making hypotheses about patterns, and computational thinning for engineering features). Future studies could explore how students leveraged personal experience and knowledge from different disciplines to build models with unstructured data through investigating patterns of data modeling practices.

5. Lived Experiences with Machine Learning and Dance

William Payne, Francisco Castro-Norwood, Kathleen McDermott, Yoav Bergner, & Kayla DesPortes

In this symposium, we will demonstrate how open-ended creative activities connecting computational models and dance led to meaningful and personally relevant discussions around the capabilities and ethics of AI systems. Researchers have shown that artistic computing (e.g., through dance) can create engaging and authentic learning experiences that embody learners' identities, experiences, and communities (Lindberg et al., 2020). Furthermore, the incorporation of physical activity may be an enjoyable and powerful method for introducing learners to machine learning (ML) (Payne et al., 2021). We briefly describe the danceON technology that enabled the intersection between modeling and dance then share two vignettes from a recent study in which a diverse group of 6 high school girls (2 Black, 2 Hispanic, 2 Asian) used danceON for 15 weeks, through a paid learning opportunity advertised as an internship.

danceON is an embodied creative coding environment that embeds ML models for pose detection enabling learners to create movement-responsive animations that are drawn and updated in real time on top of a pre-recorded video or webcam feed of solo dance. Learners write code to affix virtual animations to detected body keypoints and 2D coordinates using the keywords *what, where, when,* and *how* (Figure 1). Within this medium, simple animations can take on multi-layered meaning—e.g., learners used circles, superimposed onto dance videos, to represent a sun and moon and color change of dark to bright to signify hope.

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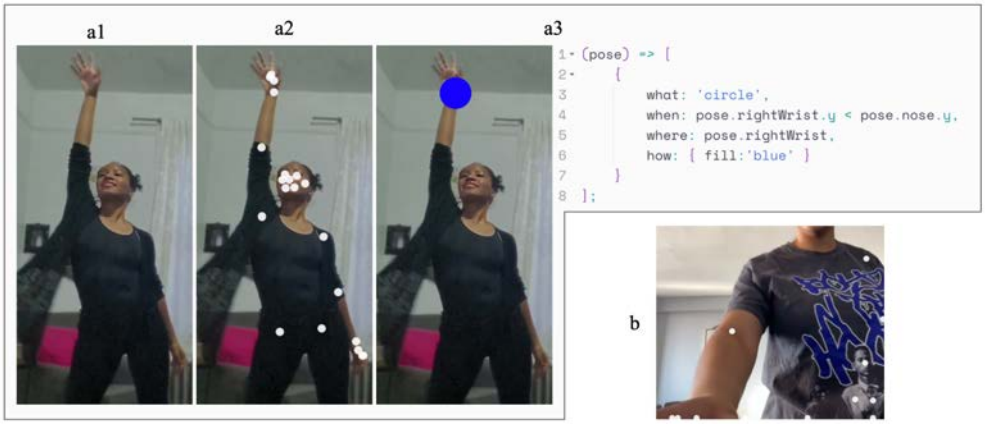
Figure 1
Video uploaded to danceON (a1) featuring pose data overlaid as white dots (a2) and a blue circle coded to appear *when* the right wrist is above the nose (a3). Participant example with shirt image mistaken for body (b).



Vignette 1, My body or my shirt?: Direct engagement with ML is central to danceON's technology and curriculum, and because participants choreographed a new dance nearly every week, they experienced ML system behavior across conditions, e.g., changes in clothing, lighting, camera position, etc. The first creative assignment, "Emoji Challenge," tasked participants in creating two positions, inspired by Merce Cunningham's solo "50 Looks" (1979), and coding a *when*-condition to draw a matching emoji over their face. Many videos yielded inaccurate and missing pose data. We discussed potential causes, and participants identified moments where their positions hid parts of their bodies, e.g., "*if my hand was here one second and then another second it was like behind my head, it would probably think it was still out there and not behind my head*," (Camille, pseudonym). One participant, Elise, demonstrated through her clothing how machine perceptions of bodies differ from human perceptions (Figure 1b): "*it like saw I had a person on my shirt and accidentally went on to that shoulder instead of the shoulder of my body.*" Participants not only discussed limitations of pose detection, but learned to work within its boundaries altering their code and choreography, and, as presented in Vignette 2, leveraged their knowledge when introduced to other ML applications.

Vignette 2, Classifying me and "everyone else": In a wide-ranging discussion in Week 8, participants connected their understanding of AI to personal experiences and publicized instances of bias. danceON integrates body-position classifiers made in Teachable Machine, a free web-application for rapidly training ML models (Carney et al., 2020). They trained models to identify two poses and read articles about misuse of facial recognition and bias towards white voices in AI home assistants (Hill, 2020). They discussed the causes of AI bias from the lack of developer diversity, "*products are right now mostly made by white people and geared towards white people*" (Janna), to the human role in training systems, "*although it is computer learning we're the ones who put it in place*" (Gwen). Caitlyn reflected on her family's Google home assistant, stating "[her parents'] *English isn't like, it's not perfect, so not like mine, or like standard American, so the Google had like a harder time to understand.*" Directly connecting pose detection and facial recognition systems, Gwen argued, "*we widen the range of what can be classified as a human face so it's like you have to take into consideration all features and all face colors and for your poses, like all heights.*" Following the discussion of bias, participants imagined a danceON performance that responds to AI bias. They noted that pose detection performs more accurately for slow movements, which Camille connected to classical dance styles that are "*expensive and only available to like a certain demographic,*" in contrast with fast movements in hip-hop dance. Camille proposed a performance with "two dancers, side by side" with "*code that like glitches for the fast dancer*" to represent the AI bias against that dancer's movements.

While the internship was exploratory and wide-ranging, moments captured in vignettes lead us to believe that future activities may capitalize on authentic encounters with AI with danceON. For example, we could use *when* conditions to illustrate key differences between rule-based AI and ML in which learners complete the Emoji Challenge with hand-written rules and Teachable Machine classifiers and compare/contrast the results. Additionally, learners could also work with each other's' code and classifiers and identify instances in which their systems work less well for others and then implement improvements. We also plan to design culturally sustaining curricula that supports embodied AI ethics education through discussions of AI in society.

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Discussion and Implications

As artificial intelligence (AI) and machine learning (ML) integrate across our society, we bring together a collective set of researchers to understand how we teach about these models and their implementations. Individuals must be equipped to understand the ways in which AI and ML are being operationalized, recognize issues within its implementations, and understand the consequences (benefits and drawbacks) of their use across contexts. The instantiation of these models is inherently interdisciplinary and thus we have constructed a set of empirical contributions exploring how AI education can integrate across various disciplines in K-12 education. Drawing on perspectives of our researchers conducting work across the learning sciences, computing education, literacy education, science education, and human-computer interaction, we pose a set of essential questions and discussion topics for the symposium authors and participants in the learning sciences community.

Promoting Disciplinary Knowledge and Practices

Interdisciplinary educational experiences are important for their ability to relate more honestly to the real world and to promote new practices for learning that develop as we connect across previously siloed content. Through the contributions we will stimulate a discussion around: How we might best support leveraging disciplinary knowledge to develop new knowledge and skills around AI? How can learners develop knowledge about AI that helps learners develop other disciplinary knowledge? How can we create learning experiences that promote reflections, experiences, and work with AI that are representative and embedded in real-world contexts and scenarios? How can the practices across different disciplinary domains with AI create new practices with AI?

Integrating Learners' Perspectives and Experiences

Learners bring a set of knowledge and experiences with AI to the learning environment through direct interaction with agents and models as well as secondary engagement through news and media. We will explore the questions: How can we use interdisciplinary contexts to promote learners' integration and reflection of their current perspectives, experiences, and knowledge surrounding AI? How can learners' lived experiences connect to their work theorizing, developing, and critiquing agents and models?

Critical Explorations of Ethics and Biases

The ways in which AI models are created and implemented have social and ethical implications. Learners must develop critical practices with developing and interrogating AI. Through the various contributions we will examine: How do different disciplinary practices provide entry to critical reflection and iteration of AI agents, models, and their implementations? How do disciplinary practices foster different ways to experience and reflect on biases within AI agents, models, and their implementations? How can we construct new practices within our learners that forefront ethics as part of how they engage in development and implementation of AI?

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International Society of the Learning Sciences

Aspiring for Equity: Perspectives from Design of AI Education

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Abstract: The explosion of Artificial Intelligence (AI) applications along with findings of algorithmic bias toward marginalized populations requires that we redouble our efforts to make AI education equitable to all youth so they can become informed consumers and responsible creators of AI, and can thoughtfully engage with others around equity issues in AI. This symposium focuses on the discussion of five AI literacy programs/projects from across the United States, each attempting to incorporate equity in diverse ways. Together, the five projects explore AI education using multiple pedagogical approaches and learning contexts with unique affordances and constraints.

Symposium focus: Designing for equity in AI education

The concept of equity is laden with multiple interpretations, particularly in the education ecosystem. Within this realm, curriculum providers play a key role in the design of learning experiences and are thus pivotal in ensuring that equity concerns, issues, and topics are embedded into the development and implementation of any curricula. This is of even greater importance in AI curricula considering the increasingly ubiquitous AI applications that affect our daily lives and ethical implications surrounding the AI technologies.

AI education cannot happen without consideration of ethics and equity. However, what this looks like will vary from curriculum to curriculum, and context to context. This brings about the question of how AI learning scientists approach curriculum design. This symposium will bring five curriculum development groups from different organizations and institutions across the United States who are currently developing and researching AI curriculum for K12 education. All five groups identify addressing equity and social justice through the curriculum as one of the goals of their project as well as a design value. As documented and observed similarly in CS education (Santo et al., 2019), equity can mean different things to different people; therefore, how equity is being manifested in these programs and curriculum evidently varies context to context. While there are increasing numbers of projects and initiatives to bring more AI education into K12 settings, the learning sciences' understanding of how we can design AI curriculum for equity and social justice is still nascent. By discussing how each group goes about addressing equity and social justice in their current project in relation to AI

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technologies and supporting young people to develop ethical AI literacy, the symposium aims to highlight different design choices and implementations, allowing the community to learn from each group's current efforts and discuss opportunities and constraints of each approach.

Each group will describe how they think about equity in their own work, and how their current effort, both in terms of processes and products, embodies equity within their AI education activities. More specifically, the presenters will address 1) the framing of equity within their program/project; 2) equity as part of curriculum development--what measures were taken to ensure inclusiveness and relevance to the intended learners? 3) equity during implementation--what type of settings, tools, and populations did they aim to serve? 4) equity as part of the assessment process--how did they design assessments to be more equitable? 5) equity as part of teacher professional development--how did they design and implement student facing workshops and teacher professional development with teachers, with communities, and with AI experts? and 6) equity as a content area in the curriculum--how are issues surrounding ethical dilemmas and harms caused by AI technologies embedded within the curriculum?

How do presentations contribute to the aims?

The contribution from Walsh et al. addresses equity and social justice by embedding ethical dilemmas as a core part of their curriculum. They do so with clever use of multimedia short stories woven into nonfiction texts and media to situate learners; their project-based learning approach engages learners in diverse learning contexts from science discovery summer camps to high school English classes. Zhang and Lee offer further insights into the integration of ethics in an AI curriculum by employing design-based research and using conjecture mapping in their theoretical framework to guide the hands-on experimentation and participatory simulation experienced by the students. The project-based learning approach is bolstered with contributions from Lin et al., who introduce a "sandwich" model of a curriculum that starts with grounding the AI topic in an authentic community-based project. They also illustrate the use of remote codesign methods with middle school students to ensure that student voice is heard from the onset of curriculum design. Aliabadi et al. expand our views on implementation with their focus on community organizations, illustrating a means of designing an educational ecosystem that can make the efforts of AI education more impactful and scalable. Finally, Long and Magerko bring AI education to informal learning contexts (e.g., homes and museums) with elements that can be adjusted to fit learner needs. Together, these papers illustrate diverse framing of equity in diverse contexts and will provide the opportunity for rich discussion at the symposium.

Following, we provide a brief description of each of the five AI projects.

A multifaceted approach to designing for equity in the Imagine AI project

Benjamin Walsh, Bridget Dalton, Stacey Forsyth, Ellie Haberl, Jackie Smilack, and Tom Yeh

Purpose

Our team of Literacy, Computer Science and STEM educators and researchers is developing and studying curriculum modules to support middle and high school youth in exploring critical ethical issues related to artificial intelligence. These project-based learning modules are centered around original short stories that feature youth protagonists at the center of AI ethical dilemmas. Students read stories and non-fiction texts and media and build and manipulate simple AI systems. These experiences support rich discussion that combines social concerns with technical understanding. Each module culminates with students expressing their stances on AI ethics issues using digital media, such as comics, videos, and chatbots. We understand AI Ethics as an urgent topic relevant to youths' current and future lives, regardless of whether they envision a career as an AI developer.

A multifaceted approach to equity

Because of the notable tendency of some AI technologies to play a role in reproducing historical injustices (Buolamwini & Gebru, 2018), we argue that providing access to AI ethics education is itself an equity issue. In addition, we will discuss approaches to fostering equity related to curriculum and pedagogy and study. We pay particular attention to the importance of recognizing minoritized voices and youth perspectives on AI and other CS topics (Lee & Soep, 2016).

Equity in curriculum and pedagogy

We utilize a project-based learning approach to curriculum design, emphasizing Universal Design for Learning principles, in order to broaden access and engagement (Walsh & Dalton, in press). We take a Multiliteracies

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perspective on literacy learning, attending closely to the role of multiple modes and languages in meaning making, actively welcoming a broad set of strengths, perspectives, and experiences into AI ethics discussions (Smith et. al., 2021). Module content and stories feature diverse individuals and explicitly address issues of bias and transparency.

Equity in research contexts

We believe that teaching AI Ethics requires educators to explore structural inequalities associated with race, gender and social class that are now being extended and amplified by AI technologies (Gebru, 2020). Teachers addressing these topics must be responsive to the experiences and beliefs students bring to class, as well as the constraints and pressures placed upon them by school administrators and local communities. In order to better understand how to support teachers in performing this balancing act we have forged partnerships with schools in rural, urban and suburban communities with students representing multiple ethnicities and language groups. Our research contexts include remote AI Ethics summer camps, high school English and Cybersecurity classes, and middle school Computer Science classes. In addition to surveys, interviews, and class observations, we collect students' multimodal products where they express themselves through image, sound, and text, and use heritage and English languages. This data we gather across these contexts is helping us understand how effective we are in helping students develop nuanced, contextualized understandings of AI ethics dilemmas.

Addressing equity in AI and AI education in the Developing AI Literacy project

Helen Zhang and Irene Lee

Purpose

The rapid expansion of AI is transforming our lives and futures. To ensure that youth can productively participate in this future, they must have knowledge of and capability to work with AI. Furthermore, the ubiquity of automated prediction and decision making is altering society by dictating who has access to information, freedoms, and economic opportunity. Those from historically marginalized communities are at greatest risk of the negative impacts of bias in AI. Thus, access to AI education will dictate who has the power to develop AI technology, and also who will be able to audit AI systems and seek justice for themselves and others. Many of the current methods of AI education, however, focus on mathematical underpinnings of AI, making it discouraging to youth who have been historically marginalized in STEM/CS education. This paper reports how the "Developing AI Literacy" (DAILy) curriculum addresses equity in AI education by incorporating a social justice and ethics lens that supports middle school students to become AI literate.

Perspective(s) or theoretical framework

The theoretical framework encompasses two elements: first, integrating ethics into AI curricula motivates learners and enables them to see the relevance of AI (Saltz et al., 2019). Second, pedagogical strategies such as hands-on experimentation and participatory simulation can make AI concepts accessible and engaging for a wide range of students (Squire & Klopfer, 2007).

Methods

Using the Design-Based Research approach (Design-Based Research Collective, 2003) and conjecture mapping (Sandoval, 2014) as the overarching methodology, the research engages in iterative cycles of design and development of DAILy while conducting research to determine the impact of the program (see Figure 1 for the conjecture map of DAILy). This paper reports the analysis and findings from the first design cycle.

Data sources

The quantitative data included student responses to a test, administered before and after a DAILy camp to all participating youth that examined their understanding of AI concepts, attitudes toward AI, and career awareness. The qualitative data included observations, interviews after the camp, and student work.

Results and conclusions

We found high engagement of students with all activities addressing ethics issues. Female students of color were especially active in the investigation and discussion of fairness and the ethical implications and bias of AI. Furthermore, participatory simulations and hands-on investigations were found to be highly engaging. The pre/posttest showed that students developed an objective view of AI and were able to articulate the positive and

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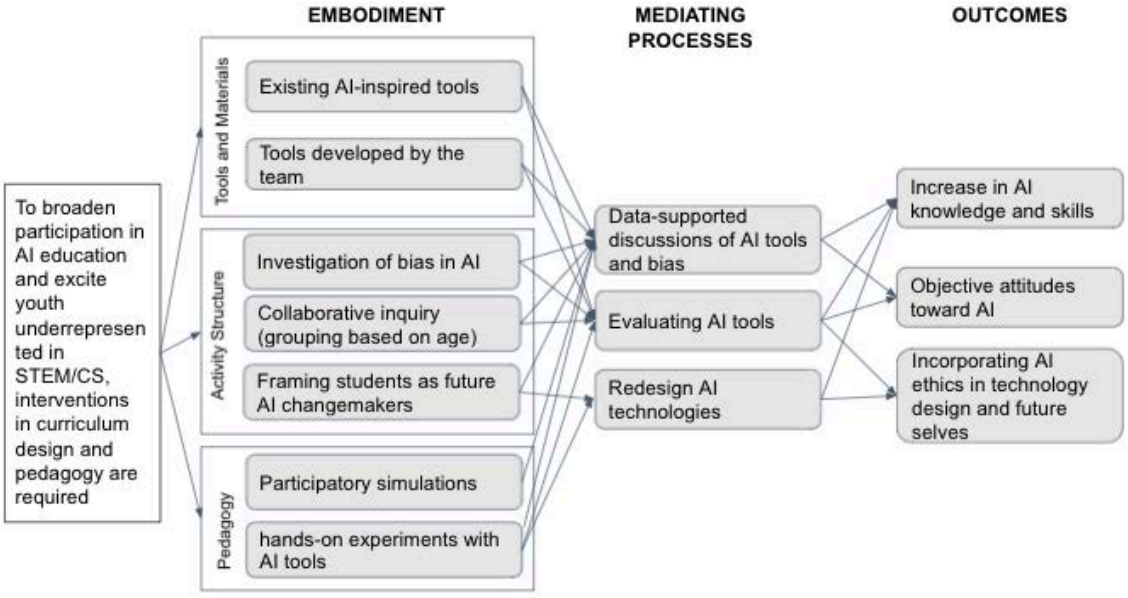
negative potentials of AI tools. The interviews showed that students were able to connect AI ethics to everyday use of technology, technology designs, and their ideation of future selves.

Scholarly significance

Our work contributes to the AI education field by demonstrating that interactive pedagogy approaches and interweaving ethics within AI curricula can engage all students. The emphasis on AI's ethical and societal implications resonates with previous research that students from historically marginalized groups are more drawn to STEM/CS programs that teach the content through social justice lenses (Mark et al., 2013; Vakil, 2018).

Figure 1

Conjecture map of DAILy curriculum



Responsible AI for computational action: Fostering AI literacy in middle school students

Grace C. Lin, Yoon Jeon Kim, Glenda S. Stump, Andy Stoiber, Amal Altuwaiyan, Hal Abelson, Eric Klopfer, and Cynthia Breazeal

Purpose

The Responsible AI for Computational Action (RAICA) curriculum for middle school students integrates Artificial Intelligence, Computational Thinking, Information and Communications Technology, and Design Thinking. RAICA aims to transform students from AI consumers to conscientious AI contributors who can create AI applications with positive social impact. A key mission of RAICA is inclusion with a focus on equity; the curriculum seeks to serve students from diverse backgrounds whose needs may otherwise be ignored or excluded, especially those who are traditionally marginalized in STEM and CS fields.

The modular RAICA curriculum model takes on the metaphor of a "sandwich." It takes a project-based learning (PBL) approach with each sandwich centered around a driving question and project theme. Ethical thinking is interwoven throughout instead of singling out ethics and biases as stand-alone units. The curriculum provides an opportunity to envision a new model of embedded assessment that supports iterative design thinking processes while providing evidence for AI literacy development. RAICA assessment embodies constructivist and situated cognitive learning principles (e.g. playful, socially mediated); it positions learners as reflective and critical leaders of their own learning, scaffolding them toward sensemaking with multiple forms of evidence that reflect diverse epistemological orientations and local norms and cultures.

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Approach to address equity concerns

In the design of the curriculum, we turned to questions from equity scholars who urge the STEM education field to ask, "How do dominant narratives in STEM education position students of color as the taken-for-granted beneficiaries of educational policy, new curricula, or equity scholarship in STEM?" (Vakil & Ayers, 2019, p. 452). Our response to this is to actively co-construct the curriculum with traditionally marginalized students rather than treating them as passive (or "taken-for-granted") recipients or beneficiaries. This conviction is the driving force behind our painstaking approach to codesign with middle school students.

Furthermore, equity scholars voice concerns with representational politics, where STEM education and careers are positioned as the avenue that racially minoritized students *should* pursue, which is also problematic because it does not take into account students' own thoughts and relations to STEM learning (Sengupta-Irving & Vossoughi, 2019; Vakil and Ayers, 2019). Our codesign and project-based learning approach address this concern. Instead of determining top-down what students should do, we explicitly involve students to solicit their ideas of what they think is important to them and what they *want* to do.

Methods

To ensure that the questions posed within modules are relevant to students' lives, their communities, and the broader world, we employ codesign as a research method to engage middle school students and teachers. This method not only allows youth and teachers' voices to be expressed in the framing of our curriculum, but also provides insights into potential content, language use, and structural modifications. To date, we have held a two-week codesign camp with nine students recruited from a Title 1 public school with a large (>90%) Hispanic/Latinx population. We have gathered students' design journals, projects, other artifacts, and video recordings of the sessions.

Results and conclusions

Analysis of codesign camp data identified potential topics to include in future sandwiches, exemplar project ideas, and concrete suggestions for the framing of Driving Questions. Additionally, analysis of the video data promises to provide insights into productive facilitation techniques for this age group, as the power dynamic inherent with adult presence may make it challenging for students to open up and be candid. We plan to apply these insights to the next round of codesign sessions.

Scholarly significance

We employ the deepest level of participatory design with students, wherein they go beyond providing mere feedback as informants; instead they are actively co-creating with developers (Martens et al., 2019). Although previous research has highlighted the use of codesign or participatory design in student empowerment and incorporating student voice (Bovill, 2020) or codesign with teachers (Van Brummelen & Lin, 2021), ours is the first that we know of that codesigns with middle school students in the area of AI education. We anticipate our findings and approach can lead to a more equitable, authentic, and inclusive AI curriculum.

Community-powered problem solving with AI: A case study of Boys and Girls Clubs

Roozbeh Aliabadi, James Carter, and Joel Wilson

Purpose

Can local communities and the after-school spaces promote inclusive AI education? There is no doubt that communities have some of the essential qualities and expertise, and the development of AI skills is nurtured through community organizations and outdoor spaces (Touretzky et al., 2019). We explore how to equip our communities with tools, training, and spaces that promote the full breadth of the AI learning/teaching ecosystem in local communities. We believe schools could also learn from being more open and flexible learning centers with access to quality materials and care in the transition from STEM to STEAM by promoting community-powered problem solving with AI (Wang & Chiang, 2020).

Perspective(s) or theoretical framework

This study takes a project-based learning approach and focuses on the assessment of three areas of competency in AI: application of AI, computational thinking, and innovation and impact (Wangenheim et al., 2018).

Methods

To explore the question, we have designed an ecosystem of recruiting, training, and deploying local community members to teach in local Boys and Girls Clubs in the eastern United States. Furthermore, we have developed a 16-week module of AI classes focusing on the five big ideas in AI. To date, we have pilot-tested the program at four local Boys and girls Clubs in the eastern US where a diverse student population participated in an 8-16 week camp. We have gathered student's projects and artifacts along with teachers' feedback and observations.

Results and conclusions

Initial results of pilot data suggest several areas of improvement in the current project-based learning cycle of professional development, lesson plans, and structuring project-based learning teams based on age and gender. Factors attributed to engagement tend to increase as students perceive project-based learning's link to problems and issues faced in the local communities.

The role of equity in designing co-creative, embodied AI literacy activities for informal learning spaces

Duri Long and Brian Magerko

Purpose

We will discuss the role of equity in our research on designing co-creative, embodied AI literacy experiences for informal learning spaces. We center our discussion on a set of three different AI education activities we have designed for family group learning in home environments and museums. We draw on findings from a codesign study conducted with family groups in a museum (Long et al., 2021a) and user studies conducted to evaluate the efficacy of the activities with families in their homes (Long et al., 2021b; Long et al., 2022). Issues of equity play an important role in the framing of our work, our curriculum design and implementation, and the content of the activities we develop. Specifically, we focus on three key ideas—equitably defining AI literacy, reaching a broad audience via informal learning contexts, and using co-creativity and embodiment as equity design considerations — that frame how we address equity in our work.

Equitably defining AI literacy

One important aspect of equity in AI education is ensuring that learning experiences are both useful and accessible. We have conducted codesign activities with family groups to learn about their priorities and interests, and we will discuss how our findings have informed our definition of AI literacy as a set of skills that can be useful to learners in their everyday lives. We have also designed our curriculum and content to be accessible to learners with no prior knowledge of computing or AI. We will present three different activities that we have developed and describe how the content and curriculum is intended to reduce intimidation, build on learners' existing knowledge, and address equity-related issues.

Reaching a broad audience via informal learning contexts

We focus on designing learning experiences for informal learning contexts such as at-home learning, after-school groups, and public spaces like museums, art events, or parks. Introducing AI education in these contexts has the potential to expand equity by reaching learners who may not otherwise seek out opportunities to learn about AI (Falk et al., 2007; Rosin et al., 2021). Our aim is to develop an AI learning ecosystem that can engage learners across a variety of informal learning contexts. We have developed activities with scalable components that can be adjusted according to learners' needs (e.g. "unplugged" activities that require no access to technology that can be scaled up to museum installations). We will present the activities and discuss how we designed the content/materials to adapt to different implementation contexts.

Co-creativity & embodiment as equity design considerations

We utilize embodied interaction, collaboration, and creativity as three key design considerations in our AI literacy activities. We focus on incorporating co-creativity and embodiment because they have previously been shown to be effective at engaging and fostering learning gains and interest development in groups without prior knowledge of AI/CS (Sulmont et al., 2019) and groups that have been historically marginalized in STEM--specifically girls (Magerko et al., 2016; Werner et al., 2004; Guzdial, 2013; Buechley et al., 2008) and African-American students (Magerko et al., 2016; Eglash et al., 2006). We discuss how we have implemented each of these design considerations in our curriculum and content and reflect on their impact on learning, interest development, and equity in practice, drawing on findings from user studies we have conducted.

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Significance of the contributions

The five projects illustrate how learning scientists in AI education are designing to address equity in this burgeoning domain. Although the varied approaches bring about different challenges and opportunities, it is clear that there is much more work to do, both to define and achieve equitable education in this realm. Including voices historically underrepresented in technical fields like AI will be imperative to reach these goals. AI education is destined to influence future generations as knowledgeable consumers and ethical creators of AI applications; thus, it is of utmost importance that we collaborate and grow as a community to learn how we can design AI curricula that are equitable and promote social justice.

Audience participation plan

This session will be conducted as a panel discussion, with five presenters, a chair, and a discussant. After an introduction to the session by the chair, each presenter will give a brief, 5-minute overview of their project/program. The discussant will then synthesize current challenges and provoke discussion highlighting affordances and constraints of each program. The remaining time in the session will be allocated to audience comments or questions.

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International Society of the Learning Sciences

Data Storytelling in the Classroom

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Abstract: With the rising demand for data skills across industries and disciplines, and the prevalence of data in all aspects and levels of our lives, it is critical to find new, more effective ways to develop students' data literacies. Stories can be an accessible way for students to personally connect to, and think critically about, data and its implications. But how can data storytelling be effectively implemented into classroom settings, in which instruction is often constrained to focus narrowly on quantitative skills? This interactive poster session showcases eight innovations in data storytelling in the classroom. Together, the contributions consider the various facets and functions of stories for supporting data literacies in contexts that span K-12 to university. By seeking to define the value and roles of storytelling in data literacy learning, this session will inform ways to create more effective and engaging data literacy instruction.

Background and goals

The demand for data skills is rising rapidly across industries and disciplines (Bargagliotti et al., 2020). Recent reports call for early instruction in statistical thinking, probability and variability, and the process of inquiry (Franklin & Bargagliotti, 2020), and for attention to asking statistical questions, working with multiple data types, and building skills to communicate with and about data.

However, the pervasiveness of data in our social lives means that data literacies are not just useful preparation for the workforce, but also critical for making sense of complex cross-cutting issues, such as the

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COVID-19 pandemic and climate change (Engel, 2017; Lee & Campbell, 2020). At the same time, classroom contexts pose numerous challenges to designers and educators who seek to promote students' data literacies. Constraints unique to the classroom, such as the need to adhere to subject standards, the limited time within a school day, and the compartmentalization of instruction to specific subjects, can focus data instruction narrowly on quantitative skills and tools. Ignoring the cross-disciplinary nature of data and the relevance of the social contexts of data limits opportunities for learners to use data for personally meaningful purposes, to address societal issues with data, and to critically examine how data is produced and used.

Stories are one way to engage students with the personal and societal impacts of data. Stories can serve as analytical tools, and for communicating both individual experiences and collective perspectives. By connecting personal, cultural and sociopolitical dimensions of data, stories offer opportunities to humanize data (Lee et al., 2021). This symposium explores innovations in data storytelling in classroom contexts. By showcasing curriculum designs and research insights from projects that span K-12 to university contexts, this symposium will examine opportunities to promote students' data literacy through storytelling and will critique the value added of stories over more conventional approaches to data literacy instruction.

What is the value of storytelling for promoting data literacies?

Stories have long been recognized as tools for sensemaking, identity building and empathy (Bruner, 1985, Cleto & Warman, 2019; Lind & Thomsen, 2018). Storytelling has moreover been mentioned in various ways in relation to data, including in fields such as science, data visualization (Park et al., 2021), and journalism (Matei & Hunter, 2021). It is also a more frequent topic in data literacy education. An informal search for the terms "storytelling," "data literacy," and "education," for example, returns 1320 results on Google Scholar, most, if not all, published after the year 2000.

However, definitions of *data story,* let alone of *story* more generally, vary. Some scholars define stories as a series of causally linked events, while others view it as goal-directed behavior toward resolving a problem, and still others define them in terms of specific components such as characters, settings, and plot (Stein, 1982). Meanwhile, in the context of science communication and data journalism, the term "data storytelling" has been defined as a narrative that offers a causal inference that counters audiences' assumptions (Matei & Hunter, 2021). Others write that good visual data storytelling draws an audience in, and helps to make data more persuasive, easier to understand, and to remember (Ma et al., 2011). Such claims about the value of data storytelling, however, remain largely under-explored (Liem et al, 2021).

In response to the increasing interest in data storytelling in education, this symposium seeks to approach a more robust understanding of the value of storytelling and of the roles that it can have in promoting data literacies in classroom settings.

Overview of contributions

Together, the 8 posters in this symposium demonstrate the various roles of storytelling in data literacy education. They show that stories can be used to contextualize and communicate about data in everyday life (Gebre); integrate different perspectives to represent and make sense of environmental events (Wagh et al.); critically engage with social inequities and stereotypes (Louie et al.); drive scientific exploration (St. Clair & Stephens); make sense of aberrant or unexpected data (Davidesco et al.), reflect on personal implications of data (Tes et al.); reframe sociopolitical crises (Rubel et al.); and identify personal connections to broader data patterns (Wei et al.).

A key theme across posters is that stories serve to humanize data, illuminating social contexts and individual perspectives. Stories are variously used as entry points into bigger ideas, invitations to inquiry, and analytic tools to make sense of data and relate to complex patterns and implications. Importantly, stories invite learners to draw upon various disciplinary practices and ways of thinking that move beyond STEM, including imagination, performance, visual expression, and writing. Together, these activities engage transdisciplinary data literacy practices such as prediction, interpretation, and communication.

Finally these posters identify and address challenges faced in implementing storytelling innovations in classroom settings, including the need to link topics to curriculum standards, and to ensure the authenticity of the different disciplinary practices involved in working with data within the structure of school.

Symposium format

Following introductory remarks by the session chairs, we will provide the audience with guiding questions, and will facilitate two rounds (4 posters each) of interaction among presenters and attendees. By allowing co-presenters to also visit and interact with co-presenters, we seek to encourage rich discussions that cut across issues raised by their own and the audience's projects and experiences.

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Following these rounds of interaction, two discussants will stimulate a broader conversation across presenters and attendees by offering reflections and insights from their unique perspectives: Amy Stornaiuolo, who studies youths' digital literacies and technology integration in schools; and Laurie Rubel, who studies the sociocultural contexts of mathematics education, with foci on data science and spatial justice.

This symposium will spark conversations about such questions as: What makes a data story a story? How is a data story different from an argument or an explanation? How can stories be used to promote data practices in meaningful and accessible ways to a broad range of learners? What challenges, opportunities, and strategies are relevant when incorporating data storytelling in classroom contexts? What kinds of support—technology-based or otherwise—benefit students and teachers in navigating their use of stories for data literacy? How can educators and learning designers leverage the affordances of stories to promote specific data literacies and practices? How can we support students' in moving from exploring data to producing a data story? Likewise, how can we support them in moving from an understanding of data situated in a story's context, to an understanding of the broader implications of data?

In answering these and other questions, educators and researchers will better know how to most effectively incorporate data storytelling into classroom settings to promote data literacies.

Descriptions of posters

1. Learning Design and Everyday Life as a Learning Context for Data Literacy

Engida Gebre

The increasing role of data in various aspects of our life prompted consistent calls for data literacy education. However, educational interventions are focused on developing technical competence and algorithmic aspects of data literacy thereby resulting in a narrow understanding of the concept (Gebre, 2018; Gould, 2017). In his critique of data literacy education practices, Mertala (2020) argued that the way we teach about data in schools is serving as a hidden curriculum for promoting data (il)literacy among students. This is because data is often framed as a "cognitive authority" and instructional practices focus on developing skill sets to deal with spreadsheets of data with limited connection to the role of data in everyday life. Addressing the disconnect between data literacy education and data practices of students in non-academic settings requires a situated data literacy education that considers students' everyday life as a learning context. That is, educators could design learning environments that involve storytelling with data where students learn with and about data as it relates to their everyday life and their communities.

In this proposal, we draw from our previous as well as newly started data literacy projects with secondary school students to a) develop learning design options that consider ways of using students' everyday life as a learning context for developing data literacy, and b) share students' work on storytelling and news reporting with data. More specifically, we build on the notion of learning as "active contextualization" (Gebre & Polman, 2020) and articulate learning design options where students consider the conceptual, competency and contextual aspects of data literacy. Using such an approach raises students' awareness about and understanding of data in everyday life thereby reducing what Brunton and Nissenbaum (2011) referred to as "epistemic asymmetry" related to data (il)literacy.

2 Investigating California Wildfires as a Site for Middle School Students to Engage in Data Practices & Modeling

Aditi Wagh, Engin Bumbacher, Adelmo Eloy, Jacob Wolf, Tamar Fuhrmann, Paulo Blikstein & Michelle Wilkerson

A central goal of science education is to support students in scientific sensemaking of real world phenomena. This often involves developing and evaluating models or representations of the phenomenon in conjunction with data about real world phenomena. The practices involved in coordinating between data and models in this process can offer productive opportunities for science learning (Blikstein, 2014; Fuhrmann et al., 2018; Georgens & Manz, 2021; Gouvea & Wagh, 2018). More research is needed to understand how to integrate these practices to foster science learning.

In this paper, we propose a conceptual framework that characterizes how students draw on different qualitative data and scientific modeling practices to answer a driving question. We draw on video data from a design-based research study on 8th grade students in California working on an inquiry-based unit on wildfires.

They build computational models and analyze actual satellite videos to investigate mechanisms underlying smoke spread from wildfires in their state.

As a lived and shared experience, the California wildfires 2020 present a rich conceptual space for student sensemaking and storytelling (Bruner, 1991). We show that the process of coordinating data and models reflects elements of storytelling identified in our previous work (Wagh & Dickes, 2020) in three ways: (1) Students consider and reconcile competing perspectives as they try to integrate between different understandings of how wildfire smoke spreads from multiple sources (Ochs & Capps, 1996) such as their own lived experiences, their own and peers' scientific models (of the phenomenon) and their analysis of the data; (2) Students construct a theory of events along a temporal dimension as they interpret how successive events impact each other (Ochs & Capps, 1996), and position the models and data at different points along that dimension; and (3) As a class, students construct collaborative meaning through co-authorship, interpretation and multiple retellings of narrative events.

3 How Do Students Use Comics to Engage with Data?

Marian Tes, Kayla DesPortes, Megan Silander, Ralph Vacca, Camillia Matuk, Anna Amato & Peter J. Woods

Creative media provide opportunities to expand on the ways learners explore and find personal connections to data (Bhargava et al., 2015, D'Ignazio & Bhargava, 2016). As a form of creative media, comics offer a unique set of affordances for making sense of data (Bach et al., 2017). However, there is little if any research on how comics can activate young students' engagement with data, which would inform new ways of promoting data literacies in classrooms. This study asks: *How do students use comics to engage with data?*

We co-designed a unit with an art and a math teacher, who implemented it in their classrooms. In the math classroom, students (*N=33*) examined two datasets: (1) a national dataset from the Pew Research Center about teens' views of and experiences with friendships, social media, technology; and (2) students' own responses to a survey we designed asking about their friendships. Based on these data, we prepared boxplots, dotplots, and bar graphs. In their art class, students used the digital comic-making tool, Pixton, to communicate stories about friendship using inferences made from the graphs. We coded students' comics to identify: (a) data reasoning apparent in their comics (e.g., reflecting on one's relationship to the data, questioning the validity of data), and (b) whether data were intrinsically or extrinsically embedded in the narratives.

We found that comics that intrinsically embed data into narratives demonstrated nuanced engagement with data. Whereas some comics served simply as an alternative to reporting statistics (e.g., "You know only 47.8% of people think it's kinda easy to make friends?"), others integrated data in ways that advanced a plot. In one comic, for example, the main character reflects on being a part of the 21.7% of people who find it hard to make new friends, while simultaneously accepting an invitation to hang out with a prospective friend. This study demonstrates how comics can be an accessible way for students to engage with data, and can help teachers identify students' emerging data literacy practices.

4 Promoting Data Literacy Skills through Authentic Research Experiences in the High School Classroom

Ido Davidesco, Noah Glaser & Jimmy Naipaul

Data literacy is critical for students to make sense of complex societal issues, such as the COVID-19 pandemic and climate change. Yet, current K-12 curricula provide limited opportunities for students to engage in rich data practices by gathering, manipulating, analyzing, and visualizing data. BrainWaves was developed to support high school teachers in facilitating student-led neuroscience-inspired investigations. In this curriculum, students first learn about neurons, brain anatomy, and brain plasticity, and then, with support from science mentors, develop a research question of personal interest to them (e.g., how does listening to music affect learning), collect and analyze data, and share their findings at a culminating program symposium (Azeka et al., 2020).

This study explored the nature of student experiences analyzing and interpreting data in BrainWaves. We used a phenomenological methodology consisting of semi-structured interviews with program participants (37 students and 25 teachers). The analysis identified several key themes. First, students and teachers reported tension between having too much and not having enough data. Some students felt overwhelmed by the amount of data and had difficulties seeing the big picture, while others felt that they did not have a sufficient amount of data to address their research question due to difficulties in the data collection process. Second, interpreting data, especially when it contradicted students' hypotheses, was a challenge, which often resulted in students focusing

on aspects of the data that supported their hypotheses. Third, support and scaffolding from teachers and science mentors emerged as a key element in shaping students' experiences of working with data. These findings suggest that student-led research investigations can provide a rich context for students to develop their data literacy, yet sufficient scaffolding and structure are needed.

5 Grappling with data stories of social groups and social justice: A strategy for building interest in data literacy among historically marginalized youth

Josephine Louie, Beth Chance, Soma Roy, Emily Fagan & Jennifer Stiles

The world today is awash in data. Although data science is one of the fastest growing occupations in the U.S., historically marginalized groups such as Blacks and Latinos/as are greatly underrepresented (Priceonomics, 2017). To broaden participation in data science and to help all people thrive in a data-driven world, schools need new strategies to draw more diverse students to data literacy learning.

The *Strengthening Data Literacy across the Curriculum* project has been working on such a strategy. In line with Gutstein (2003) and Ladson-Billings (1995, 2014), the project developed prototype curriculum modules with a social justice focus to promote stronger statistical thinking and interest in data literacy among students from historically marginalized groups. In these modules, students use person-level data from the U.S. Census Bureau to articulate data stories (Pfannkuch et al., 2010) about whether and why group outcomes diverge. Using the online data visualization tool CODAP, students address questions such as: What have the incomes of higher- and lower-income earners looked like over time? What might explain the wage gap between males and females? How might we respond to a claim that immigrants are less likely than the U.S.-born to work?

Pre- and post-survey data from over 200 students in non-AP statistics classes from seven high schools with high proportions of Blacks and Latinos/as indicate that students who used the modules showed statistically significant growth in their interests in statistics and data analysis. Student focus groups and written reflections suggest that students found it engaging and meaningful to use multivariable data to wrestle with stories about real or purported inequalities among groups relevant to themselves and their families. Building students' abilities to tell data-based stories about social group outcomes requires interdisciplinary knowledge and skills, however, with implications for teacher training and professional development to support this learning approach.

6 Using data stories to motivate student exploration of science phenomena

Natalya St. Clair & Lynn Stephens

We want students to have the experience of learning science by doing science (Bell et al., 2005). Data stories can be used to frame guided inquiry so that students can use data they produce (Hardy et al., 2020) to communicate their thinking. In *InquirySpace 2: Broadening Access to Integrated Science Practices,* we frame curricular units with a phenomenon in which students produce data with sensors and then explore those data in an integrated data analysis environment. By developing a set of compatible technologies and approachable activities, students from many backgrounds may learn science by doing science—and communicate their findings with data.

In this exploratory case study, we visited a high school where half of the students are economically disadvantaged and a high proportion are minority students. A 9th grade biology teacher used the question, *Might having a fever affect your ability to digest dairy?* to motivate exploration of how temperature affects the reaction of milk and lactase. Using data she had collected with a glucose meter, one student interpreted the possible effect of several variables. When presenting to the class, the story she told of her data continued beyond the driving question, as she discussed where a lactase enzyme might be produced in the body and why. We consider which curricular and teacher supports may have helped motivate this student to expand on the story that was used to frame the inquiry.

7 Storytelling with Data in Response to Crisis: Shifting Away from 'Maths of the Morgue'

Laurie Rubel, Beth Herbel-Eisenmann Shiyan Jiang, Jennifer Kahn, Vivian Lim & Lee Melvin Peralta

Note on Authorship: This work represents the equal contributions of this writing group. Lead authorship is rotated on publication pieces; subsequent authors are listed alphabetically.

Storytelling in times of crisis–often told from the points of view of governments, corporations, and other institutional actors–typically showcases data using what we call "maths of the morgue" (Lim et al., under review). "Maths of the morgue" presents detached, disembodied, and unemotional views of crises, through visualizations that present an accounting of loss, using dehumanized quantities (e.g., fatalities, case numbers, unemployment rates). This form of storytelling benefits those in power by enabling governments, corporations, and institutional actors to exert and maintain influence over others with the effect that "maths of the morgue" becomes a technology of domination and control (Cisney & Morar, 2015). A "maths of the morgue" approach has become the default in K-16 education (Wilkerson & Polman, 2019), which increasingly emphasizes data and data visualization without adequately attending to the pivotal roles that emotion, action, and the imagination play in data (Kahn et al., under review). This approach to data storytelling in education neglects other possible liberatory functions for data storytelling like cultivating imagination and hope.

We present a reimagining of storytelling with data using a "maths of the living" approach, which draws on a synthesis of critical frameworks that attend to dimensions of power, race, gender and place (Data for Black Lives, n.d.; D'Ignazio & Klein, 2020; Loukissas, 2019). Our conception of "maths of the living" highlights the underappreciated capacity of data and data visualizations to embrace an animated view of life and personal experience; to embrace culture, history, power dynamics, ambiguity, and rule breaking; and to inspire action and shift our ethical orientations rather than representing the world from afar (Lim et al., under review). We formulate suggestions for learning designs that shift away from "maths of the morgue" towards our alternative of "maths of the living" and illustrate this shift using examples of storytelling with data.

8 Storytelling with Data in the Third Space: leveraging students' data literacies for scientific investigation and social change

Xinyu Wei, Cherise McBride & Michelle Wilkerson

The Storytelling with Data for Social Change workshop was designed to develop students' scientific data literacy through investigating, reorganizing, and reasoning the publicly available datasets on the Common Online Data Analysis Platform (CODAP). The workshop aimed to make data science education more accessible for middle school students from socioeconomically minoritized communities.

In partnership with the Lawrence Hall of Science, we recruited seventeen participants ranging from 12 to 14 years old. Participants were mostly from the Greater Bay Area, CA, USA, and from both dominant and non-dominant backgrounds. During five workshop sessions, students journeyed through a scaffolded introduction to the topic of environmental racism. They first read case studies and interviewed family members, then analyzed local datasets using CODAP to situate data patterns in terms of personal and historical contexts. Leveraging their repertoires of practice (Gutierrez & Rogoff, 2003), students used the Story Builder plug-in within CODAP (Wilkerson et al., 2021) or Google Slides to compose multimodal data stories and presented them on the course's last day.

We designed this workshop to be a third space (Gutierrez, 2008), whose curriculum is built on students' underlife (Goffman,1968; Gutierrez et al., 1995) to foster a co-constructed dialogic learning opportunity. We examined how people in different neighborhoods can be impacted by health hazards disproportionally, which inspired some students to investigate why some jobs are dominated by particular racial groups. For example, one 7th grade Latina student noticed the correlation between the dusty air and the frequent usage of eye drops by her father, a long-time construction worker. It prompted her to filter the asthma dataset and compare the mean number in her zip code to other nearby cities.

These stories position students' everyday practices and interests as grounds for expansive learning. They also demonstrate students' data literacies as sociological and historical practice, a frame that enriches data literacy in K-12 classrooms as culturally-sustaining, sociocritical, and ultimately supporting the construction of just social futures.

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International Society of the Learning Sciences

The Nature(s) of Embodied Mathematical Failure

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Abstract: The purpose of this symposium is to consider the embodied nature of failure in different learning environments, contexts, mathematical situations, and age groups. Our exploratory work was guided by the following questions: (a) How is failure represented through our bodily actions? (b) How is failure co-constructed through our bodies? (c) How are our reactions to failure embodied? (d) How might embodied failure be framed or conceptualized across mathematical situations? We explore these questions through a close examination of the intersection of embodied cognition, failure, and mathematical activity as presented and challenged by a diverse spectrum of scholars. While grounded in mathematical activity, this symposium will contribute to the ongoing state of learning science research regarding how the mind, body, and environment work together to highlight student's reasoning and thinking, particularly within moments of failure.

Introduction

This paper begins with two examples from research collected from seven groups of students in grades 3-5. Our goal with these two examples is to illustrate what we as co-organizers were noticing in terms of the embodied nature of failure within a low-notation environment (Williams-Pierce et al., 2021). The task was two-fold. First, students laid a path for Dash, a programmable robot, to traverse by placing sections of tape from one side of the room to the other. Second, students used the Blockly app to program Dash to travel on the path laid by another group. The first example is from a group of Grade 5 students negotiating about a specific angle between two adjacent strips of tape.

> As Ben[1] laid a section of tape to the end of the path, Olivia stated, "Make it jagged. That's way too long." To explain what she meant and perceived, she performed an action of pulling up the tape section from the floor, ripping it into two parts and laid one piece of the ripped tape back down. She then stated, "keep doing that pattern," and pointed toward a specific angle on the path (see Figure 1). Later, Olivia changed her suggestion from 'jagged' to 'zig-zag', saying "We can do zig-zags." Olivia pointed toward the same angle as earlier to illustrate what she meant. Responding to Olivia's suggestion, Red proposed to the group, "We have to make really tight angles." Chris added, "Make it a tight angle." Next Ben added, "Make it zig-zag."

Figure 1
Use of pointing gesture to indicate angle to repeat

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In this example, Olivia perceived Ben's section of tape to be a failure in that it was too long. Olivia corrected Ben's action and provided feedback to him and the group through using her bodily actions to remove and manipulate the section of tape to what she perceived as an appropriate length to construct a zig-zag pattern. In addition, this example highlights how the use of pointing gestures supported Olivia to clearly communicate what she meant by 'jagged' and 'zig-zag' as the group came to a shared understanding of the informal word 'zig-zag' in relation to other words such as 'tight-angle.' The second example is from a group of Grade 4 students testing Dash's movement along the path, particularly if the next line of code – left thirty degrees – was appropriate based on their perception of the angle measure formed between two sections of tape. The enactment, or the testing, of the program by Dash made Patrick conclude that turning left thirty degrees was not enough for Dash to be positioned directly on the next section of tape.

> Patrick stated, "It [Dash] was off a little bit." Before they began discussing and negotiating the angle measure, Almond created a border of the path with his hands (see Figure 2a). Next, he repositioned his body/head to over Dash (see Figure 2b), then stated, "So maybe like thirty-five, thirty-five."

Figure 2
Almond using his body to make-sense of Dash's position

Figure 2a

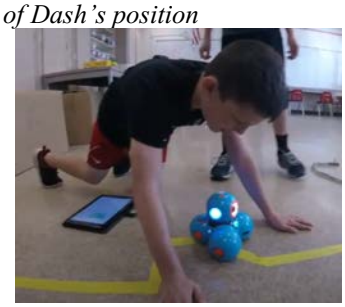


Figure 2b

To make sense of the failure in the code as enacted by Dash, Almond used his body to imagine himself traveling along the next section of tape (Figure 2a) before considering the perspective of Dash as positioned on the path (Figure 2b). In other words, Almond seemed to embody Dash through his bodily actions to conclude that the angle measure should be 35-degrees as opposed to 30-degrees.

Building on our observations, the purpose of this symposium is to consider the embodied nature of failure in different learning environments, contexts, mathematical situations, and age groups. Our exploratory work was guided by the following questions: (a) How is failure represented through our bodily actions? (b) How is failure co-constructed through our bodies? (c) How are our reactions to failure embodied? (d) How might embodied failure be framed or conceptualized across mathematical situations? This collective work is situated within mathematical activity as we are focused on the actions and behaviors of participation in different mathematical practices (e.g., relating, problem solving) across a variety of environments, contexts, and situations (Plaxco & Wawro, 2015). As described by Rasmussen et al. (2015), as students engage in mathematical activity, they enact their understandings while also building and/or expanding their ways of knowing and reasoning. As such, we contend that the implications of this symposium lies in the potential to develop a range of descriptions that highlight the multiplicity of established and potential relationships between embodiment and failure (i.e., embodied failure) and inform the theoretical and/or empirical groundings of ongoing and future scholarship.

Shared theoretical groundings

Each contributor thinks critically about embodiment and failure within mathematical activities– but in a wide variety of ways. We share theoretical groundings in the sense that each contributor considers these elements to be crucial – but how we perceive, operationalize, and analyze each are different. That difference is the subject of this symposium, so we only briefly describe foundational work for embodied cognition and failure below.

Embodied Cognition

Recently, learning scientists argued that human cognition is embodied, human abilities to solve problems are deeply intertwined between body and brain (e.g., Hollan et al., 2018). Our gestures and bodily action can be considered cognitive components because they shape our thinking (Krish, 2013). Gestures play an integral role in interpersonal communication where core problem domain concepts may be difficult to explicate in language

(Nathan et al., 2013; Reynolds & Reeve, 2001), and gestures can contain unique communicative content separate from spoken language (Williams-Pierce et al., 2017). In addition, full-body movements are vital resources for sense-making and understanding and using mathematical concepts (e.g., Hall & Nemirovsky, 2012; Vogelstein, 2020). Central to embodied perspective in learning science is understanding learning in terms of learner's "participation in practices of inquiry and discourse that include interactions with others and with the material, symbolic and technological resources in their environment" (Kozma, 2013, p 206). In this way, an embodied perspective on the nature of tools and representations includes attending to how tools and representations are perceived and used alongside language, bodily actions, and gesture, as well as their roles within rich social and physical interactions (White & Pea, 2011).

Failure

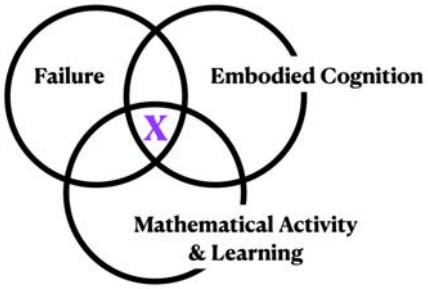
Prior research has highlighted the complex nature associated with failures as it can be viewed as "whatever [felt] like a failure to the person experiencing it" (Bishop, 2017, p. 962), or synonymously referred to as mistakes, errors, desirable difficulties, and unhappy eventualities to name a few (e.g., Simpson et al., 2020). Some consider failure as productive, an opportunity to develop conceptual understanding and engage in the iteration design process (Kapur, 2015; Searle et al., 2018). Conversely, others, for example educators, feel uncomfortable allowing youth to experience failure due to the negative associations and feelings regarding failures within learning environments (e.g., Lottero-Perdue & Parry, 2017). Further, perceptions and feelings about failure experiences do not necessarily transcend learning environments as failure in an academic context may be viewed as a negative, debilitating experience while failure in a DIY-making context as a positive, enhancing experience (Simpson et al., 2018). In the field of mathematics, students too often withdraw from completing a task or a set of problems that is perceived to result in an incorrect response, or in failure, which in turn leads to learned helplessness and a negative attitude toward mathematics (e.g., Chinn, 2012). As this scholarship implies, failure cannot be explicitly or clearly defined as what it means to experience a "failure" is dependent on many factors such as the individual perspective, the environment, the activity, and the interactions with self, others, tools, and materials.

Session overview

As the organizers of this proposal, we have been examining failure and/or embodiment in a variety of mathematical learning contexts (Shokeen et al., 2020; Simpson et al., 2018; Williams-Pierce, 2019). In particular, we invited scholars who approach research in embodied mathematical failure from a variety of different directions that lie in the intersection as illustrated in Figure 3. We contend that the significance of the collective work lies within this intersection, particularly the nature of failure within the teaching-learning process. For example, Soto (Paper 1) primarily focused on embodied mathematical cognition, with failure backgrounded (but still crucial) in their work, while Kapur (Paper 5) focused on productive failure in mathematics classrooms and used embodied cognition to better understand his students' reasoning and communication. Plaxco (Paper 3) and Katirci and Williams-Pierce (Paper 4) both examined the embodied failure of learners when interacting with designed objects that give feedback directly with each interaction, such as a Rubik's cube or touch-screen videogame, respectively. Further, we varied the age of participants, as well as the context of learning - Ellis (Paper 2) examined middle-school students in a teaching experiment, while Baker and DeLiema (Paper 6) focused on informal childhood playground activities. The symposium will be structured as follows: (1) engage the audience in an experience to evoke and reflect upon the embodied nature of failure; (2) individual presentations; (3) the discussants will make connections across individual presentation and discuss implications of the collective work; and (4) questions and comments from the audience.

Figure 3

The intersection of Failure, Embodied Cognition, and Mathematical Activity & Learning is the focus of this symposium.



In the following sections, we introduce the proposed symposium presentations to provide an overview of the breadth of the discussion.

Learning: When our bodies contradict known facts

Hortensia Soto

It has been said that geometric reasoning is to gesture (or other utterances) and diagrams as algebraic reasoning is to speech and symbolism (Soto-Johnson & Troup, 2014). A goal for our students is for these two types of reasoning to work in tandem. Unfortunately, this is not always the case, and in general, students tend to question their geometric reasoning even if their embodied experiences support their geometric reasoning. There are also instances where students believe in the embodied experience, even though it conflicts with mathematical facts that can be proved algebraically. This phenomenon has been observed repeatedly when learners are asked to traverse the sides and internal angles of a triangle. Instead of traversing the internal angles, learners traverse the exterior angles and thus, convey that "maybe the sum of the interior angles of a triangle is 360 degrees." Thus, embodied failure can manifest as a disconnection between the two types of reasoning. This may emerge when learners fail to believe their embodied actions or fail to recognize the inaccuracy in their embodied actions.

Generalizing beyond body-supported dimensions

Amy Ellis

Our talk will consider the effects on students' generalizing of transitioning from contexts in which students can use embodiment to imagine, visualize, act, and determine failure to contexts in which they cannot. Specifically, we report on a teaching experiment with two secondary students who explored the volume of a growing cube and determined expressions for additional volume as the cube grew. In the three-dimensional context, students engaged in embodied actions with physical cubes to validate or invalidate their hypothesized expressions. When shifting to higher-dimensional hypercubes, students no longer had embodied contexts to support their reasoning, and consequently moved from a physical representational register (Duval, 2006) to a combinatorics representational register. We identified and explored these shifts in registers as a supporting mechanism for students' generalizing activity.

Twisty puzzles and intentional temporary failure

David Plaxco

In my recent work, I am developing instructional materials that leverage the Rubik's cube and other twisty puzzles to support mathematical content and practices during transition to upper-level mathematics courses. When solving a twisty puzzle, part of what makes the process so difficult is that the object itself requires the solver to temporarily un-solve the parts that they have already solved, requiring a deal of faith in the algorithms the solver uses to manipulate the pieces of the puzzle. I have come to view this moment in which the solver has (necessarily and intentionally) "messed up" their prior work as a temporary fail state. Naturally, when first learning to solve the cube, this process is not always successful and the solver is set backward in their journey (making the fail state slightly more permanent). Overall, the solving process can be viewed as a fluctuation between fail states and equilibrium states at which the solver has resolved more pieces of the cube. At the moment, this is only a theoretical framing; in my future work, I will apply this lens to actual scenarios that involve participants in order to refine the perspective.

Gesture-failure-feedback (GFF) loop in games

Nihal Katirci & Caro Williams-Pierce

Tablets and mobile phones games have touchscreen technology that promotes the interaction between touchscreen devices and humans through touchscreen gestures. These touchscreen gestures are, for example, tapping (touching the screen with a fingertip), dragging (moving fingertip over the surface without losing contact), and pinching (touching the surface with two fingers and bringing them closer together) (Villamor et al., 2010). These touchscreen gestures, notwithstanding success or failure, is paired with feedback (Williams-Pierce, 2019). The feedback is dependent on how game designers created the system feedback of the game. In many mathematical education games, there is just one correct answer, and the game gives only summative feedback. When the player submits the answer, the game system compares the player's answer and the correct answer. If the player's answer is not the same as the correct answer, the game penalizes the players. However, in well-designed educational

games, games provide feedback in three different ways: formative (Heron, 2010), summative (Deci et al., 2001), and informative (Kim et al., 2018) feedback. Formative feedback is given during the solving of the puzzle and it helps players avoid or learn from failure. Summative feedback is given after the player solves the puzzle. Informative feedback is given when players need extra information or clues to solving the puzzle, such as clicking the Hint icons on the screen. Well-designed games also give space to the players to do comparison themselves. Hence, when players are playing, they are also learning.

Gestures in productive failure

Manu Kapur

In productive failure, students first engage in problem-solving activities that are deliberately designed in a way that students are unable to generate the optimal or correct solutions. Yet, it is precisely this process of generation sub-optimal or incorrect solutions that is the locus of deep learning as it prepares them to learn from subsequent instruction. In the absence of canonical tools and language, students invariably resort to a diverse set of motor actions and gestures to communicate their ideas, representations and solutions. These spontaneously occurring gestures function as grounding actions, anchor and communicate intuitive understandings, aid the development of a shared language during collaboration, and form a bridge for understanding the canonical solutions subsequently.

Mathematizing embodied play and failure

Justin Baker & David DeLiema

In a classic text on mathematical cognition, Lave et al. (1988) argue that “snags” during grocery shopping cause shoppers to question and revise their arithmetic problem-solving. More recent studies on informal parent-child engineering tasks have revealed the role of interactions with physical objects in stimulating externalized mathematical thinking (Simpson et al., 2021), and the impact of caregiver scaffolding and questioning in fostering understanding of mathematical concepts involved in an engineering design task (Simpson & Zhong, 2021). We extend these arguments about the situated nature of mathematical thinking to naturalistic, outdoor play between parents and their young children (age 2-8). We examine how embodied failures during informal play activities serve as generative moments for the intergenerational discussion of mathematical features of problems. Using interaction analyses of video data (Jordan & Henderson, 1995) of naturalistic, outdoor play captured by families themselves, we highlight three play episodes in which children's self-directed pursuits (reaching for a rope, running down a ramp, passing objects through a pool noodle) and subsequent impasses (failing to reach the rope, falling down the ramp, getting a stick stuck in the pool noodle) create an occasion for talk about mathematical features (distance, speed, and size respectively). The talk about mathematical features serves the specific purpose of clarifying the causes of the impasse and/or solutions to the impasse. Children's intrinsic desire to pursue challenging play tasks, and the inevitable embodied failures that occur, combine to create a scenario ripe with potential for this kind of mathematical learning.

Conclusion

Collectively, the presentations will contribute to exploring the intersection of embodied cognition, failure, and mathematical activity, as well as consider the embodied nature of failure in different learning environments, contexts, mathematical situations, and age groups. As such, we contend this symposium addresses the conference topic, elucidating theories and processes of learning and teaching, as we consider the inclusion of failure to contribute to the ongoing theory development of embodied mathematical activity and learning (Hall & Nemirovsky, 2012). As described by Tall (2004), “There is a period of exploration and incubation that precedes the eventual formulation. In this case of the theory…, it is moving towards a stable form, it is still in the process of being filled out and refined” (p. 29). By bringing together a wide variety of scholars who explore embodied mathematical failure in various ways, this symposium will move us towards a more stable and refined understanding of our guiding questions: (a) How is failure represented through our bodily actions? (b) How is failure co-constructed through our bodies? (c) How are our reactions to failure embodied? And (d) How might embodied failure be framed or conceptualized across mathematical situations?

Endnotes

(1) Pseudonyms are used for participants.

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International Society of the Learning Sciences

Mapping the Complexities and Benefits of Research-Design Partnerships

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Abstract: Increasingly our field is recognizing the necessity of close, collaborative relationships with educators, policy makers, students and other potential stakeholders if our design and research work is to have a lasting and more equitable impact on education. However, this work is not easy or quick, and we lack both detailed examples of how it is done and training for new (and current) scholars in how to do it. This symposium brings together a group of scholars who actively engage in RPPs and DBIR in order to highlight the lessons that have been learned and extend our discourse into the realities of this work, how to prepare students and current scholars to design their work with partners at the center, and how to accurately plan for work that engages stakeholders.

Introduction

Design-based implementation research (DBIR) seeks to address the reality that even high quality, rigorous research in education often fails to transfer across real educational contexts and therefore cannot have a sustained impact on students' learning. In order to address this issue, DBIR places partnerships at the center of the research and design processes, with the goal of creating interventions that are sustainable and adaptable across settings (Penuel et al., 2011). Research practitioner partnerships (RPP) are often formed as part of DBIR work, and position research as a response to needs of practice, rather than to gaps in the literature (Henrick et al., 2016). RPPs are collaborative partnerships between research teams and practitioners, where defining the problem space and designing solutions is a collaborative endeavor.

This type of work is essential as we begin to recognize the limited impact research in our field has had on education (Wise & Schwarz, 2017), and the significant limitations of traditional learning theories and methods in education for creating equitable learning opportunities that are free from oppression and bias (Nasir et al., 2021). Without research and design that is embedded in partnerships with the intended users and stakeholders, we run the risk of being at best ineffective, and at worst, continuing the cycle of oppression and discrimination seen in educational contexts today.

However, as noted by Fishman and Penuel (2018) the long cycles of collaboration and iterative design and implementation studies are at odds with a lot of the typical structures within educational research (e.g. funding cycles, productivity expectations for early career scholars) and there is little formal training for doing this type of work. In addition, while there are some examples of case studies and descriptions of RPPs (e.g. Farrell et al., 2021) and studies that attempt to analyze the design and collaboration processes (e.g. Lawrence & Mercier, 2019; Lawrence, 2020), we still lack frameworks to understand how this work is conducted across cases (Cheng, Clark & Van Horne, 2020) and critical analyses of the implications of our interactions and design processes.

This symposium brings together researchers who are actively working with partners, in DBIR studies and/or RPPs. The papers represent a range of projects and approaches to DBIR and RPPs, and each presents an opportunity to consider elements of this work. Across these papers, we seek to understand how to establish and maintain RPPs (Benichou et al., Mercier), models and frameworks for conducting DBIR work (Ahn et al., Arce-Trigatti), the infrastructure necessary to develop capacity for DBIR work (Mckenny & Poortman), a microanalysis of the design process (Lawrence) and a reflection on bringing children into DBIR practices (Borge). We will seek commonalities across the work, and also to use the different perspectives to identify future directions for frameworks and capacity building activities.

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Paper 1: Boundary Crossing Processes in the Forming Stages of Multi-Sector Research-Practice Partnerships: Three Cases of School-Based Citizen Science

Maya Benichou, Yael Kali & Yotam Hod

Citizen science is a genre of research in which stakeholders from different fields of expertise – scientists and non-scientists – work together to advance scientific knowledge with the assumption that science is not the property of experts but should be made accessible to the general public (Shirk et al., 2012). Citizen science projects have been active around the world for many years, however technological advances have recently led to a dramatic acceleration in projects of this kind in diverse fields (Lewenstein, 2016; Sagy et al., 2019). Leveraging the exciting opportunities of citizen science to bring together citizens and scientists, recently we (and other colleagues) expanded on this vision by creating the nationally funded, *Taking Citizen Science to Schools* (TCSS) research center. At the core of the center is a network of research practice partnerships (RPPs) (Hod et al., 2018) that bring together school practitioners (teachers and administrators), policymakers, educational researchers, and active scientists on a number of citizen science projects. To date, over 90 schools and hundreds of teachers have participated, contributing to this network by sharing challenges and best practices, developing curricular materials and activities, and supporting one another as schools enter new relationships that break the traditional boundaries that separated them in the past.

This paper – which is based on a forthcoming chapter in an edited book about teachers and teacher learning in the learning sciences (Benichou, Kali, & Hod, forthcoming) – zooms into the formation stage of three RPPs that participated in this network, where the first RPP took place prior to the second and third, offering opportunities to redesign the partnerships in the successive round of implementations. The formation stage plays a vital role in creating sustainable partnerships around educational innovations. We focus on the teachers in the formation stage within these partnerships, with an eye on elucidating how the teachers began transcending their existing professional development boundaries. Little is known about the new opportunities for learning and professional development of teachers as part of the multi-sector partnerships between students, teachers and scientists that school-based citizen science affords.

Drawing on extensive field notes, digital communications between the different stakeholders, written reflections, and interviews, we applied a boundary crossing framework (Akkerman & Bakker, 2011) to analyze how identification, coordination and reflection processes took place across our cases. Our research highlights the mistakes made during the first implementation, particularly as part of the coordination processes, that did not fully support the mutualistic relationships that were the goal of these multi-sector RPPs. We show how the nuanced changes made during the subsequent implementations led to far different outcomes, whereby the teachers felt a growing sense of meaning as they expansively framed their work and took productive agency to initiate new citizen science projects in their schools. These insights are important to understand as design-based implementation researchers seeking to foster sustainable partnerships have to negotiate complex, multi-sector relationships in the field (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013).

Paper 2: Developing DB(I)R researcher capacity

Susan McKenney & Cindy Poortman

If design research is to realize its potential contribution to education in general and the learning sciences in particular, then explicit attention must be given to holistically developing Design-Based (Implementation) Researcher (DBIR) capacity. Collaboration between researchers and practitioners is shaped by shared goals and resources, but also by the values, expectations and expertise of the parties involved. For example, early stages of problem articulation and exploration benefit highly from open-mindedness and realism, while one's sense of moral purpose, belief that change is possible, and self-efficacy may prove particularly valuable during the implementation of interventions (McKenney, 2016).

Understanding and accepting the variety of personalities, processes, and convictions present in a particular project is crucial to being able to structure a fruitful process. DB(I)R researchers must be able to do so while they fulfil multiple roles, notably the those of: *Consultant*, *designer*, and *researcher* (McKenney, 2016). While most DB(I)R researchers are afforded formal opportunities to develop their research skills (e.g., through seminars and courses on research design, interview techniques, data analysis, etc.), the consultant and designer skills receive far less explicit attention and tend to be learned informally, at best (McKenney & Brand-Gruwel, 2018). In light of these three roles and four core DB(I)R processes (analysis and exploration; design and construction; evaluation and reflection; and implementation and spread), McKenney and Brand-Gruwel (2018)

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describe four foundational competencies that are required to enact each role. *Empathy* is needed, for example, to explore (un)shared goals or becoming exposed to the incentives, motives, and reward structures in different settings. *Orchestration* helps simultaneously attend to research framing, data collection, solution design, implementation, infrastructure woes and stakeholder ownership. Creative and analytical *flexibility* supports optimization of the human and material resources available in ways that remain aligned with instructional goals. Finally, *social competence* includes having a robust repertoire of interaction strategies to be selected as needed.

This paper focuses on the infrastructure that serves DB(I)R researcher capacity building. Here, infrastructure refers to the human, material, and structural features of context which contribute to the development of the four competencies described above and the ability to fulfill the roles of researcher, designer, and consultant, in ways that respond to the shifts in DB(I)R processes through the lifecycle of a given initiative. This prospective analysis is situated in the context of university campus collaborations between DB(I)R researchers and (communities of) teachers in engineering disciplines who share the goals of (1) redesigning courses and degree programs to be anchored in authentic challenges, and (2) investigating how to do so in ways that are effective and enjoyable (Kirschner & Gerjets, 2006) as well as sustainable. Specifically, the paper presents a framework for inventorying assets and needs with regard to the infrastructure for developing design researcher capacity when working in this kind of setting. A key discussion question during the proposed symposium pertains to the applicability of this framework for researcher growth in other DB(I)R contexts.

Paper 3: Centering Race in DBIR: Methodological Choices and Internal Work

June Ahn, Kimberly Gomez, Ung-Sang Lee & Christopher Wegemer

In this paper, we share our current experiences and insights from a DBIR project that is focused on centering racial consciousness and anti-racist goals. DBIR as a methodology focuses on developing mutually beneficial research agendas with partners, co-designing these research activities, developing solutions, and iteratively testing and improving upon these joint endeavors (Penuel et al., 2011). In our work, we are developing up to 6 partnerships with local schools in Southern California, using a DBIR approach, but exploring how processes unfold and might be facilitated in ways that bring race and anti-racism to the forefront. Our work addresses recent calls by Doucet (2019) and Kirkland (2019) for community engaged researchers to attend to critical issues of who is at the table when developing partnerships, what questions are posed and which are pursued, and to re-imagine the solutions that we design to address key obstacles to racial justice.

Drawing upon a dataset of field notes, reflective memos and team documents, as well as artifacts from the DBIR projects, we will shed light on how the project teams were: (1) initially structured with careful attention to understanding the racial histories of different partners, including ourselves as researchers, and how these histories shape DBIR work at the outset; (2) how jointly negotiated foci of work were developed as a partnership, with an eye towards how different design goals are reshaped when thinking through the lens of anti-racist goals and outcomes; and (3) how the focus of design efforts shift from tools or organizational strategies, to re-designing relational ways of partnering and mobilizing for root issues that more directly impact racial justice. We argue that a racially conscious DBIR methodology requires attention to new facets of practice, that extends and enriches racially neutral processes. A key need in the field is to better articulate how **partnership infrastructures** (Penuel, 2019) and **the relational moves we make** (Hennessy, Howe, Mercer, & Vrikki, 2020) within partnerships, combine to develop DBIR projects for racially equitable aims.

Finally, we will work from the notion of anti-racist, DBIR partnerships, to illuminate how partnerships can observe impacts. Specifically, we hone in on how DBIR partnerships can aim their designs and change efforts on (1) the perceptions that partners express about racism and equity, (2) how partners talk to each other as they do their joint work, and the language they invoke which can reveal their underlying frameworks about race, and (3) how DBIR teams can be positioned within organizations – such as K-12 schools – to best facilitate specific actions (policy, programmatic, or behavioral) that partners ultimately enact, which can also reveal the changing and underlying frameworks at play. The contribution of this conceptual framework is to inform more precise conjectures about how design, implementation, and research can be utilized towards racially just change in local partnerships.

Paper 4: Children as transformational agents in the co-design process

Marcela Borge

In previous work designing technologies to enhance science and collaborative learning, my colleagues and I have often worked with learners of all ages as co-designers or as part of participatory design to help inform design processes in ways that better meet their needs (Borge & White, 2012; Borge & Shimoda, 2019).

Collaborative design of this kind is quite common in HCI and learning sciences related fields, but the purpose of the design is on the end-product, i.e., what the designer is creating (Abbas, et al., 2018; Rosson & Carroll, 2002). With some notable exceptions, such as the work of Yip and colleagues (Woodward et al., 2018; Yip et al., 2013; 2016) fewer researchers focus on other import and aspects of the co-design process like the process of co-design itself or how/what participants learn from the process.

The focus on the process of co-design is of particular interest to me and my research group, because my area of expertise is on collective regulation processes and how individuals and groups reflect on processes for the purpose of improving upon them. However, much of my work has been informed by the work of scholars who lie on the more cognitive end of the learning theory spectrum (Pandero, 2017; Wecker & Fischer, 2011; Winne & Nesbit 2009; White & Frederiksen, 1998). As such, I have historically approached such work from a top-down model, where the goal, even during co-design, was to show participants optimal processes as defined by my group and partner with them to enhance how well my interventions pushed them to use and imitate these processes.

Recently, I have come to realize that this approach to co-design serves me and my group more than it serves the children we work with. Over the last six years my research group has been working in partnership with children ages eight to twelve as part of a design-based afterschool maker space. During this time, our emphasis on the project has shifted from co-design for the purpose of creating more equitable and engaging after-school spaces that help children "optimize" collaborative processes to co-design for the purpose of critical reflection as defined by Paulo Friere (1996).

Critical reflection shares many commonalities with the classic regulation literature; they both view awareness and self-reflection for the purpose of action as an essential aspect of learning. However, critical reflection does not use reflection as a way for learners to compare their actions to models that researchers define as "optimal" for the purpose of getting users to better align with those models. The purpose of critical reflection is for learners to become aware of the artificial designs around them (Simon, 1968) and how they interact with them for the purpose of transforming those designs to better meet their humanistic needs. Thus, reflection becomes a means for learners to engage in sense-making about their world and the ways they behave within it for the purpose of self-empowerment.

As part of this symposia, I will provide examples from our club to show how and why we have gradually made this change based on our growing awareness of our young learners' needs. I end by discussing how we can push Frierre's work towards promoting digital literacy for the purpose of empowering the next generation of technology designers and users. My aim is to help young learners become more aware of how technology is shaping their world and help them and us better understand how they can transform these interactions for the better.

Paper 5: Examining design-based implementation research through linkographic analysis

LuEttaMae Lawrence

There has been much work describing the foundation of DBIR research, including the importance of building relationships, building capacity, attending to sustainability, co-constructing designs iteratively, among other high-level factors (Penuel et al., 2011; Sabelli & Dede, 2013). While this is a widely used methodology in the CSCL community, open questions remain regarding how nuanced practices and decisions in DBIR are made to produce interventions. Innovative learning takes place during the design process, and researchers rarely document or assess this to the same extent as other forms of learning (Kali, 2016). Examining the interactions in the design process can inform how to improve our processes, share insights about scaffolding collaborative conversations, and provide rich examples to scholars learning to collaborate with communities. Responding to the call for more in-depth analysis of collaborative design processes (Kolodner et al., 2016), I examine how an interdisciplinary team of researchers and users designed a collaborative orchestration tool.

In this study, I examine interactions, design ideas, and collaboration within a design brainstorm meeting of eight team members from four disciplines, two of whom were part of the design community and six from the research team. Members of the team had been collaborating within a DBIR project for several years leading up to the meeting, with the broader goal of improving collaborative problem solving in engineering higher education courses at a midwestern university in the United States. The present study describes the collaborative process to create an orchestration tool to support novice, engineering instructors as they facilitate collaborative learning. To explore the co-construction of designs, I used a traditional design method called Linkography to assess the design process at a fine-grained level by visualizing relationships of "design moves" during collaborative design

discussions (Goldschmidt, 1992). This analysis examines, patterns of interaction within discussions to understand how ideas were generated and taken up, and by whom.

In total, 1,984 turns of talk were analyzed in the design process from a three-hour design meeting. Fifty-nine critical moves emerged, defined as turns that were linked to by more than 10 other turns of talk, and the quality of interconnectedness and collaboration fluctuated throughout the meeting, but was overall high (see Lawrence, 2020). Through this analysis, I identified a pattern of interaction, wherein one turn of talk generated a high density of linking, showing that this discussion was highly connected. Through thematic analysis of these patterns of interaction, three themes emerged during the meeting, including segmented, intersected, and integrated areas. Segmented areas were patterns of interaction that were isolated design discussions that did not build on multiple areas; these areas had fewer critical moves and lower levels of collaboration. Intersected areas were patterns of interaction that were linked by one bridging turn of talk. These areas of talk had a wide range regarding quality of collaboration and design ideas that emerged. Integrated areas were interaction areas that were highly convergent conversations. Integrated areas had two to thirteen areas overlapping and had more critical moves and higher collaboration compared to segmented and intersected areas. This analytic approach allowed me to explore how the design process occurred and analyze how the team adapted ideas over time at a fine-grained level. My findings highlight the context around productive and unproductive design discussions and share importance insights for facilitating design meetings with diverse perspectives including scaffolding discussions with common goals, reflecting on tensions in the moment, and documenting ideas to scaffold integrated conversations.

Paper 6: The ebbs and flows of a multi-year DB(I)R project

Emma Mercier and the CSTEPS team

In an ideal situation, a design-based implementation research project emerges from a joint vision between groups of researchers and practitioners, who remain involved in the project throughout, and where the practitioners remain involved in the education context after the project has finished. However, this is not always the case. In this reflective analysis of a multi-year project, we will explore the fluid nature of DBIR in a university context, noting the standard of DBIR sometimes slipped more into a simple DBR project. The goal is to identify processes that fostered true collaboration across the groups, issues that stalled the collaboration and principles to embed in future projects.

This paper reflects on a seven-year collaboration with an instructional team in engineering, focused on redesigning core, required undergraduate courses. The collaboration began as two separate endeavors: 1) a DBR project focused on creating CSCL tools to support the creation of joint representations during collaborative problem solving and 2) a college-level strategic initiative to embed innovative pedagogies in required introductory courses. The DBR project was funded in the second year of the pedagogic initiative, and through a series of serendipitous events, a funding stream dedicated to moving projects from exploratory to development phases and commitment across both groups, the endeavors merged, at times, and in pieces, in such a way as to allow for true collaboration around various aspects of the reform and research processes.

The instructional team consisted of a rotating set of faculty members, with varying degrees of experience and enthusiasm for teaching introductory courses and engaging in pedagogic reform, and due to the reform process, additional support from teaching faculty on content development. In addition, discussion sections were taught by graduate and undergraduate student teaching assistants, who were employed for one or more semesters, often until graduating. The research team consisted of faculty in education and engineering, graduate students, mostly from education, and undergraduate students, primarily from engineering. There was some intentional overlap between the two groups, with a small number of Teaching Assistants hired as Research Assistants during key semesters of the project, and members of the instructional team joining the research team formally during the second half of the project. In addition, one Teaching Assistant moved to education to complete his doctorate, while another continued to work on course content with the research team after graduation. Collaboration occurred at various levels, in large groups, but also in smaller working groups.

Recognizing the importance of not just describing collaborations, but creating frameworks to draw comparisons and critiques across projects (e.g., John-Steiner et al., 1998; Wasser & Bresler, 1996) this paper reports an analysis, based on calendar entries, meeting notes and project plans and report documents. We will first describe the timeline of the project, then identify patterns that emerged over the timeline of the project and finally identify themes from these patterns. These themes are: 1) The importance of time, openness, autonomy and belonging to DBIR projects; 2) The importance of examining difference circles of collaboration, particularly in relation to understanding how different elements of the work were completed; 3) The central nature of ongoing reflection on interpretation of reform experiences from multiple perspectives; 4) Relationship development and

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career transitions in higher education and 5) The co-existence of pedagogic reform and innovative educational technology research.

Paper 7: Lessons Learned from the National Network of Education Research-Practice Partnerships

Paula Arce-Trigatti

The National Network of Education Research-Practice Partnerships (NNERPP) is a professional learning community of education research-practice partnerships (RPPs) based at Rice University. Launched in 2016, NNERPP was created in response to a need for a permanent infrastructure that would allow for ongoing RPP-led learning and support. With NNERPP serving as a key mobilizer of RPP-based knowledge, the network helps catalyze the ongoing development of individual partnerships and the advancement of the field as a whole through four main activities: curation, teaching, leadership, and brokering. An annual forum brings members of our community together to share, workshop, and teach about lessons, challenges, and experiences from their RPP work. Recognizing the need to build and share a strong and robust knowledge base, NNERPP maintains an online repository and a quarterly magazine which serve as channels of communication between various actors in the RPP space sharing new insights, responses to pressing topics, and identifying community-wide challenges.

RPPs can take on many forms and pursue diverse goals, involving a wide array of representatives from research, practice, community, and everywhere in between. This feature is both a strength, in that strong partnerships typically follow the mantra of "form should follow function", and also a challenge, in that it makes learning across partnerships more complex. We have found, for example, that trust building and relationship development, co-production in the research process, and logistical aspects of the work related to project management are all processes that interact with characteristics of partnerships including the number and types of stakeholders represented, the history of the relationships among stakeholders, forms of power/authority across the partnership, etc. It has, notably, proven beneficial to have RPPs of various and diverse forms in conversation with each other, in order to spark new ways of thinking about the work.

Another challenge for the learning community is to collectively understand what it means to be "successful". These definitions emerge from characteristics of the partnership including the longevity of the partnership, what goals were named and whether they were achieved), whether and to what extent their work resulted more narrowly in research use, whether and to what extent student outcomes were impacted, whether district processes were changed, etc. Subsequently, partnerships vary in *how* they measure impact and/or value of their work. Some RPPs have used the framework proposed by Henrick et al (2017) as a starting point, others have developed their own surveys, and some use self-report, asking their partners what's working. The variation in partnership structures, approaches, and ways of documenting their value make the identification and aggregation of best practices challenging.

This poster will present examples of various models of RPPs, focusing on the collaborative processes that have been useful in various contexts of partnerships and how partnerships have judged their success. We will explore how and why particular characteristics and goals of partnerships were critical in shaping the ways illustrative partnerships have conducted their work.

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International Society of the Learning Sciences

Regulation of Teaching as an Individual or Collaborative Process: Theory Meets Practice

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Abstract: There are calls for researchers and practitioners to build joint communities to narrow down research-practice gaps. Regulation of teaching, a process during which teachers direct attention, set goals, plan, monitor and evaluate their teaching for improvement, is very likely to benefit from communication and collaboration between researchers and teachers given its complexity in terms of multiple phases and various levels. This symposium aims to facilitate researchers' and practitioners' direct conversations on self-, co-, or socially shared teaching regulation. A theoretical framework that details different phases of teaching regulation at the self-, co-, or socially shared teaching levels guides teachers' reflections on their teaching regulation, which then serve as a basis for a panel discussion between three (groups of) teachers and three invited researchers. The panel discussion will be focused on identifying practical challenges and research gaps regarding teaching regulation and discussing how teacher and researcher communities can collaboratively respond to these issues.

The overall focus of the symposium

There is an abundance of research on teaching and learning in the field of Learning Sciences. However, the research does not extensively impact teaching practice, which is referred to as research-practice gap (Chi, 2021). The gap between research and practice may be attributed to the following reasons: teachers perceive the questions addressed by researchers irrelevant to their practice; researchers' work is not very accessible to teachers because of writing style and subscription issues; teachers lack time to read research findings; and research-based knowledge may be too general and abstract but not specific enough (Chi, 2021); what works in research may not be effective in local practice (Joyce & Cartwright, 2020). To address these issues, researchers and practitioners should build joint communities that include research and practical focus (Korthagen, 2007), and negotiate problems of practice (Coburn & Penuel, 2016). Despite this call, at our conferences, researchers still mostly communicate with other researchers, while teachers are rarely involved in the discussions.

Among many topics, regulation of teaching might benefit from conversations between teachers and researchers. In practice, teachers often need to revise their teaching practice in order to improve the effectiveness of lesson plans or to respond to the evolving learning theories and changing societal values and structures (Butler et al., 2004). This necessitates teachers to engage in regulative teaching practice, a process during which they apply a variety of activities and strategies to direct attention, set goals, plan, monitor and evaluate their teaching to improve it (Lindblom-Ylänne et al., 2011; Ukrop et al., 2019). However, there lacks specific advice or rules on the process of regulation that teachers can follow. Furthermore, teachers can regulate their teaching practice as self-, co-, or socially shared endeavors. Both make teaching regulation complex and challenging. On the other hand, there is a rich body of research literature on teaching and regulation that can be made better use of to support teachers.

For these reasons, this symposium aims to create an opportunity for researchers and practitioners to have direct conversations on self-, co-, or socially shared teaching regulation. To scaffold the discussion, we provide (a) a theoretical framework that details different phases of self-, co-, or socially shared teaching regulation to guide teachers' reflections on their regulation experiences; (b) reports from three (groups of) teachers on their teaching regulation, which can serve as a basis for discussions. At the conference, the three (groups of) teachers will discuss their practical challenges regarding teaching regulation, and the panel will identify research gaps in

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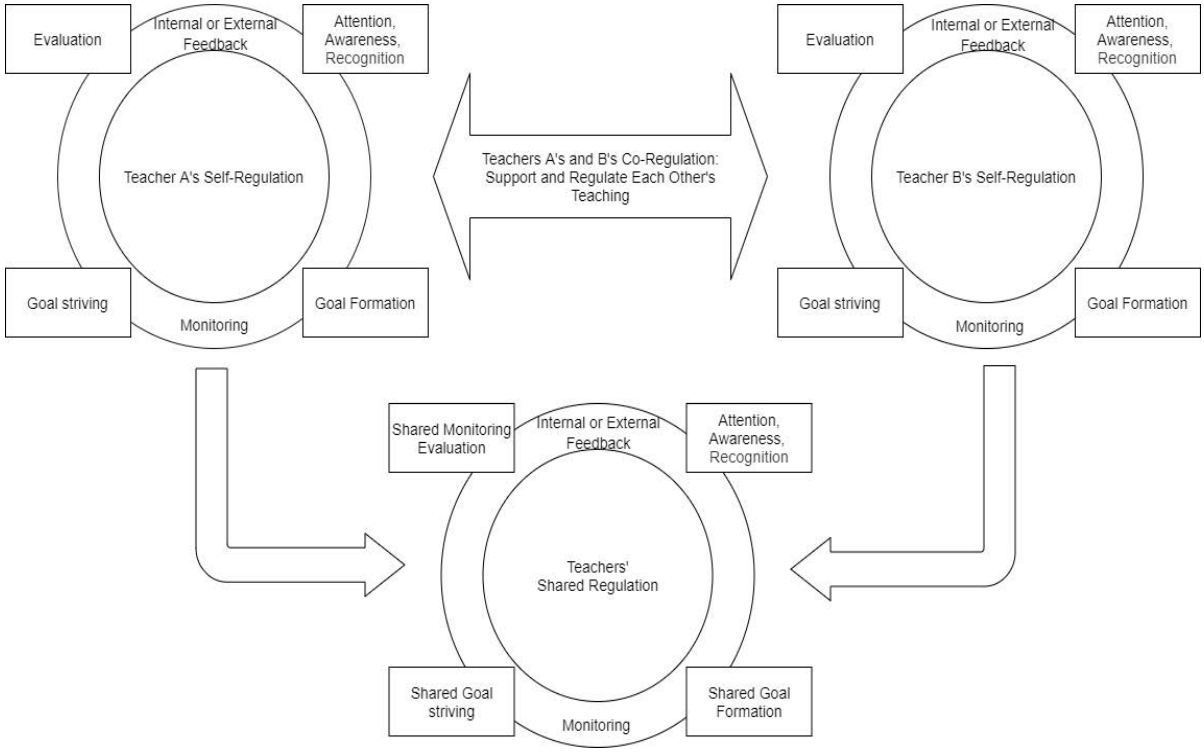
the field. Then the teachers and researchers will discuss how to bridge and address the practical challenges and research gaps in a feasible and collaborative manner.

Here, we first elaborate on self-, co-, or socially shared regulation. Self-regulation is an individual activity in which individuals plan, enact, monitor and adjust their learning using cognitive and behavioral strategies (Zimmerman & Moylan, 2009). Co-regulation processes are directed to influence the behavior, cognition, and motivation of one specific group member (Grau & Whitebread, 2012). Teachers' co-regulation involves other people such as teacher trainers, advisors, or fellow teachers supporting certain processes of the regulation (Hadwin et al., 2018) and can happen in daily school practice, during school meetings or at professional development activities. Socially shared regulation (SSR) emerges when teachers negotiate their goals, plans, and strategies concerning shared tasks and maintain positive interactions by listening and considering each other's ideas (Hadwin et al., 2018; Malmberg et al., 2015). In SSR, teachers identify shared teaching problems, set shared goals, integrate different knowledge and ideas, and evaluate the process as a group or community (Hadwin et al., 2018). Relating the concepts, self-regulation is the basis of co- and shared- regulation. Compared to co-regulation, SSR emphasizes that a group, as a unit, shares convergent regulation of the team activities, cognition, motivation, emotion, and behavior (Hadwin et al., 2011).

Figure 1

Phases of regulation of teaching at the self-, co- and shared levels



We integrated Järvelä and Hadwin's (2013) socially shared regulated learning model, Borge et al.'s (2018) model of regulatory processes during collaboration, and Nesbit's (2012) self-directed leadership-development framework, constructed a teaching regulation model (see Figure 1), and applied it to the teachers' regulation context. This model specifies four cyclical phases and relevant executed processes in each phase. During Phase 1, a teacher or a group of teachers directs their attention to a specific topic that they are interested in or a specific teaching process that they want to improve because of their beliefs, motivation, or internal or external feedback. In Phase 2, teachers usually form their teaching goals. During Phase 3, goal striving, teachers make efforts and commitment to implement task strategies to achieve goals. This phase is followed by evaluation (i.e., Phase 4) in which teachers reflect on the affective and cognitive consequences of their performance. This phase is usually facilitated by internal feedback arising from one's self-observation (Kolb, 1984) or external feedback from other stakeholders (Ryan et al., 2000). This phase usually circles back to forethought phases. Each phase is accompanied by monitoring to ensure that the aim and function of each phase is sufficiently fulfilled, according to teachers' standards (Winne & Hadwin, 1998).

The four phases of self-, co- and shared regulation are influenced by internal cognitive conditions and external task conditions (Winne & Hadwin, 1998). Internal conditions such as (a) specific knowledge or skills, (b) beliefs, and (c) motivation influence the regulation process. Teachers' knowledge about the context (e.g., students involved; the history of the teaching situation) and skills in integrating different pieces of knowledge plays a crucial role in the regulation process. Moreover, teachers hold beliefs about how knowledge is acquired (Chinn, 2014) and have specific teaching philosophies, which guide them to develop goals and options for action. Goals and action plans are affected by intrinsic and extrinsic motivational incentives. For example, some teachers may be intrinsically motivated to continually improve their teaching while some may be mainly motivated by extrinsic reasons such as demonstrating good teaching performance to principals and colleagues. Furthermore, teachers' regulation processes depend on the availability of external knowledge resources such as literature, social media, and direct personal interactions with fellow teachers. In addition, time constraints limit how extensively teachers may regulate.

Overarching/integrative points that will be addressed by teachers and researchers

The theoretical model described above can help pinpoint, differentiate, and organize teachers' teaching regulation experiences. However, due to lack of research on teaching regulation (Lindblom-Ylänne et al., 2011), it is yet unclear whether and how teachers self-, co-, or socially shared regulate their teaching practice and how to foster their regulation. To better bridge the gaps between practice and research, we create opportunities for practitioners and researchers to identify and reflect on practical and research challenges concerning teaching regulation, and negotiate and co-design feasible solutions to address the issues. Practitioners and researchers will work together at the symposium as follows:

First, three (groups of) teacher experts have shared their regulation practices (e.g., regulation experience, desired goals, gaps and challenges, and support needed) at the self-, co-, and shared-regulation levels, separately. The above-described regulation model informed and structured teachers' reports of their experiences.

Second, these reports will be shared with three researchers from complementary fields ahead of time. Researchers will look at teachers' successful and challenging regulation experiences with scrutiny from their perspectives of expertise. We will request the research panelists to connect research gaps and the practical challenges that teachers face, and invite researchers to draft potential solutions to fill these gaps.

Third, at the conference, teachers and researchers will discuss the feasibility and potential impact of the solutions, and co-design to detail the solutions.

The significance of the contributions

Direct conversations between teachers and researchers benefit both sides. For teachers, the symposium may improve their awareness of the importance of teaching regulation and understanding of regulation procedures and types, and encourage them to take actions in the future. From the perspective of researchers, the symposium tends to help them better understand the practical challenges that teachers face and how they may co-design research with teachers. Taken together, this symposium will serve as a step to better identify practical and theoretical challenges in teaching regulation, and better connect teachers and researchers to respond to the challenges (which is mentioned in the Regulation Experiences of Teacher Experts 3).

Structure of the session

This symposium will include three teacher presentations on their self-, co-, and shared-regulation experiences concerning teaching, respectively, followed by a panel discussion between teachers and researchers on how to better support teaching regulation. We will adopt the following session organization:

1. Welcome and theoretical introduction by session chairs (6 min)
2. Teachers' presentation on self-regulation of teaching (8 min)
3. Teachers' presentation on co-regulation of teaching (8 min)
4. Teachers' presentation on shared-regulation of teaching (8 min)
5. Researchers analyze teachers' experiences, identify research gaps, and propose future research directions to promote positive changes in teaching regulation (24 min)
6. Open discussions between teachers, researchers, and audiences on how to respond to the practical and theoretical challenges on teaching regulation, and the feasibility of researchers' proposals (26 min)

International Society of the Learning Sciences

Regulation experiences of teacher expert 1: Self-regulation

Regina Hegele, Parkschule Stadtbergen

Planning, implementation and reflection of lessons

In everyday school life, the choice of content covered in class depends largely on agreements within the colleagues of a grade level, the learning situation (homeschooling or face-to-face teaching), and the textbooks used.

After the contents of the upcoming lesson sequences have been determined in the team, I develop sequence plans that include the contents of the individual teaching units, the competencies to be achieved, learning opportunities and their realization. Here, it is also important to consider where the children might encounter obstacles that are not manageable for them. Furthermore, as far as possible, I attempt to address questions that are currently arising in the class and, if necessary, to include them in the lesson planning. However, this can also happen during the sequence because some questions only arise from the joint work.

Whether a designed unit can be successfully implemented in the classroom depends on many different aspects, not all of which can be planned in advance. However, for a favorable outcome, it is imperative that I keep the learning structure of the class in mind. In my opinion, this includes the performance spectrum of the class (strong and weaker students), the usual forms of work in the class (such as think, pair, share, group work), a positive classroom atmosphere, adherence to the agreed-upon rules of conversation, and the motivation of the learning group. Factors that cannot be planned are already existing knowledge about the chosen content (which, however, can also be integrated spontaneously) or possible short-term events within the class (disputes or other differences).

Reflection on lessons usually happens very briefly and unbureaucratically in everyday life. As a rule, I do not analyze further any units that go as planned when I have gained the impression, while reflecting with the children on the content which we worked on, that the children were able to use the learning opportunities. If this is not the case, I consider at which points the children had difficulties and how these could have been eliminated. After identifying the “stumbling blocks”, I note them briefly, which will be useful when re-using the content. Unfortunately, teachers rarely receive external feedback, as there are currently no models for peer coaching in my state, and as the assessment by the school management, which takes place every four years, is not useful for this purpose.

In order to further develop my own teaching in the interests of the children, I am in close exchange with my colleagues: I hear how they prepare content didactically and what methods they have been successful with and compare this information with my work. We also plan various lesson sequences together and benefit from the experiences and ideas of the team. On the other hand, I regularly attend further training courses, have contact with the university and thus always try to be up to date.

Conditions for optimal lesson planning, implementation and reflection

- Lesson planning: Teachers must be motivated to teach new content to their students. They should have the necessary expertise and have their students in mind.
- Lesson implementation: Small learning groups (maximum 22 students), a warm learning climate, students have skills necessary for successful learning (listening with understanding, ability to work in teams, positive attitude towards learning and achievement)
- Lesson reflection: sufficient time, models that enable joint reflection (e.g., peer coaching)

Challenges in lesson planning, teaching, and reflection

In my eyes, one of the greatest challenges in planning, implementing, and reflecting on lessons is the fact that we have to teach classes that are far too large (sometimes up to 29 students in elementary school), with a very heterogeneous structure in terms of performance (children with disabilities, children with increased special educational needs, children with varying degrees of language deficits). It seems almost impossible to do justice to all the children. In addition, there are more and more "administrative activities" that we teachers have to take on during our working hours. Unfortunately, the resulting time deficits cannot always be compensated for by extra work and additional commitment.

Support for optimal lesson planning, teaching, and reflection

Basically, this point follows from my previous remarks. In my opinion, the following factors would be beneficial: a reduction in class sizes, additional pedagogical staff to support teaching, and a reduction in the number of hours per week for primary school teachers because the workload is very high in full-time teaching and it cannot be ruled out that the quality of teaching will suffer in the long term.

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Regulation experiences of teacher expert 2: Co-regulation

Heidrun Printz, Dr.-Max-Josef-Metzger-Schule

How do you give teacher trainees optimum support in designing and reflecting on their teaching?

Effective and lasting support for young teachers will be more necessary than ever in the coming years in order to meet and withstand the changing demands on schools. Ideally, this support should be designed as follows:

The basis for a good start in the teaching profession is mutual trust, willingness and curiosity in learning as well as enjoyment in working with people. Up until their first lesson, teacher trainers attend my lessons to observe, evaluate, discuss and assess certain methods and didactic focuses. For this purpose, these criteria are visualized on a lesson plan. Reflection on lesson observation in this initial training phase is crucial. At this stage of their careers, the complexity of teaching should only be demonstrated very gradually so that the trainee teachers do not feel insecure and also to make them aware that they are allowed to make mistakes.

When planning their own lessons, I allow the trainee teachers to choose their own area of interest in order to promote self-activity and increase intrinsic motivation. A lesson matrix also enables the trainees to reflect on the correct location and design of certain learning phases. The learning goal-oriented action is stimulated by the external or own definition of a minimum learning gain. Even when they are already in the planning phase, I always remind them of pedagogical-psychological and social characteristics and of the pupils' level. If they take the characteristics of the addressees into account, then the learning objectives can be achieved.

In the teacher training college, I encourage discussion about interests, learning content and learning goals as well as learning methods. This supports the development of skill in their particular subject and their teamwork abilities. It also contributes to the development of the teacher's personality by being self-reflective and reflecting upon others.

While the trainees are teaching, I support as much as necessary and as little as possible. I only intervene in the trainees' lessons when there is potential danger, for example in Physical Education. Ideally, I expect the trainees to reflect on their lessons. For example, by introducing a topic in different classes or grades, the trainees realize that there is never just one correct solution pattern.

In the post-lesson discussion with the trainee alone or in the trainee group, I believe it is very important to address and explain the skills necessary for educational and subject-specific action objectively and constructively. I limit my feedback to three main aspects for further development. The feedback on their lesson and what they should be aiming for is communicated in an appreciative and honest manner. It is tailored to each individual trainee's level of teaching and contains practical solutions and suggestions for improvement. In choosing the timing of the trainee's feedback I take their timetable, mental and physical state into account to ensure a productive reflection of their lesson. In addition to the post-lesson feedback sessions, I also comment on the trainees' lesson plans and hand them back at a suitable time. A video recording of the lesson and subsequent discussion of it often provides valuable insight for the trainee and can be an excellent way of observing the interaction between teacher and pupil.

Which conditions do you require to provide optimal supervision for teacher trainees?

A core condition for the optimal supervision of trainees by teacher trainers is up-to-date, well-founded and professional competence combined with curiosity. In addition, it is advantageous if the teacher trainer has a sound knowledge of human nature and a broad range of experience in school, based on the enjoyment of educational and creative activities. The college workload can be reduced by having good organizational conditions, e.g., a teaching timetable which leaves enough room in the college timetable for effective teacher training and study. The technical equipment (e.g., media, subject-specific materials) also has a noticeable effect on the quality of the training. Co-operations with other educational institutions complement and reinforce the objectives of the training at the school and also give the trainees the opportunity to network. They demonstrate that schools are constantly evolving.

What challenges get in the way of your supervision?

I find school days very challenging when plans are changed at short notice, making it necessary to cancel appointments. However, it is also challenging when there are too many appointments: this disturbs intensive, close exchange in the college setting. Progress is negatively affected when trainees can't work well in a team, if they are not honest with each other and also if they demonstrate excessively competitive behavior.

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What support do you require to optimize scaffolding teacher trainees?

Important building blocks for optimal teacher training are, on the one hand, solid support and complete trust from the training supervisor and the specific subject mentor. On the other hand, cooperation, exchange and constructive criticism by the college staff are beneficial. Participation in further training, access to an up-to-date specialist library, and excellent supervision and psychological backup in critical situations as support for self-reflection have a positive effect on the teacher training.

Regulation experiences of teacher experts 3: Socially shared-regulation

Jenny Melo León, Gimnasio La Montaña
Laura Calzado, Dolors Monserdà-Santapau school
Raadiyah Nazeem, Dr. Eric Jackman Institute of Child Study

How do you collaboratively identify your shared interests and goals?

There is always somebody who suggests a topic and then we discuss the topic and see how we can put it into practice. In this current project, our colleague Raadiyah from Toronto said that discussing what a community is could be interesting, and we immediately agreed. It has been fantastic because we have the same shared ideas or shared interest in developing something basic in our class, which is understanding what a community means and what their roles are in the community. In the current project, Jenny, who likes to meet teachers with the same interests, was invited to join the community project. She liked it and worked to fit it into her curriculum. Through a previous project, Jenny and Laura worked together for two years. They were first introduced by Mercè and then joined by the big idea of developing awareness towards Sustainable Development Goals, which are important for their students in Colombia and Spain. Regarding choosing specific global goals to work on, they chose gender equality, specifically, responsibilities at home that can differ from their responsibilities at school. Students also compared their parents' and their grandparents' household responsibilities in order to see if there were gender differences between mothers/grandmothers and fathers/grandfathers. Mercè helped Laura and Jenny through the project.

How do you design to respond to your shared interests or specific goals?

The first thing we did was to create a shared document where we can provide ideas, record our next steps, and have the meeting dates and time. Shared documents help us develop the project step by step, record concrete ideas, and build or design collaboration. Second, we have in mind that we should not stop learning or improving our teaching; rather, we need to make changes whenever it is needed. Third, we have to take some time to meet and discuss how things are going on, not only in the working hours, but also during our own time.

How do you know whether your designs are well implemented in classrooms?

We have a Google Doc where the goals and activities are described. Sometimes we have video conferences to share what students produced, and then we know exactly how the design has been implemented in the classrooms. For instance, in the gender equality and responsibilities at home project mentioned above, Jenny and her students created a mathematics table with Steven balls, while Laura's students created a mathematical table but with numbers and colors. There were two different ways of doing the same visual representations. Laura learned from Jenny's way and presented it to her students. During the implementation, they have to be very flexible because things may need to be changed due to time constraints or according to students' products.

How do you negotiate with your design partners to move forward or improve your teaching?

When we have clear goals, it is easy to negotiate what you're going to do. Having or establishing desired goals at the beginning is very important for the project. Our goals are about promoting students' authentic experiences to communicate with people around the world and let them explore differences and similarities in our cultures. Even though we cannot be in presence, we can take advantage of these technological tools to get in touch with people. No matter what we do with our students and what their products are, it is important that we contribute to the goals. Furthermore, we have to be very flexible and understand that another partner may need more time or does it in a different way. Because we must discuss with the other partners, our teaching can be improved through these international projects.

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Which are the conditions that make your collaborative design, teaching, and reflection possible?

Even if we do not have the physical or time conditions, etc., as we are motivated to work together, see the project clearly and we like teaching, that's the reason why we are here. Furthermore, today the world is global, so we cannot teach just in our class. We have to teach with others and to see what they think about. The international project in a second language makes what the students do more realistic and meaningful. Finally, having support from the school authorization and principals and knowing their interests in promoting these projects make things possible and easier.

Which are some challenges, if any, that hinder your collaborative design, teaching, and reflection?

In the past projects, lacking time was a permanent issue. We had many things that we wanted to do. We planned it in a way and then we had to modify it either because we needed more time to develop this specific part of the project, or students responded in a way that we thought was not very adequate, or what we planned was not really what our students needed. Still in the pandemic, we have more demands at school with the curriculum, so it is becoming harder.

What support do you need to optimize your design, teaching, and reflection?

We need collaboration. It is very important to have somebody supporting us from outside, support in general from the university. The collaboration between schools and universities should be more frequent. Researchers at universities want to improve teaching, we as teachers want to improve our teaching as well. Researchers have new theories and we have teaching experiences, so we should collaborate much more closely. In particular, we need more support on methodologies for projects, how to develop projects and how to better handle each project. Interactions between universities and schools, between experts and people working at schools are fantastic.

In the three reports on self-, co-, and shared-regulation of teaching, some common themes such as collaboration with colleagues and researchers at universities, limited time issue, or teachers' motivation emerged. Further interpretations and discussions will be made at the conference by the panelist, including teachers and researchers.

Invited panelists: Areas of expertise and reasons for participation

Dr. Marcela Borge, Associate Professor of Education (Learning, Design, and Technology), Pennsylvania State University. Dr. Borge's research expertise includes but is not limited to technology supported self-regulated learning, socio-metacognition, design-based research methods, and computer-supported collaborative learning (CSCL). The model of regulatory processes during collaboration constructed by Dr. Borge in her article Learning to monitor and regulate collective thinking processes informed the integration of the regulation of teaching model shown in Figure 1.

Dr. Chew Lee Teo, Senior Research Scientist, National Institute of Education (NIE), Nanyang Technological University. Dr. Teo founded the Knowledge Building Community-Singapore and has led the local and international Knowledge Building Community Network Learning (KBC-NL) series. The KBC-NL brings together teachers and researchers to explore germane issues on 21st century competencies and pedagogies. The KBC-NL sessions have reached out to more than 1000 teachers and researchers. Recently, Dr. Teo and her team have gathered about 200 students and teachers to work on the theme of "Saving Lives, Saving Planet" in Knowledge Building Design Studios.

Dr. Mercè Bernaus, Emeritus Professor, Autonomous University of Barcelona. Dr. Bernaus has rich experiences working as a teacher, researcher, and Ministry of Education officer. She specifically focuses on second language learning and language awareness. For instance, in the Linguistically Sensitive Teaching in All Classrooms Project, Dr. Bernaus and other researchers develop, test and evaluate a reflection tool to help future and in-service teachers become more linguistically sensitive in their teaching, thoughts and attitudes. Dr. Bernaus has long-term collaboration with the invited teachers who will talk about socially shared regulation of teaching.

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International Society of the Learning Sciences

At the Heart of Learning: Affect, Identity and Care

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Abstract: Over the last few years, learning scientists have become increasingly interested in research around student's motivational and emotional processes, guided by a commitment to affirm learners' individual identities and support justice-oriented design and pedagogies. With ample evidence to show that the Covid-19 pandemic has exaggerated learner's struggles with their thoughts, feelings, and identity, the importance of such research has never been higher. This symposium brings together an international group of scholars with varying research contexts (online, in-person, hybrid, blended), working with students of different age groups (K-12, Undergraduates, pre-service teachers) to present their work around affective learning and teaching. The symposium's focus on affective learning designs that acknowledge learner emotions, affirm their identity, foster designer empathy and build a pedagogy of care will springboard deeper discussions in the ISLS community to further explore "global perspectives on equity and justice that promote the empowerment of educational innovation for all" (ISLS, 2022).

Introduction

This symposium responds to repeated calls by UNESCO (2020) and education scholars (Darling-Hammond et al., 2020; Ladson-Billings, 2021) to "redesign, reorient, and realign" and "build back better" beyond the crisis phase of the COVID-19 pandemic by exploring how learning and teaching can be situated in affective contexts that care about the students' being. Such care is deeply rooted in and intrinsically related to emotions, cognitions, and identities (Frijda, Manstead, & Bem, 2000). Understanding this relationship between emotion, cognition and identity would help researchers to reveal complex key issues in the learning sciences research that concern justice-oriented pedagogies. Yet, although research on emotions and learning goes back many years, there has been scant connection with emotions, identities, and care. Further, research and discourse on the nature of nurturing affective empathy in students is lacking. This symposium aims to reflect on the relationship between empathy, emotions, and identities by looking at these co-constructed, overlapping concepts to advance our understanding of learning and teaching in varied contexts. Identities influence the kinds of emotions and beliefs of care and empathy that individuals attribute to themselves and to others. Emotions, in turn, can influence identities and how we construct them. The learning sciences work could leverage such dimensions in novel assessments, learning analytics, and equitable justice-oriented pedagogies.

Overall Focus of the Symposium

Organized as a blended event, the symposium will focus on increased awareness and discourse around humanistic learning designs and pedagogies. In order to "redesign, reorient, and realign", we plan to have all registered attendees of the Conference participate in an optional online identity-awareness activity that will engage them in empathetic scenarios in a simulated environment. These scenarios will be informed by our research and collective understandings of affect. The symposium will be enacted in two parts at the Conference. First, each presenter will introduce their research and present findings and implications of the same, engaging the audience affectively. Second, a panel of discussants including scholars from psychology (Prof. Earl Woodruff), knowledge building (Prof. Marlene Scardamalia) and Engineering (Prof. Greg Evans) alongside a member of the ISLS board will provide insights from their experiences and share paths forward as informed by the presentations from our symposium.

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Major Issues Addressed

As highlighted in the "Identity Feedback in Humanistic Emotional Configurations" paper, humanistic activities as essential to helping learners hold more tentative views of knowledge, be more open to considering and working with different viewpoints, see the connections between the ideas participants advance with their identities, and be willing to give and take feedback both about their ideas as well as their identities. Such identities are deeply connected to emotion. Thus, it is important to investigate what types of emotions students experience and how their emotions evolve in the Knowledge Building process as elaborated in the "Evolution of the Academic Emotions of Academically Low-achieving Students in Knowledge Building" paper. Such affective classroom environments require the teacher to model, dialog, practice and confirm care. The "Caring for the Online Learner" paper describes ways in which the teacher can be supported by learning analytics in fostering caring pedagogies. Another way to foster a caring environment is through empathetic design. Empathy is both a cognitive and an affective process that involves a person's perceptions, thoughts, and feelings and how those concepts become manifested into a deeper understanding of others. The paper on "Developing empathy through a learning progression" shares experiences from senior under-graduate students on their growth as empathetic designers. In our final paper of the session, "Punks, Troublemakers and Inventors" we explore theoretical frameworks and conceptualizations to unpack the phenomenon of troublemaking and deviance in school, thereby bringing the conversation back to affirming identity and building communities and practices of care.

Contributions

This symposium brings together a variety of voices (from the US, Canada, Hong Kong, China, Singapore and Israel) and settings (two in K-8, one in high school, one in undergraduate Engineering and one in teacher education). Our research is focused on students (three papers) and teachers (two papers). We bring experiences from Science, Engineering, Education and Art. Further, we share insights on working with both under-achieving and academically successful students. We explore ways in which troublemakers can be knowledge-builders through humanistic practices and identity affirmation. Finally, we hope to deepen conversations in the learning sciences around what is at the heart of learning: affect, identity, and care.

Identity Feedback in Humanistic Emotional Configurations: An Analysis of a Humanistic Knowledge Building Community

In the learning sciences, human development is often viewed as a process of peoples' transforming participation in the sociocultural activities of their communities (Rogoff, 2003). From this perspective, learning is a matter of identity, whereby people pick up the valued discourses, practices, and values of the cultures where they participate as they gradually become more central members (Lave & Wenger, 1991). This enculturation process is laden with emotions, too, as participants negotiate the unique emotional configurations as they learn how to emote in culturally-valued ways (Mesquita & Leu, 2007; Vea, 2020). Identity and emotions are thus inextricably linked.

With an eye on elucidating some of the ways that emotions and identities are interrelated in the context of schools and classrooms, our research has focused on designing and researching humanistic knowledge building communities (HKBCs: Hod & Ben-Zvi, 2018). This model of classroom communities not only addresses advancing collective knowledge (Scardamalia & Bereiter, 2014), but also aims to support the transformation and growth of its members' identities. We view these humanistic activities as essential to helping learners hold more tentative views of knowledge, be more open to considering and working with different viewpoints, see the connections between the ideas participants advance with their identities, and be willing to give and take feedback both about their ideas as well as their identities.

The current study as part of this symposium focuses on identity feedback, which we define as the stories that participants in a community tell about a particular member about their ways of knowing, doing, or being (Herrenkhol & Mertl, 2010; Sfard & Prusak, 2005). Identity feedback can relate to what a person tells about themselves outside of the community, but the most potent type of this feedback also connects to the way any one person experiences another in the here-and-now of the group (Yalom & Leszcz, 2020). This type of feedback is often overlooked and at times culturally taboo, out of fear of embarrassing a peer. But, under the emotional configurations – combinations of feeling, sense-making, and practice (Vea, 2020) – that are unique to humanistic discourse, participants can be more direct and open with one another, ultimately giving them invaluable feedback that can help them make intentional changes to their identities. The humanistic emotional configurations include active and empathic listening, unconditional positive regard, and being congruent or real (Rogers, 1969).

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For this study, we collected data focused on the identity feedback that several students within a semester-long HKBC received. We used a grounded approach (Charmaz, 2008) to examine every instance of identity feedback that we could find that related to these students. We categorized the hundreds of instances that we found into nine types of identity feedback, each of which could be expressed at three different levels (non-elaborated nor specific, elaborated or specific, elaborated and specific). In this presentation, we will illustrate some of these ways that identity feedback was given in the context of the unique humanistic emotional configurations with the aim of showing how this feedback was consequential to the identity transformations of these students.

Evolution of the Academic Emotions of Academically Low-achieving Students in Knowledge Building

Knowledge Building is a pedagogical approach in which students take collective cognitive, metacognitive, and emotional responsibility to continuously advance the frontiers of their community knowledge (Scardamalia & Bereiter, 2014). Improving community knowledge, which involves continuous cognitive disequilibrium and equilibrium experience, is exciting but challenging, especially for low-achieving students. Low-achieving students usually enter schools with relatively weak collaborative, cognitive, and metacognitive competencies, and limited interest in learning (Becker & Luthar, 2002). Supporting low-achieving students' successful Knowledge Building can greatly benefit them (Yang et al., 2020). The Knowledge Building process can trigger various emotions (e.g., curiosity, confusion) that may promote or hinder idea improvement.

Emotions can critically influence students' regulative actions, motivation, and learning processes and outcomes (Di Leo et al., 2019; Muis et al., 2018; Zhu et al., 2019). Generally, positive emotions (e.g., curiosity, joy) can facilitate learning, while negative emotions (e.g., frustration, anxiety) can hinder learning (Di Leo et al., 2019; Muis et al., 2018). Low-achieving students may be more likely to experience negative emotions because of their relatively weak learning interest and preparation. These negative emotions may lead to unproductive collaboration, and inquiry during Knowledge Building. This study aimed to investigate what types of emotions low-achieving students experience and how their emotions evolve in the Knowledge Building process.

The participants were 120 students from two Grade 9 classes and two Grade 11 classes in Hong Kong. In total, 1,565 Knowledge Forum notes on Visual Arts were collected. Concerning data analysis, first, we classified the notes of each class into inquiry threads. An inquiry thread is a sequence of notes addressing the same problem or topic (Zhang et al., 2007). Second, we conducted content analysis to understand the academic emotions reflected in each thread (each note within a thread as a unit) using an academic emotion coding framework. The framework includes seven emotions: joy, surprise, curiosity, confusion, anxiety, frustration, and boredom; and none to indicate no obvious cues of emotions. The development of the framework drew on the model of impasse-driven emotions (D'Mello & Graesser, 2012) the framework for measuring epistemic-related emotions (Pekrun et al., 2017) and the definitions of emotions proposed by Craig et al. (2008). Finally, we employed sequential pattern analysis to analyze the evolution patterns of emotions in inquiry threads.

Figure 1
Significant sequential transitions of low-achieving students' emotions (Class A as an example)

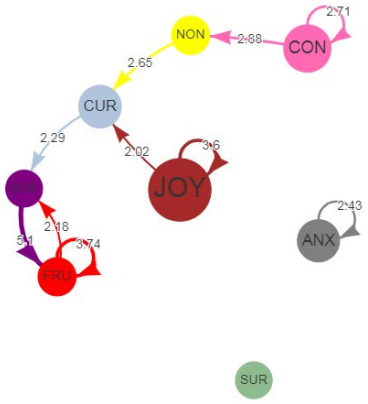
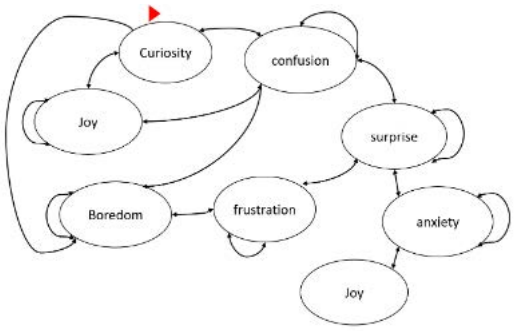


Figure 2
The evolution model of low-achieving students' emotions in Knowledge Building



Caring for the Online Learner: A Role for Affective Learning Analytics

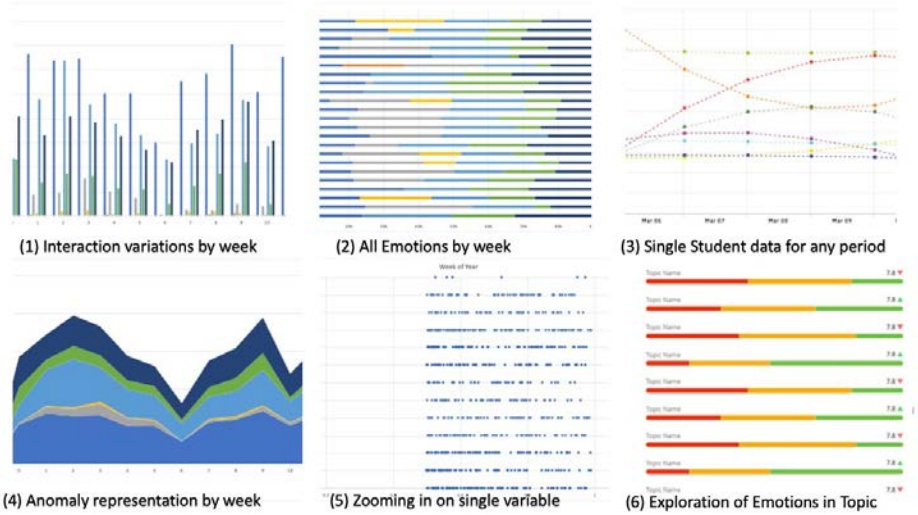
The COVID-19 pandemic has accelerated the shift of higher-education institutions towards online learning (cite), with many institutions continuing to offer online asynchronous courses to provide more flexible access to content and instruction at any time, from any place at a lower cost (Castro & Tumibay, 2021). While research in the online learning field has spanned decades (Means et al., 2009), there is still much work to be done in building and supporting a pedagogy of care in online learning environments.

Caring classroom environments help students "support and be supported by others" (Appleby et al., 2020), "operate from a collective struggle orientation" (Maloney & Matthews, 2020), "support students' perseverance and self-efficacy" (Lewis et al., 2012) and lead to better academic outcomes (Lindmark, 1996). Care, in face-to-face classrooms, is conveyed through active embodied interactions, dialogue and modeling, enabling instructors to experience their student's voice, body language, facial expressions, and shared physical context. Asynchronous online spaces are different and the question of whether, and how these spaces support an environment of care is unanswered. Any studies on care in the classroom would be most effectively situated within Noddings (2010) Framework of Moral Education, which provides a systematic lens through which affective inquiry and constructive classroom orchestrations could be studied. This framework comprises four components: Modelling, Dialogue, Practice and Confirmation, each of which is briefly shown in Figure 3.

Figure 3
Nodding's Pedagogy of care informed by analytics

In this design-based research study (Barab & Squire, 2004), we examine the features and representations of affective learning analytic instructor dashboards (see Figure 4) that provide an integrative view of student interactions, artifacts and tones, and anomalies in individual student data that help make caring intents more visible and provide ways for the instructor to express and enhance care in the online learning community (see Figure 2). Each of these representations will be demonstrated at the symposium and their influence through and on the four components of caring elaborated upon.

Figure 4
A few representations of instructor dashboards designed for the course



Developing empathy through a learning progression: Perspectives of senior-year engineering undergraduate students

Fostering empathy within engineering education may have many benefits, such as promoting the individual engineer's ability to self-regulate interpersonal difficulties, to understand the aspirations of society (Rasoal et al., 2012), to become intrinsically motivated to act selflessly (Batson et al., 2009), or to augment ethical decision-making skills (Oxley, 2011). Nonetheless, within engineering education literature, explicit attention on empathy has been minimal, as shown in a literature review research study by Strobel (2013). Engineering design courses provide space in the curriculum where students are required to empathize with the design context and potential users of their designs. Within design courses, empathy may involve an awareness of the broader context and how elements or multiple stakeholders within that context fit together. Often empathy is instigated by the instructor's encouragement and left to students' willingness and intentions to truly understand their stakeholders. However, in many instances, design requirements include both technical and human-centered constraints. Specifically, due to the vast range of potential target users of products that engineers design for, it is imperative to incorporate the needs, emotions, challenges, restrictions of such clients into the design process (Gray et al., 2015).

Empathy is both a cognitive and an affective process. It involves a person's perceptions, thoughts, and feelings and how those concepts become manifested into a deeper understanding of others. Broadly defined, empathy refers to 'the reactions of one individual to the observed experiences of another' (Davis, 1983). As these distinctions show, even in fields where empathy is frequently used, it is a complex and nuanced construct. Kolko (2014) suggests that empathy, which he believes can be both taught and developed, is imperative for the creation of human-centered products, and that successful design requires the integration of human factors and an empathy with the users. In a developmental sense, there are several stages and schematic models where one moves from less to more advanced cognitive, social, or moral stages/schema through milestones. For example, we used conceptual models that integrate all aspects of development into a single unifying staged theory, be it their cognitive/ethical development (Lochrie, 1989) or their reflective judgment (Zeidler et al., 2009).

In the context of this study, design courses are required for all students across their four-year education and offered through a learning progression called the design spine. We conducted a workshop and designed a reflective assignment for students to reflect on their various design experiences and how empathy played a role in each of the years. Through a thematic analysis, we found that students emphasized that the nature of the first-year design course involved more on framing design problems and allowed them to explore their identities as a designer. Building empathy in the design process starts with making space for self-empathy (Krol & Bartz, 2021)). In the following course, students had to design for a local community. Students pointed out that perspective-taking was essential to understand the problem space that they were designing for at this stage (Hess

et al., 2015). As students advanced into their specialization years, they reflected on the specific tools that they used to gain empathy and how that connected to the norms of the professional world. Lastly, students articulated complex understandings of empathy in their profession such as through team interactions, course objectives, and industry expectations. The implications of empathy in engineering entails a deep understanding of the engineering problem, including the values and perspectives of different stakeholders (e.g. the end users, design partners who may represent different sub-disciplines or geographic or cultural aspects of the project) which will be discussed in the symposium presentation.

"Punks", "Troublemakers" and "Inventors" – A Tension between Aspired and Embodied Values in STEM Education

Particularly in science, technology, engineering, and mathematics (STEM) education, we value innovation, creativity, "thinking outside the box", "pushing boundaries", "challenging paradigms" and "coming up with new solutions" - (Hart Research Associates, 2015). But instead of allowing an unrestricted application of knowledge in order to come up with new solutions, many school systems and learning environments value compliant originality and conforming behavior over independent thinking (Beghetto, 2016). Thus, non-compliant personalities and non-conforming behaviors in young learners are often interpreted in a negative way, teachers try to shut it down (Ripley, 2016) and call the students misbehaving or "troublemakers". As a consequence, classroom management styles like the imposition of sanctions are a first step toward penalizing unwanted behavior. Even suspension is often used due to what the teacher interprets as misbehavior (c.f., Lewis et al., 2008).

There seems to be a clash between aspired STEM attributes and values and what is considered a good student and how this notion is embodied in schooling systems. Defiance, disturbance, and misbehavior in general are serious issues in every-day schooling: It stresses students and teachers (Aldrup, Klusmann, Lüdtke, Göllner, & Trautwein, 2018; Kulinna, 2007) and distressed teachers are more likely to interpret behavior as misbehavior (Herman, Hickmon-Rosa, & Reinke, 2018). Most disciplinary classroom management styles lead to negative emotions, impaired wellbeing, impeded learning or negative student-teacher relationships and do not lead to behavior change (Goodboy, Bolkan, & Baker, 2018).

Unfortunately, a large number of students, who are defiant and do not have the tools to adapt, do disengage, lose interest and may even drop out of school. Furthermore, negative disciplinary actions in an US-context are immoderately applied to non-white and male children, especially African Americans and Hispanics (Blomberg, 2004; Losen et al., 2015; Townsend, 2000) and though male students and students of color and underrepresented minorities (URMs) are disproportionately more likely to be suspended and labeled "troublemakers" by their teachers, and thus suffer negative outcomes.

This contribution to the symposium brings together results on an emergent research agenda on troublemaking sharing (1) theoretical frameworks and conceptualizations to unpack the phenomenon of troublemaking and deviance in school, (2) and preliminary results on teachers' conceptualizations of troublemakers (Strobel & Koch, 2019). The long-term goals of this line of research are to differentiate between individual actions and their intentions of so-called troublemakers; reframing what it means to be a troublemaker and how to respond and support behaviors of troublemaking.

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The Neural Basis of Learning through Productive Failure

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Abstract: Productive Failure (PF) is a learning design wherein learners generate solutions for novel problems prior to formal instruction. Research has demonstrated the effectiveness of PF, indicating cognitive mechanisms for why students learn better after encountering difficulties. However, neurophysiological mechanisms underpinning "learning from failure" have yet to be explored, despite robust evidence connecting neural activity, heartbeats, and cognitive processes. The present study explores neural and physiological mechanisms underlying PF, employing neural signature and heartrate variability measurements.

Background of the project

Problem-solving followed by instruction (PS-I), as entailed in learning through Productive Failure (Kapur, 2014), is a powerful design shown to advance students' conceptual understanding and transfer compared to instruction followed by problem-solving (I-PS; Sinha & Kapur, 2021). Within research on PS-I, various cognitive mechanisms have been explored; however, the physiological and neural basis of this design have not yet been studied. The present study-in-progress investigates underlying neural and physiological mechanisms of PS-I compared to I-PS, using electroencephalography (EEG) to measure brain activity and electrocardiography (ECG) to measure heartbeat activity during learning in a naturalistic environment.

EEG research in the past years shows that various neural oscillations or waves are related to cognitive processes. For example, while problem-solving and having an insight, gamma oscillations are enhanced in right prefrontal regions (Rosen & Reiner, 2017), in right anterior superior temporal gyrus (Jung-Beeman et al., 2004), and fronto-central regions (Sheth et al., 2008). Moreover, alpha oscillations are associated with semantic information processing, in particular with searching, accessing, and retrieving information from long-term memory (Klimesch et al. 1997). Since most cognitive tasks draw on these processes, alpha event-related activity can be observed in a wide range of task demands (Klimesch et al. 1997). Theta activity has been related to episodic and working memory as theta event-related synchronization increases parametrically with working memory load and is sustained during the retention period (Jensen and Tesche 2002; Kahana et al. 2001). Since these are all cognitive processes relevant to a learning situation, we measure delta, theta, alpha, beta, and gamma in the present study.

Recent findings have begun to disentangle how different heartbeat measurements are associated with both top-down and bottom-up cognitive processing of emotional stimuli and lower-order cognitive skills (Park & Thayer, 2014; Mather & Thayer, 2018), including for example recalling or memorizing basic knowledge. Specificall, higher resting heartrate variability is associated with more adaptive and functional top-down and bottom-up cognitive modulation of emotional stimuli (Park & Thayer, 2014). We use ECG to investigate different heartbeat measurements, including heart rate variability (HRV), along with differences in EEG activity related to the type of learning situation (i.e., PS-I versus I-PS).

Research goals

With this project I set out to study the physiological and neural mechanisms involved in the Productive Failure learning design. I will investigate the HRV and change of oscillatory brain activity during a learning situation including several simultaneous cognitive processes like attention, working memory, memory retrieval, creativity/search of novel ideas. To do so, I conducted a neuro-physiological study to investigate whether there are differences in brain oscillations between the phases of the conditions (problem solving vs. instruction), between the conditions in the same phases, and how heart rate variability (HRV) is influencing post-test performance. The results will help us understand why the productive failure design is so powerful and what the difference is in terms of cognitive activity in the condition PS-I versus I-PS.

Methodology

We followed previously confirmed methodologies and increased sample size. A total of 60 healthy right-handed participants (age: 18 – 25 years old), randomly assigned to one of the conditions I-PS or PS-I (30 participants in each condition) were tested using EEG and ECG for all participants. We set up a naturalistic EEG/ECG study in

a learning setting. A computerized (Python w/ EEG trigger) version of a validated PF design (Kapur, 2014) was used. EEG data were collected with the Ant Neuro EEGO MyLab 128-channel EEG system at the ETHZ Decision Sciences Lab. At the same time, ECG data was collected with an electrode attached to the limb extremities and chest. The computerized version of the PF tasks had integrated markers sent to the EEG systems accordingly in order to form blocks of baselines, and different parts of the experiment. Additionally, participants' answers to multiple choice formed questions in the posttest were recorded and scored by the computerized task. The EEG data is being processed and analyzed using MATLAB custom scripts and the following toolboxes: EEGLAB for data preprocessing, including Independent Component Analysis (ICA) and artefact correction. Independent Component Analysis (ICA) is being used to identify and remove the eye-blink artifacts. Subsequently, the data will be visually inspected for other large artifact removal. Current source density (CSD) transformation (surface Laplacian) will be subsequently applied to the data in order to attenuate the low-spatial frequency features from the data, especially the cardiac-field artifact (CFA). The power spectral density (PSD) will be calculated using Welch's method. The power values at each electrode for each condition will be averaged over standard EEG frequency bands: delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (13–30 Hz), gamma (30–70 Hz) and subsequently log-transformed to normalize their distributions.

Statistical analysis: Repeated measures ANOVA and false discovery rate will be used to calculate differences between the conditions.

Expected Findings

Because of the underlying interdependent mechanisms proposed by Kapur (2016) and based on previous electroencephalography research, we expect enhanced gamma oscillations in the PS-I condition (compared to the I-PS condition) in the right prefrontal regions (Rosen & Reiner, 2017), in right anterior superior temporal gyrus (Jung-Beeman et al., 2004), and/or fronto-central regions (Sheth et al., 2008) during the problem-solving phase. Furthermore, we expect enhanced alpha oscillations during the problem-solving phase in the PS-I condition compared to the I-PS condition (Klimesch et al. 1997). As higher HRV is related to a better inhibition, we therefore expect that a higher HRV shows advantages in the PS-I condition (Park & Thayer, 2014).

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Supporting Multilingualism in Preschool: A Play Responsive Teaching Approach Mediated by digital technologies

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Abstract: This design-based research focuses on timely challenges such as multilingualism and the use of digital technologies that teaching in preschool is facing. Play-responsive teaching is the theory that informs the design and implementation of the study. Data will be generated from recordings where children and teachers engage in playful activities with tablets where multiple languages may be used. Analysis will investigate how teaching in preschool can be responsive to multilingualism by utilizing digital technologies (tablets).

Introduction

In our globalized world, multiculturalism is the societal norm for many contemporary societies and according to Turner and Cross (2016, p.289) today's education reflects an "increasing normalisation of multilingualism". However, even though multilingualism is now regarded as a valuable asset, there is still a need to identify pedagogical approaches, strategies and practical concepts for teaching in such circumstances.

Purpose

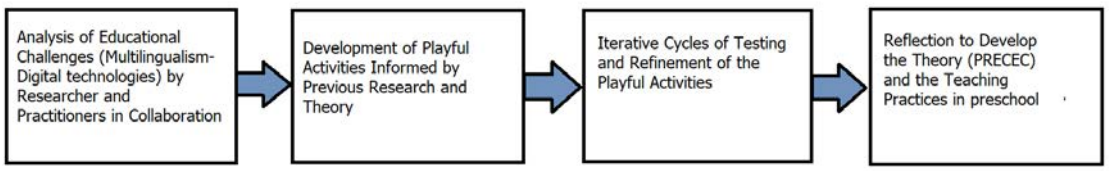
The purpose of this study is to produce new pedagogical knowledge oriented towards teaching in the field of Early Childhood Education (ECE) regarding multilingualism and digital technologies. More precisely, by applying a design-based research methodology it will be empirically explored how teaching in preschool can be responsive to a multilingual context, when playful activities with tablets (book creator app) are developed and teachers build pedagogy (teaching) on some principles of play-responsive teaching theory (PRECEC; Pramling et al., 2019).
The research questions are:

- How do activities with digital technologies (tablets) develop in linguistically diverse groups with preschool teachers building pedagogy (teaching) on PRECEC?

- What are the challenges and opportunities preschool teachers identify when reflecting on working according to some principles of PRECEC, in linguistically diverse groups of children and using digital technologies?

Method

Figure 1
A design-based research approach (from Reeves, 2006)



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Design-based Research (Brown, 1992; Collins, 1992) is chosen because it corresponds to the dual focus of this study to develop theory (PRECEC) and to improve practice (teaching in preschool). Design-based Research (DBR) is characterized as theoretically oriented, interventionist, iterative, and collaborative (McKenney & Reeves, 2018). Those characteristics will be included in this study and are viewed as standards/commitments for the quality of DBR (see Figure1).
Two preschool classrooms from two different international preschools in Sweden will participate in this study. The study will consists of observations of preschool environments, field notes, interviews with the principals and preschool teachers, and video recordings of playful activities. Since the study involves video recordings where children participate, it has been ethically approved by the Swedish Ethical Review Authority.

Expected Findings

Findings will clarify:

- How teachers work with some principles of PRECEC to engage multilingual children in playful activities with digital technologies.
- What kind of interactions develop between teacher-children or between peers during these activities.
- An understanding of how the mediation of digital technologies in the playful activities might change or expand the nature of PRECEC.
- Challenges and opportunities that preschool teachers identify after participating in this study.

Conclusion

This study, addressing the issues of multilingualism and the use of digital technologies in preschool, is timely and will make important contributions, both to the existing body of knowledge about and in ECE and to a wider societal discussion on these matters. Generalizability is established by placing the findings of this study in a broad theoretical context (PRECEC) to demonstrate whether and how the study is an example of the phenomenon under investigation.

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International Society of the Learning Sciences

Conceptualizations of Teaching and Learning in Impact Statements for Tenure and Promotion

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Abstract: This study investigated conceptualizations of teaching and learning using complex systems theory and network analysis. In 226 impact statements for promotion and tenure in one university we found two conceptualizations. In the Content-Processing conceptualization, teaching is the delivery of content and learning is acquisition of knowledge. In the Framing-Facilitation conceptualization, teaching is preparation of students for future careers and imparting truth, and learning is skill development. We also identified leverage points within each conceptualization.

Background

In complex systems interdependent elements interact in ways that lead to emergent phenomena which cannot be explained through linear cause-and-effect analysis (Bar-Yam, 2016). The interdependent elements in complex conceptual systems are related ideas which together form conceptualizations, leading to emergent phenomena in the form of practices. Because practices are emergent from conceptualizations, changing practices requires that conceptualizations must change. In prior studies we found two dominant conceptualizations of learning (Donaldson & Allen-Handy, 2020). In the Transfer-Acquisition conceptualization, learning is the acquisition and manipulation of knowledge objects. We found this conceptualization to be dominant among the general public (Donaldson, 2018), as well as among STEM educators (Donaldson & Allen-Handy, 2020). In the learning sciences we found widespread use of the Construction-Becoming conceptualization (Donaldson, 2019) which sees learning simultaneously as becoming and as construction of meaning. This study seeks to identify which conceptualizations professors across all disciplines in a Research 1 university use to relate the impact of teaching and learning.

Methods

We collected 226 anonymized impact statements from faculty being considered for tenure and promotion to associate professor across 16 colleges in a Research 1 university in the United States from 2015 to 2019. In MAXQDA Analytics Pro we coded the data using emergent coding processes within the following categories: non-metaphorical characterizations of teaching and learning; metaphors of teaching and learning; practices in teaching and learning; and value statements. The coding stage resulted in a final codebook which contained 291 codes covering 9,383 coded segments. We then calculated code co-occurrence correlations using Pearson's r for all pairs of codes within each category. Symmetrical correlation matrices were created at the $p < 0.05$, $p < 0.01$, and $p < 0.001$ confidence levels. UCINet network analysis software was then used to analyze the matrices as 1-mode networks. We used Girvan-Newman cluster analysis to identify network clusters (Girvan & Newman, 2002), which were visualized using the NetDraw network visualization software with different colors of nodes indicating membership in a cluster. To identify leverage points within each conceptualization, we developed an innovative methodology: semantic network maps in which node sizes were adjusted such that nodes with higher betweenness centrality measures were larger, and nodes with high betweenness values are key leverage points.

Findings

Girvan-Newman analysis identified two conceptualizations of teaching and learning (see figure 1) at Q=319. Although they were significantly distinct non-overlapping clusters, these two conceptualizations of teaching and learning had so much semantic overlap that we suspected they are actually two variations of one conceptualization, which was further supported by the finding that both conceptualizations were aligned with the Transfer-Acquisition conceptualization found in prior studies. In the current study, the Content-Processing conceptualization of teaching and learning (blue cluster - 88.9% of the professors) saw teaching as involving creating courses and structures for delivering and explaining knowledge. Professors who used this conceptual story often seek to improve their courses and teaching practices, often with a focus on trying to motivate students. These professors believed that learning involves acquiring and using knowledge, and often value adjusting their teaching according to their students' learning styles. It often framed teaching and learning in terms of content—

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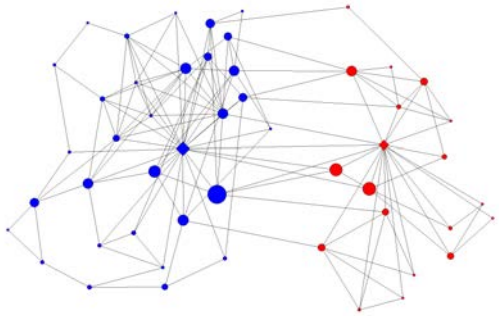
content which is conveyed to students, which forms a foundation or body of knowledge. This content comes in the form of pieces of information which students obtain. A major focus was covering material which students receive and process. This conceptualization was aligned with the Transfer-Acquisition conceptualization found in prior research. We also found a Framing-Facilitation conceptualization of teaching and learning (83.6% of professors - red cluster) focused on facilitating student development of skills to prepare them for future careers. It used a perspective on learning which sees learning as a process which takes place on the level of the individual student, and the role of the professor is to impart truth and correct facts to students. This conceptualization used visual metaphors such as exposure, illumination, and lenses. This conceptualization was also mostly aligned with the Transfer-Acquisition conceptualization found in prior research, but to a lesser degree than the Content-Processing conceptualization.

Figure 1

Two conceptualizations of teaching and learning at $P < 0.001$ with leverage points



Within the Content-Processing conceptualization of teaching and learning there were leverage points which could be used to help faculty question their assumptions about teaching and learning, including metaphors of knowledge such as "basic" knowledge (large blue node to the lower left of the diamond in the center of the blue cluster) and a knowledge "foundation" (largest blue node in the right of the blue cluster). Other leverage points are thinking of teaching as something which should be grounded in theory (largest node in the upper-left part of the blue cluster) and involving continual efforts to improve teaching methods (large blue node to the upper-right of the diamond). Within the Framing-Facilitation conceptualization of teaching and learning leverage points include framing knowledge as something which is created (rather than acquired or discovered - largest node in the upper part of the red cluster in figure 1) and thinking of learning as focused primarily on understanding (largest red node in the center-left part of the red cluster), which is connected also to preparing students for future careers (the large red node in the center of the red cluster).

Discussion and Implications

This study used an innovative methodology which leverages network analysis tools to investigate these questions, and we were able to further develop the methodology such that it provides insights about key leverage points in complex conceptual systems. We found two conceptualizations of teaching and learning used by professors in impact statements for tenure and promotion. By virtue of identifying these conceptualizations we gain insights into both 1) the motivations for faculty teaching and learning approaches and 2) how faculty members perceive their colleagues value teaching and learning during the promotion and tenure process.

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International Society of the Learning Sciences

The Gateway for Optimizing Design of Micro-credentials: Higher Education Faculty

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Abstract: Despite the growing prevalence of micro-credentials in higher education, there is still no consensus on best design practices. To address this, we identified existing design knowledge held by faculty that designed micro-credentials in a pilot program at a large public research university. We found that faculty may know how to design micro-credentials to address credentialing affordances, but may need support in recognizing and designing for assessment affordances.

Introduction

A micro-credential is a small learning experience in terms of length of time to complete and the amount of knowledge and skills that are assessed (Abramovich, 2016). Relatedly, a digital badge often accompanies a micro-credential as a "visual representation of learning and skills" (Besser & Newby, 2020, p. 484). Because micro-credentials are significantly different from traditional credentials (Ghasia et al., 2019), the same processes and principles that educators apply when designing the corresponding learning experience may not be optimal. Simply put, designing a micro-credential for a learning opportunity is different than designing the learning experience that accompanies a diploma, certificate, or course grade. This is problematic because, although micro-credentials are increasingly used (Besser & Newby, 2020), there is little research about what are the optimal design processes for different types of micro-credentials. This problem is compounded since we know that a design process influences factors such as student persistence, sense of progress, and perceived learning (Gray & Diloreto 2016; Groening & Binnewies, 2019). A misapplied design process may be the reason for unsuccessful micro-credentials (e.g., low interest, misrepresentation of the credentialed knowledge) and may even hamper learning outcomes.

To identify optimal design process for micro-credentials in higher education, we investigated how faculty leveraged the affordances of micro-credentials in their design process. Guiding our investigation were the following exploratory questions: *What are faculty perceptions of micro-credentials? How do faculty address these perceptions when they design a micro-credential?* We intentionally chose broad, guiding questions to uncover "subjective insights, intuitions, hunches, and ideals" that could serve as a "crucial basis" (Nonaka & Takeuchi, 1995, pp. 8-10) for building design knowledge for micro-credentials.

Theoretical approach

This study was informed by literature that theorizes design as a form of knowledge that is enacted (Nonaka & Takeuchi, 1995), and by research of design processes where the designer is a mediator of knowledge (McKenney & Schunn, 2018). Therefore, we aimed to reveal design decisions (i.e., knowledge) held by faculty (i.e., mediators of knowledge) that designed micro-credentials.

Methods

We interviewed five faculty members on their experiences (e.g., practices, processes, decisions) designing a micro-credential as part of a pilot program at a large, public research university. Interviews were transcribed, to which we applied a hybrid process of inductive and deductive thematic analysis. We first conducted open coding, and the concept of 'affordances' emerged as a core theme. Next, we reviewed our initial codes and identified two main subcategories of affordances: assessment and credentialing.

To determine how the identified affordances were considered in the faculty's design processes, we examined literature to identify design attributes of quality assessments and quality credentials. In our final round of coding, we used the design attributes that were repeatedly referenced (i.e., in at least three peer reviewed articles) as an a priori template (Crabtree & Miller, 1999) to analyze how faculty designed micro-credentials to address assessment and credentialing affordances.

Findings and conclusion

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We found that all of faculty perceived micro-credentials in terms of their assessment and credentialing affordances. When describing their experiences designing a micro-credential, faculty recognized the following qualities of assessment design, as applicable to the design of a micro-credential: Formative and summative components; Alignment with delivery method; Sustainable assessment; Clarity of outcomes and criteria; Optimized for the unique aspects of the learning opportunity; Equity-oriented. Faculty recognized the following qualities of credential design, as applicable to the design of a micro-credential: Meets needs of employers; Prepares learners to succeed in the workforce; Understood by stakeholders.

However, in designing a micro-credential, faculty addressed the assessment and credential affordances to varying degrees. While the design attributes of quality credentials were ubiquitously applied by the faculty, few attributes of quality assessments were consistently applied. This suggests that for micro-credentials to be optimized, faculty may need additional support to be as consistent with the affordances of assessment in the design process as they are with credentials. This support could come in the form of professional development, where faculty can explore how credentials and assessment are symbiotic.

Our findings also indicate that some critical attributes of assessment design were largely not discussed, or not applied (e.g., aligning with the delivery method, ensuring clarity of outcomes and criteria, establishing equity-oriented assessment). Therefore, we suggest that faculty may need support in recognizing and integrating assessment qualities when designing micro-credentials. To address this need, support may include planning sessions that highlight strategies for integrating qualities of good assessment design, facilitating meetings with experienced micro-credential designers for knowledge-sharing, and structuring design tasks through templates and models.
We also conclude that further research is needed to refine and build upon the design considerations revealed in this study, and to determine their applicability to micro-credential design practice across other institutions of higher education. More specifically, educational design practice is situated and highly shaped by institutional environment and socio-cultural system (Butler & Schnellert, 2012). We recommend research that extends to other types of higher education institutions, including two-year institutions. Additional research may also identify potential discipline-specific factors relating to micro-credential design. Faculty design decisions are closely related to "discipline-embedded assumptions and beliefs" (Stark, 1988 p. 221). A micro-credential for one type of knowledge may have different assessment and credential affordances than a micro-credential for another field.

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International Society of the Learning Sciences

Taking up opportunities to practice in a social studies-themed digital simulation game: A quantitative ethnography

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Abstract: We use quantitative ethnography and Epistemic Network Analysis to examine how the social studies-themed digital simulation game *Offworld Trading Company* generates opportunities for players to practice using disciplinary knowledge, skills, and concepts (DKSCs) as tools for taking goal-mediated action. Our study design places particular emphasis on establishing inferences regarding specific game mechanics as generative of such opportunities to practice, as well as the DKSCs they invite and require of players.

Introduction

This poster proposal describes work currently in progress. Preliminary results will be ready for reporting at the time of the conference. Previous research indicates that *Offworld Trading Company* (*OTC*), a digital simulation game thematically aligned to social studies--particularly economics and geography--invites players to practice using disciplinary knowledge, skills, and concepts (DKSCs) associated with social studies to plan, take, and reflect on goal-mediated actions (Kessner, 2021). The goal of the present research is to explore in greater depth the structural design elements that afford these opportunities to practice (OTPs). We define OTPs as embodied interactions in which players are positioned within identities and with access to tools to solve problems; and in which the relevant identities, tools, and problems are disciplinarily integrated.

Good games are excellent learning environments. They privilege experience before text, performance before competence, identity play, and systems thinking; and they present players with interesting, well-structured, and well-sequenced problems players solve by mastering and applying game-valued skills (Gee, 2003). Good games often align better than formal education environments to long-standing claims of situativity theorists that what we learn cannot be disentangled from how and why we learn it (Gresalfi et al., 2009).

For these and other reasons, games have maintained a level of popularity among both educators and researchers. In the context of social studies education, however, a mismatch exists between this interest and the available evidence of effectiveness, as well as conceptual guidance around what (kinds of) games are useful and why. Use of games in social studies education contexts may indeed represent a unique challenge.

Done well, social studies education should prepare students to don the mantle of citizenship, with particular emphasis on active, critical participation in making choices that (re)design the world to align as tightly as possible to shared visions of a just and equitable pluralist democracy (Banks, 2006; Barton & Levstik, 2004; Kessner et al., 2020). This form of civic preparation requires opportunities to practice using disciplinary knowledge, skills, and concepts as tools for taking action. Good games are particularly good at providing such opportunities generally, though what design elements (e.g., game mechanics) generate these opportunities specifically remains unclear in the context of social studies education; far more attention has been paid to these design issues in the contexts of math and science (Sengupta & Clark, 2016).

We use quantitative ethnography (QE) (Shaffer, 2017) to examine small-group play of *OTC* to explore the following research questions:

1. To what extent do learners take up OTPs to practice using DKSCs to take goal-mediated action in *OTC*?
2. What DKSCs do learners leverage while planning, taking, and evaluating goal-mediated actions in *OTC*?
3. What game mechanics generate these OTPs in *OTC*, and which DKSCs do they invite students to use?

Theoretical framework

Humans learn best through embodied interactions with the world. These interactions are further mediated by tools. In the context of games, we frame these embodied interactions as *conversations with the world*, cycles of thinking and action in which people identify goals, plan actions, and gather feedback on those actions from the world (Gee & Gee, 2017). These actions are probes into the world, a kind of question put to it, and the world "talks back" (p. 2). In videogames, players are embodied in the game world as avatars, which come with toolkits (Gee, 2015). It is with these tools and through these avatars that players (are able to) take actions in games. In *OTC*, players' avatars, their associated toolkits, and the problem spaces presented to players, align conceptually to those of economists and geographers (Kessner, 2021); we contend OTPs emerge at their intersection.

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Methods

QE leverages quantitative designs and analyses to make sense of complex qualitative discourse data (Shaffer, 2017). Recent games scholarship leveraging QE has explored how an online game community forum facilitated participants' identity exploration processes (Barany & Foster, 2019), when and why students quit learning-focused games (Karumbaiah et al., 2019), the correlation between students' facial expressions and their understanding of biological and complex systems concepts (Martin et al., 2019), and the connection between multimodal observable behavior and collaborative problem-solving skills (Andrade et al., 2019).

As with the above applications of the method to games research, QE represents articular affordances for the present study. Games are immensely complex systems, making purely qualitative accountings of the connections between many diverse variables difficult if not altogether untenable. Additionally, at least two games take place concurrently during gameplay: the game on the screen, and the game in players' heads. Our research questions are additionally concerned with a third space: the game that takes place behind the screen, which includes game mechanics.

Participants for this study are a class of high school students enrolled in an Academic Decathlon elective course in a public school in the American South. Students came from diverse backgrounds, and their varied levels of academic achievement, from "low" to "high," as measured by school-calculated grade point averages, indicates a wide and potentially representative sample of academic interest and engagement with school. We are collecting discourse data by recording students' conversations as they plan and deliberate which actions to take as they play the game in small groups. We will then transcribe this data for *a priori* coding based on prior analysis of DKSCs implicated in the *C3 Framework*. The results of this coding will guide our segmentation of the gameplay data (screencaptured) and accompanying video data in OTPs. Using Epistemic Network Analysis, we will then identify game mechanics that generated OTPs, as well as which (kinds of) mechanics generated stronger or weaker OTPs and stronger or weaker DKSC use.

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International Society of the Learning Sciences

Undergraduate and Graduate Student Perspective on Teaching for Critical Pedagogy

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Abstract: In critical pedagogy there is an intrinsically interrelated relationship between education and society. The fundamental purpose for education is to improve society and fight for justice for all. These core ideas translate into a set of principles for the design of transformational learning. These principles involve rejecting positivism and embracing constructivism, developing critical consciousness, questioning assumptions, learner autonomy and authority, and transforming realities. To explore these principles, the first and second author presents an autoethnographic analysis of these principles in their own educational experience.

Background

There is not a set of practices for critical pedagogy, but it provides a set of principles that guide the design of courses, learning activities, and learning environments. The first involves rejecting positivism and embracing constructivist and situative perspectives (Kincheloe & Steinberg, 1998) because positivism reproduces and enforces systems of power that cause marginalization and oppression resulting in social injustice. The second principle is developing critical consciousness—a frame of mind that creates and rebuilds the world by self-transformation of one's context which cannot occur from the traditional "from the top down but from the inside out" (Freire, 1974), and is developed by building knowledge through human and world relations and interactions (hooks, 1994). The third principle is transforming realities towards alleviating the suffering of those around you who are marginalized and/or oppressed. This is only possible when working with learners to gradually understand and embrace their own authority (Donaldson 2019). In critical pedagogy, we have students and teachers in positions of autonomy and authority—the fourth principle (Freire, 1974; Kincheloe, Steinberg, & Tippins, 1999). Developing learner authority and autonomy is necessary to enact all principles of critical pedagogy. The fifth principle is questioning assumptions (Kincheloe, 2008) and recognizing that not everything has one answer, and that answers are constructed by people who have intersecting identities and power.

Methods

We used theory-focused autoethnographic study (Jones 2016) to analyze our own educational experience through the lens of critical pedagogy. We approached our analysis by first delineating three aspects of auto-ethno-graphy. The "auto" (self) aspect includes the experiences of the two authors of this paper. The "ethno" (socio-cultural context) aspect includes three communities: 1) the family and community of the first author, 2) the family and community of the second author, and 3) the community of higher education in a large land-grant university in the United States. The "graphy" (formal research investigation) aspect included analysis of researcher-generated field notes. The first author is a graduate student, first in her family to graduate university. She grew up in a marginalized community in San Antonio, TX, where the community lacked access to healthcare, higher education, and other resources. The second author is an undergraduate student, and will be the fourth in her family to graduate from college. She grew up in a predominantly Hispanic community where many families live below the poverty line. Both authors grew up in low-income communities and attended Title I schools.

Findings

Principle 1 findings: Reflecting on our grade school education, specifically high school, we both remember students at our schools being generalized as troublemakers because of the school's Title I status. Both schools consistently reported low test scores, high pregnancy, and dropout rates, and violations. On the surface, from a positivist perspective based on the statistics and facts, it was assumed that these students didn't care about school—that school was something students had to do, or they would go to truancy court. By rejecting positivism and looking deeper past just numbers, we can understand why the statistics are what they are. Analysis of our own experiences helped us realize that factors like race, citizenship status, mental illness, sex, and class are socially constructed concepts that have real-life consequences, especially in terms of producing and reproducing societal hierarchy. These hierarchies invade institutions like education, creating differences in its quality depending on socioeconomic status. As we continued with our education, we realized that these hierarchies that have been put in place—are not a natural nor inevitable feature of reality. The realization that

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social constructs are not "real" in terms of natural sciences but do have real-life consequences transformed our worldview.

Principle 2 findings: During my undergraduate career, I (the first author) was faced with obstacles that only presented themselves to students who are different from the traditional college student. Being a woman of color from a low socioeconomic background who is also the first in her family to go to college, I quickly realized that the environment of higher education I was experiencing was not created for people like me. And yet, I also realize that even though the system was not created for me, I belong in higher education. I have the right to be here, and a right to succeed.

Principle 3 findings: Do I belong or not? Looking at sociohistorical assumptions in society, I (the first author) was able to recognize that the structures and institutions of higher education were designed by and for white upper middle class men. It became important to me that I challenge these barriers that impact disenfranchised communities. Education is not a privilege but a human right, which contradicts the initial assumption that education is reserved for the higher class. Growing up, college was seen as unattainable in my community and family due to lack of resources and awareness of how to access and navigate higher education. Within higher education, the lack of representation of minority students deepened the notion that students from marginalized communities are unwelcomed. There is a constant battle between knowing I belong, yet being aware of the preexisting systemic issues within the institution of higher education.

Principle 4 findings: During the spring semester of my sophomore year, I (the second author) was enrolled in a course where most class periods consisted of open discussions surrounding the ways in which education has failed marginalized communities, as well as discussion of present and future solutions. This course was one of the first I had that focused on discussion-based learning where students had the autonomy to express their opinions and lead discussions. The professor also allowed students to decide what to research and how they want to demonstrate their understanding. Through the professor's use of open discussion and choice in assignments, they were able to engage students in developing identity. It proved that I have the authority and autonomy to explore what I find interesting, know that I'm intellectually valued, and use my experiences to demonstrate knowledge.

Principle 5 findings: We are currently working in a learning sciences research laboratory that assists faculty from all disciplines conduct research about learning in their own courses. We are able to create a positive impact in higher education. We take different principles from critical pedagogy in order to help faculty revise their courses. In our lab we approach our roles and responsibilities through exercising agency and autonomy. We have the authority to craft our own research projects, collaborate with members in the lab, and work with faculty as co-equals. We support the lab in other ways such as data cleaning and writing overview papers for faculty to better understand learning theories. We are working in collaboration with top professors in their fields to develop more powerful and empowering learning experiences in their courses. This allows us to have an impact on transforming student's learning, as well as their worldviews and critical consciousness.

Discussion

As both learners and scholars, we are driven by a need to work toward creating an equitable education system that benefits everyone. Through learning and collaborating with others we create knowledge that has the potential to change the society we live in. By transforming how we approach teaching and learning by using critical pedagogy we have the ability to create an institution that changes lives for the better. Our autoethnographic analysis found that theoretical constructs from the critical pedagogy literature reflect the truth of our own lived experiences.

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Looking Beyond Disciplinary Silos: Students' Interdisciplinary Science Understanding of Carbon Cycling

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Abstract: Natural phenomena and scientific issues are intrinsically interdisciplinary. A variety of academic disciplines of natural science are essential for students to explain a phenomenon or related issues along with their reasonings for the phenomenon. The primary goal of the current study is to examine how students' interdisciplinary understanding of carbon cycling manifests itself using the latent Dirichlet allocation model. This study provides important insight into the potential impact on diverse curricular and instructional approaches in science.

Introduction

Natural phenomena and scientific issues are intrinsically interdisciplinary (ID). ID understanding in a variety of disciplines of natural science is essential for students to explain a phenomenon or related social scientific issues. The current science education system focuses mainly on a discipline-based curriculum, but recent national documents and standards for science education in many countries have demonstrated the value and essentiality of ID approaches to learning. Despite a growing emphasis on ID learning and teaching in K–16 education, few researchers have identified the ID connections within student science knowledge. This study involves students' answers to constructed-response (CR) questions in the Interdisciplinary Science Assessment for Carbon Cycling (ISACC, You et al., 2021) to interpret what core science concepts and corresponding disciplines are evident in their answers using topic modeling. We examined the relationship between the proportions of science disciplines and students' scores. The guiding research questions for this project were as follows:

a) How is students' ID knowledge about carbon cycling represented in their written answers?
b) How is the relationship between the proportion of the ID represented in the students' answers and scores?

Theoretical Framework

Interdisciplinary understanding

ID understanding has been defined as "the capacity to integrate knowledge in two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means" (Boix Mansilla & Duraisingh, 2007, p. 219). You et al. (2021) argued that the combination of knowledge from different individual disciplines could be a prerequisite for demonstrating ID understanding.

Topic modeling

Interest in the use of topic modeling techniques to discover abstract "topics" in the collection of documents has increased (Nagwani, 2015). The students' answers to the CR items provide an example of the texts educational scholars are interested in. The most popular model of the topic modeling technique is latent Dirichlet allocation (LDA; Blei et al., 2003). It is commonly used to discover the scope of topics and the underlying patterns contained in text documents.

Methods

Participants and ISACC

The ISACC consists of 454 students' responses to 19 items, including 11 multiple-choice (MC) items and eight CR items, collected at a public high school and a research university in Texas (You et al., 2018, 2021). From eight CR items, we excluded three items based on a single discipline's knowledge and the lack of information to extract topic structures. Thus, we analyzed students' written answers for five CR items (i.e., Item 8, Item 12, Item 14, Item 15, Item 19) in the ISACC.

Data analysis

The first step of the topic modeling is data cleaning, which eliminates the meaningless texts, "don't know" texts, and empty texts. In the second step, we preprocessed the data through a) tokenization (i.e., breaking the sentence into multiple words), (b) lemmatization (i.e., converting the words into their

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word stems), and c) stop-word removal. We extracted topic structures using the LDA model and then fitted a regression model to reveal the relationship between topics and students' scores.

Results

After the data cleaning, the average lengths of the written answers were from 19.66 words (Item 12) to 50.78 words (Item 19). Table 1 shows the most representative words for the topics of each CR item. Through the key words, we found interdisciplinary connections between the students' answers and the five CR items. We extracted three topics from Item 8: Topic 1 (integration of biology, chemistry, and earth science); Topic 2 (integration of chemistry and earth science); and Topic 3 (integration of biology and chemistry). The other four CR items had a two-topic structure. Interpretations of the topics of five CR items will appear in the presentation.

Table 1

Representative Words for Topics of Five CR Items

Item 8	Topic 1	ocean, pH, atmosphere, create, acid, organism	Item 14	Topic 1	food chain, carbon dioxide, acid, atmosphere, marine
	Topic 2	CO_2, air, release, temperature, turn		Topic 2	phytoplankton, population, eat, source, organism
	Topic 3	reef, coral, fuel, fossil, warm	Item 15	Topic 1	reduce, intake, animal, create
Item 12	Topic 1	fossil, fuel, burn, atmosphere		Topic 2	tree, atmosphere, balance
	Topic 2	vapor, radiation, cycle, heat, trap, loop	Item 19	Topic 1	solar, season, energy, plant
				Topic 2	sunlight, earth, radiation

We used the proportions of the extracted topics as predictors for estimates of students' scores in a linear regression model. Table 2 shows a linear regression equation of Item 14 that displays the association between topic proportions (independent variables) and student scores (dependent variables) of ID understanding for Item 14. The two topics have made significant contributions in predicting ID understanding scores. The other items' results appear in the presentation.

Table 2

Regression Analysis Summary for the Topic Proportions and Students' ID Scores for Item 14

Multiple R-squared: 0.722	Estimate	S.E.	t	p-value
Topic 1: Chemistry + Earth	1.175	0.236	4.971	<.001
Topic 2: Biology	5.220	0.242	21.559	<.001
$Item14_ID\ Score = (1.175) * (Chemistry + Earth) + (5.220) * Biology$				

Discussion

ID understanding is a key desired outcome in science education. The analysis of the CR items to measure ID understanding revealed how the students integrated their disciplinary knowledge and to what extent disciplinary knowledge was used to build ID knowledge. The significance of this study lies in its potential ability to guide how science could be taught to foster ID knowledge that would explain a natural phenomenon. A metaperspective on multiple scientific disciplines and sufficient knowledge could eventually lead to successful ID teaching, even though the science courses would remain as separate disciplines. The results of the study have encouraged additional development of ID-focused curricula.

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International Society of the Learning Sciences

Instructional dialogues in an inquiry-based classroom: Towards a typology of teacher self-positioning

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Abstract: Effective classroom dialogues are vital for knowledge building in inquiry-based classrooms, and the positioning of teachers and students play an essential role. This qualitative study explored the patterns of and decision-making process underpinning the dialogues through analyzing lesson recordings and conducting stimulated recall interviews. Three types of teacher self-positioning were identified, which were associated with considering the cognitive-developmental needs of the respective students and the contextual constraints.

Introduction

The concept of dialogic teaching emerged as more comparative studies on classroom discourses were conducted. Dialogic teaching empowers students to use talk power to collectively construct knowledge alongside teachers' supportive layout and active engagement (Alexander, 2004). A body of literature has studied the dialogue patterns (van de Pol et al., 2017), effects on specific learning skills (VanDerHeide et al., 2016) and talk functions (Boyd & Markarian, 2015). However, the implicit decision-making process behind the instructional dialogues is scarcely explored (Reznitskaya & Gregory, 2013). Teachers constantly decide on and re-negotiate their discursive positions, which could be understood through the lens of positioning theory (Davies & Harré, 1990) by considering how students' rights and duties are being assigned and negotiated. Their self-(re)positioning could uncover the dilemma faced by the teachers regarding their adoption of the dialogic approach. The current study qualitatively analyzed a classroom in-depth to explore dialogue patterns and accentuate the thinking process of participants. This study aims to develop a typology of teacher self-positioning in classroom inquiry processes and provide interpretative accounts of the respective pedagogical intentions. It is hoped that the current effort could sustain the scholarly discussion on positioning theory as an analytical tool of classroom discourse analysis, particularly of the inquiry-based classroom discussion of science-related social issues (e.g., Bossér & Lindahl, 2017).

Methods

Our participants included a teacher and a Secondary 5 (Year 11) class of 32 students at a secondary school in Hong Kong. By far, 12 lessons have been recorded for identifying dialogic elements at the turn- and lesson-levels. The lessons observed were under the subject of Liberal Studies, which required teachers and students to co-construct interdisciplinary understandings of social issues under various curriculum-specified themes. The recordings of the in-class videos were analyzed by the analytical framework derived from the dialogic indicators developed by Alexander (2004) and the dialogic features distilled by Mercer and Littleton (2007). To disentangle the decision-making process behind dialogues, stimulated recall interviews were conducted with the teacher and students to unearth the respective motives of their behaviours in various talk moves, together with the perceived effects of their actions on learning and teaching. The interview data were inductively processed to permit typological frameworks of teacher self-positioning to emerge, with particular attention paid to role assignment and negotiation processes.

Findings

Three types of teachers' self-positioning have emerged from the preliminary analysis, and they were found to influence the substantiation of instructional dialogues: "self-background" (Type 1), "co-construction" (Type 2), and "self-foregrounding" (Type 3). "Type 1" episodes put students in the foreground to their arguments in extended dialogues, whereas "Type 2" episodes involve conversational participation opened to the whole class alongside a foregrounded teacher-student pair. "Type 3" episodes resemble monologic teaching where dialogues are less negotiable. Students' responses are expected to be concise and direct, and the teacher always provides quick evaluative remarks. The characteristics and underlying rationales of the three types of teacher self-positioning are summarized below in Table 1. Other types of self-positioning and additional features of the currently identified types of self-positioning are expected in the subsequent rounds of data collection and analysis.

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Table 1
Types of teacher self-positioning

Types	Self-backgrounding (Type 1)	Co-construction (Type 2)	Self-foregrounding (Type 3)
Foregrounded characters	A particular student	1 Student & 1 Teacher	Teacher
Interlocutors	A student, a teacher	Several students, a teacher	A student, a teacher
Duty of the students	Initiating & sustaining dialogues	Participating in teacher-initiated dialogues	Listening & giving brief responses
Speaking turns per episode	Fewer	More	Fewer
Student thinking time	Shorter	Longer	Very short
Teacher scaffolding	Fewer	More	Very limited
Rationales of use	As challenges for more able students	Students expected to require more help	When time pressure to complete exists

The following excerpt demonstrates a typical "Type 2" episode:

(1) Teacher: Any other thoughts? [answers raised by the audience] Is it Michael?
(2) Michael: Umm…firstly, immoral.
[*Speaking turns (3) – (6) omitted, during which teacher jotted down keywords on board and asked for a further argument.*]
(7) Teacher: And? [other students give cues]
(8) Michael: I did not say I would answer this question.
[*Crowd laughing and teacher stepping backwards feeling surprised.*]
(9) Teacher: Wow, that's such a disclaimer! (Teacher laughing) Why didn't you reject my invitation earlier on?
(10) Michael: Ah, it's okay, let me still try. [*Silence for 20 seconds*]
(11) Michael: Right, I thought of high price levels…
(12) Teacher: Then, what would happen? [*Teacher moving his hand to cue Michael to keep elaborating.*]
(13) Michael: (inaudible)…because of the high price level, people cannot afford it, and that leads to more severe conditions for their sickness.

This excerpt shows how an episode in which co-construction stemmed from a possible misunderstanding. Initially, the teacher declared Michael the preferred interlocutor after seemingly hearing his voice. Subsequently, at the speaking turn (8), Michael challenged the teacher's duty-assignment decision. The teacher softly reiterated that speaking turn (1) was an invitation that Michael had not declined, which resulted in Michael's duty to remain in the dialogue. After the negotiation, Michael resumed his duty again. Despite the teacher's power to assign rules, he gave much wait time for Michael to elaborate his answer and body gestures were used to cue for elaboration. The teacher also allowed space for the students to showcase their independent thinking and viewpoints. This episode contrasts with "Type 3" episodes, in which the teacher usually gives less wait time and emphasizes the evaluation more than individual viewpoints. It is also distinct from "Type 1" episodes, in which the teacher intentionally backgrounded one's self for the students to state their arguments independently.

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International Society of the Learning Sciences

Effects of narratives on undergraduate student understanding of fundamental concepts in biology

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Abstract: Undergraduate students frequently struggle to understand biological concepts. Embedding conceptual information in a historical narrative holds the potential to support their learning. We developed learning materials comparing narrative or expository texts and assessed students' conceptual understanding via post-tests. Results showed that students, who read the narrative text, understood the concept of randomness better. No difference was found for the enzyme energetics concept. Furthermore, students in the narrative group reported higher situational interest after the intervention.

Keywords: Narrative, Biology, Conceptual Change, Understanding, Higher Education

Introduction

Recent studies have shown that university students often fail to fully understand biological concepts, including enzymatic energetics or stochastic processes (i.e., randomness) on a molecular level, and retain incorrect conceptions despite instruction (Champagne Queloz et al., 2016).

Along with university lectures, textbooks, written as expository texts, are a major source of information for natural science undergraduate students. Despite their ubiquitous use in natural science education, there are also caveats regarding presenting concepts abstracted from real-world contexts. For example, theoretical and empirical evidence argues for more context-dependent, enculturating and social forms of learning and teaching (Brown et al., 1989). In contrast, narratives naturally provide a social and cultural learning environment that may reduce the abstractness of concepts (Avraamidou & Osborne, 2009). This could allow learners to better relate new ideas to prior experiences and social contexts (Dahlstrom, 2014). Further, narratives may facilitate the activation of prior knowledge (including knowledge about related concepts from different disciplines) and in addition to that the integration of new concepts into the pre-existing knowledge framework instead of learning isolated knowledge fragments (Dahlstrom, 2014). Eventually, using narrative elements in educational texts could prompt dissatisfaction with incorrect student explanations more efficiently, ultimately supporting conceptual change from prior explanations to scientifically accepted theories. However, recent research findings report contradicting evidence regarding the effectiveness of using narrative-embedded theory elements to improve the understanding of biological concepts in higher education: learning with narratives resulted in higher (Dai et al., 2021), but also lower (Wolfe and Woodwky, 2010) post-intervention performance in contrast to learning with expository texts. Therefore, the present study aims to investigate:

1. What are the effects on understanding when using narratives compared to expository text materials?
2. How do the different text materials affect the situational interest towards the topic affected?

We hypothesize that narrative text materials lead to greater conceptual understanding than expository ones, and that students in the narrative intervention group show increased situational interest in the topic.

Methods

Sixty-one first-year undergraduate natural science students (20.1 ± 1.6 years old; 61.6% female, 38.4% male, 0% non-binary) from a highly ranked Swiss university participated in the study. The university's ethics committee approved the study before implementation. Participation was voluntary, and no compensation was paid.

Text materials covered the concepts "enzyme energetics" and "randomness". These topics were selected as they were shown to constitute frequent difficulties in understanding for natural science students (Champagne Queloz et al., 2016). The conceptual information was embedded in a historical context for the narrative text materials. The expository text focused solely on conceptual information. The validity of the text materials was analyzed with experts in biology and literature. The narrative text was slightly longer than the expository one (narrative: 112 sentences, expository: 79 sentences), but displayed similar text characteristics, including type-token ratio (TTR) (narrative TTR: $M = 0.39$, $SD = 0.12$; expository TTR: $M = 0.39$, $SD = 0.16$) and Flesh readability indices (narrative: 37.02, predicate difficult; expository: 41.56, predicate difficult).

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The conceptual understanding was tested in the post-test using four multiple-choice questions per concept ($\alpha = 0.52$). Correct answers were awarded one point. A single-item question on a five-point Likert scale was used to measure situational interest.

Participants were randomly assigned to read either the narrative text (n = 31) or the expository text (n = 30) before the students took the post-test and were then asked to answer the questions covering putative learning mechanisms. An ANOVA was conducted to determine post-test performance differences. Differences regarding learning mechanisms were assessed by performing a Kruskal-Wallis test.

Results

The ANOVA revealed that students in the narrative group performed significantly better in the randomness test questions ($F(1, 59) = 4.337$, $p = .0492$, $d = 0.51$, 95% CI = [-0.01, 1.04]). In contrast, no statistically significant performance difference was found for the enzyme energetics concept ($F(1,59) = 0.365$, $p = 0.548$, $d = 0.15$, 95% CI = [-0.36, 0.67]). Thus, we found partial evidence supporting the hypothesis stating that learning with narrative texts could lead to greater conceptual understanding. Concerning situational interest, students in the narrative group reported a significantly higher interest in the topic than students from the expository group ($H(1) = 4.52$, $p = .033$, $BF_{10} = 9.80$). Hence, we found evidence in favor of the hypothesis regarding higher situational interest in the narrative intervention group compared to the expository intervention group.

Discussion and conclusion

Prior research has demonstrated the need for novel teaching approaches in biology at the university level. Embedding conceptual information in narratives could constitute an effective way to convey biological concepts than expository texts. In the present study, the use of narrative learning materials resulted in a significantly better performance on a post-test related to questions on the concept of randomness compared to the expository materials. Moreover, situational interest after the intervention was significantly higher in the narrative group. Demonstrating a greater interest could thereby go hand-in-hand with greater cognitive activation and more active engagement with the materials. No differences were found for the enzyme energetics concept, potentially because a relatively low number of questions was used to infer students' understanding of this concept, and a ceiling effect was observed. Hence, extending the number of conceptual questions, as well as adding questionnaires investigating potential learning mechanisms, could help better understand whether and how the different text sorts affect understanding.

In conclusion, our results provide support for the effective use of narratives to enhance understanding of natural sciences in higher education. Given that a well-grounded scientific understanding is crucial to discuss, evaluate, and eventually solve current real-world problems, it will be essential to find ways of improving the learning of core biological concepts. Our study might thus inspire other developments in this area.

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International Society of the Learning Sciences

Museum Educators' Knowledge Brokering with Boundary Objects

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Abstract: Museum educators often use objects as part of education programs for visiting school groups. We examined how museum educators leveraged boundary objects and forms of talk to as part of knowledge brokering between the bounded communities of palaeontology and school groups. Findings show how educators broker with talk and objects, and how brokering can fail.

Introduction and background

Commonly, natural history museums are institutions built around collections of objects such as authentic artifacts, replicas, and exhibits (Paris, 2002). Museums and their objects can also facilitate boundary crossing between social worlds, such as between scientific disciplines and the general public. At such boundaries, objects can act as boundary objects, which are useful to the inhabitants of multiple social worlds, but in different ways (Star, 2010). To facilitate boundary crossing museum educators often act as knowledge brokers that translate and communicate specialized knowledge between bounded communities of disciplinary experts and the public (Meyer, 2010). Our interest lies in how museum educators leverage boundary objects and different forms of talk in knowledge brokering processes within education programs for school groups visiting a palaeontology museum.

Studies have examined how museum visitors such as families (Zimmerman et al., 2015) or school groups (Achiam et al., 2016) interact with museum objects, but rarely from the perspective of museum educators who often facilitate such interactions. Boundary objects are "plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star & Griesemer, 1989, p. 393). For instance, a fossil can serve paleontologists as an object of study, the public as a general interest, or school groups visiting a museum to learn about the Earth's history. Museum educators often reside at these boundaries and use boundary objects to broker across worlds. Knowledge brokering always involves making decisions about what to include and what to leave out and what to expand or contract, mediating the experiences of participants' contact with bordering worlds (Crowley & Jacobs, 2002). We explored the following question: How do museum educators facilitate knowledge brokering using different forms of talk in conjunction with boundary objects?

Context and methods of data collection and analysis

We observed and video-recorded three museum educators lead four educational programs for three groups of middle school students visiting a paleontology museum. Each 60-minute program took place within dedicated learning spaces (separate from the public galleries) or outdoors. Each program had a different format including a readers-theatre, a trivia-style game, fossil casting, and an outdoor walking tour. All the educators had a university-level science background and were trained by the museum to facilitate the programs.

Using literature and our data we developed three categories of objects and three forms of talk. The object categories include Authentic, Disciplinary, and Educational objects (Hampp & Schwan, 2015). Authentic objects were original objects such as fossils, rock samples, and geological features (e.g., rivers), but excluded replicas (e.g., fossil casts) or images. Disciplinary objects were those used in disciplinary work and they could be specialized (e.g., dental plaster) or common (e.g., toothbrush for fossil excavation). Educational objects were typically human made for the purpose of explaining or showing information, such as images, diagrams, and replicas or simplified/abstracted versions of other objects. We categorized objects based on how they were used in the observed contexts, even if they were relevant to multiple categories.

The educator talk categories include perceptual, conceptual, and connecting talk (Allen, 2002). Perceptual talk relied on sensory perceptions to interact with, observe, or describe objects, such as when an educator showed and described a fossil's features. Conceptual talk involved the educator using information or observations of an object to encourage students to make inferences and develop causal explanations about objects and concepts. This was often posed as questions in forms such as, "Knowing X about a dinosaur, what do you think will happen when in Y scenario?". Connecting talk invoked prior knowledge and experiences beyond a specific interaction, such as what students might know from school, media, or other parts of the museum.

Findings

The recordings were transcribed and using the categories of talk and objects, we coded a total of 201 utterances and 83 unique objects across all four programs (Ostrowdun & Kim, 2022). We observed the educators use multiple

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combinations of object types and forms of talk with varied success in brokering. For instance, in the walking tour, the educator successfully used all three forms of talk in relation to a petrified tree stump (authentic object). They invited students to observe the tree stump (perceptual talk); described correlations between the object and scientific knowledge of climate, vegetation, and geological history (conceptual talk); and asked students to recall the meaning of rings on the stump (connecting talk).

In another episode, an educator used posters (educational objects) of a Tyrannosaurus Rex skeleton to explain how social worlds are dynamic and evolve, but not always in congruent ways. One poster showed the skeleton in a vertical stance, while the other showed a horizontal stance. The educator explained how advances in disciplinary understanding found that the horizontal stance was no longer considered accurate, but portrayals of Tyrannosaurus Rex in popular media were inconsistent and often still used the horizonal stance. This instance showed how new discoveries and evolving knowledge requires educators to broker and re-broker knowledge and understanding of objects.

The usefulness of an object in brokering has limits and brokering can "fail" when the limits are exceeded. For instance, the educators often referenced a geological timescale (educational object) to relate chronological time periods (e.g., Cretaceous, Devonian) with rock layers and fossils. In one program, plastic rings were stacked chronologically with each ring showing dinosaur glyphs, and students answered related trivia questions (connecting talk). The stacked rings coarsely showed when dinosaurs came into existence relative to each other and time but provided no other details (e.g., climate, environment). So, when the educator referenced the timescale and asked students whether mammoths and Tyrannosaurus Rex coexisted, the object failed as a brokering device because its scope of usefulness was exceeded. Students could not answer the question because they could not glean the necessary information from the object and did not have sufficient background knowledge (e.g., mammoths lived during the ice age, which was too cold for Tyrannosaurus Rex).

Conclusion

Using boundary objects and forms of talk in concert can be a powerful way for museum educators to broker across worlds. However, we observed brokering was most successful, and could bridge students more deeply to disciplinary knowledge, when educators used all three forms of talk in conjunction with boundary objects. Heavy reliance on any one form of talk limits brokering opportunities. For example, connecting talk can promote factual recall and perceptual talk can address observed object features, but on their own each have limited conceptual depth. As well, successful brokering relied on the educators working within an object's scope of usefulness and dynamically adjusting their talk. Brokering is especially challenging in museum programs where educators often know little about students' prior knowledge and have limited contact time (Tran, 2008).

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International Society of the Learning Sciences

Building an Interdisciplinary Community of Emerging Scholars Amid the COVID-19 Pandemic

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Abstract: With increasing funding for synergistic research and educational solutions informed by multiple disciplines (e.g., learning sciences, computer science), there is a need to build the field's interdisciplinary capacity and nurture the next generation of researchers. In this poster, we share our approach to creating a community of emerging scholars inspired by the concept of *landscapes of practice* and based on a design thinking process. We discuss our approach's key design features, affordances, and challenges.

Introduction

The conference theme, "International Collaboration toward Educational Innovation for All," calls our attention to the importance of international and interdisciplinary collaboration. Indeed, a growing international consensus argues that complex scientific and societal challenges of the 21st century necessitate interdisciplinary ventures, which, in turn, require students and early career researchers to develop new skills and competencies for interdisciplinary approaches (e.g., International Society of the Learning Sciences, 2019; Science Europe, 2018). To have a robust next generation of our society, we need to pay more attention to the learning needs of emerging scholars.

Although challenges of interdisciplinary research work and careers have been well documented even before the COVID-19 era (e.g., Science Europe), the global pandemic created significant additional burdens and barriers especially for the next generation of researchers. In a recent report, Levine and colleagues (2021) identified multiple critical impacts of the COVID-19 pandemic on the early career educational scholars and doctoral students, including the diminished sense of connections and community-belonging with other scholars and absence of networking and professional development opportunities. The authors also reported the emerging scholars' concerns about limited support offered by their home institutions. Hence, there is a need for holistic and purposeful support systems that extend beyond single institutions and address the unique professional needs of interdisciplinary emerging scholars in educational research.

In this poster, we describe our process for creating a community of emerging scholars in the interdisciplinary field of learning and computer sciences. We envisioned this community drawing on the concept of *landscapes of practice* (Wenger-Trayner & Wenger-Trayner, 2015) and used the design thinking process (Stanford d.school, 2010) to distill the following features to guide our community-building work:

- Foreground diversity, equity, and inclusion (DEI)
- Center activities identified as needed by the members of the community
- Identify and implement activity feedback loops to ensure continuous improvement.

Design

Knowledge and identities of interdisciplinary scholars in today's global, interconnected society are shaped by their participation in various communities of practice comprising complex and dynamic landscapes of practice (Wenger-Trayner & Wenger-Trayner, 2015). Each community of practice has its own histories, traditions, and values and influences landscapes of practice and scholars' journeys through them differently. Hence, it is important to understand both how best to support interdisciplinary scholars and how that support might need to change over time. To this aim, the design thinking process with its five stages (i.e., empathize, define, ideate, prototype, and test; Stanford d.school, 2010) was particularly well suited for our task of community creation. It enabled us to understand and empathize with the needs of the emerging scholars, bring clarity to our vision for the community and define its features, generate ideas for possible solutions and prototype, test, and, importantly, iterate the ways of engagement with and support of the community members.

Creating the community with DEI at its core

We launched our emerging scholars' community in January 2021 through calls for participation via the organization's newsletter, website, direct outreach letters to the minority-serving institutions (MSI), and by asking previously funded PIs in the field to encourage their students and postdocs to join. We also emphasized and invited

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inclusion of scholars with disabilities (e.g., deaf scholars) and ensured appropriate support (e.g., American Sign Language interpretation) was available to them when needed. Although we initially conceptualized the community as primarily supporting researchers in the United States, we found that our community was fulfilling the needs of international emerging scholars. Currently, ten months after launch, our community has 123 members from four continents and ten countries.

Implementing need-based activities with feedback loops

After launching the community, we investigated emerging scholars' needs through conversations in our meetings, informal conversations, and a survey. At the time of the survey, our community had 80 members, and 32 responded to the survey. The majority of the respondents were graduate students, postdoctoral researchers, and faculty members. We found that our members needed more opportunities for networking and mentoring with established scholars as well as professional development opportunities (e.g., a session on grant proposal development). In response to the identified needs, we created the following three types of activities: a quarterly small group mentoring series with established scholars, professional development sessions, and affinity groups based on the common research interests of the participants.

To enable timely and meaningful iteration of the existing activities and the creation of new ones, we designed them to include feedback loops (e.g., a participants' survey after each mentoring session). Feedback loops integrate the three key features necessary for continuous improvement in education—Frequency, depth, and system contextualization (Park et al., 2013). These features help us respond to the feedback quickly and at the appropriate level. For example, a participant's feedback after one of the first mentoring sessions led to a change for future sessions and the implementation of a shared document for mentors and session participants to discuss potential topics and exchange contact information before the session. In our poster, we will provide additional details about the praxis of our group and its transformational effects.

Affordances, challenges, and next steps

As indicated by participants' feedback and continued attendance, our small-group mentoring sessions have been effective in providing valuable networking and learning experiences for the emerging scholars. For example, a recent participant reflected on his learning: "I especially loved the discussion on adaptive learning, how different people interpret adaptivity differently and what meaningful adaptivity should include." Although all of our organization-led activities were well-attended and received positive feedback (e.g., mentoring series), getting emerging scholars to assume responsibility for organizing and leading activities (e.g., affinity groups) has been challenging and represents an important next milestone for our community. Additionally, reaching and inviting in new scholars, those at MSIs, and those who do not have advisors and peers engaged in interdisciplinary work remains of paramount significance for our community, organization, and the field.

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International Society of the Learning Sciences

Examining the Complex Webs of Supports that Sustain Classroom Practices

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Abstract: Reform of educational systems is difficult, with changes often fading or diverting in unproductive ways. To disrupt this pattern and understand why unwanted practices persist and new ones distort, we need to consider how new and old practices are sustained at multiple levels. I discuss the framing and methodological findings from a larger study that investigated practices and supports within an undergraduate course for elementary education majors and discuss how these can inform educational change.

Introduction

Reform efforts in education are often ineffective, either not creating lasting change (Payne, 2008) or losing sight of the key constructs behind them (Dancy et al., 2016). A focus on "best practices" or "Evidence-Based Instructional Practices" reduces the problem of reform to a simple practice change without addressing the supports needed to sustain that change within the complex, contextualized, sociocultural structure that maintains classroom practices (Payne, 2008). In order to make lasting changes, we need to consider how the complex, multileveled system sustains patterns of classroom practices. For example, looking at teacher development framed with process-product logic cannot explain why change efforts fail (Opfer & Pedder, 2011). Reform efforts must consider what supports sustain classroom practices.

The research question I address in this poster paper is: how can systematic examination of patterns and the supports that sustain them inform educational change efforts? Within a larger study (see Zeller, 2022; Zeller, Under Review), I utilized the MoRe Institutional Framework (Anderson & Colyvas, 2021) to look within the classroom for patterns of practice and across multiple system levels for supports that institutionalize these practices. The MoRe Framework offers flexibility for researchers to investigate supports that sustain patterns at a specific level without excluding the influence of the other levels.

MoRe Institutional Framework

Institutional theory offers a framework for considering how patterns of practice are supported and sustained within classrooms. The MoRe Institutional Framework starts with Jepperson's (1991) definition of institutions as "social patterns" that are sustained through "self-activating social processes" that continually reproduce institutionalized patterns (pp. 144-145). The self-activating social processes manifest in various modes and at multiple levels of social systems (Anderson & Colyvas, 2021). Focusing on these modes of reproduction (MoRs) offers a view into why some patterns of classroom practices are sustained while others fade within the complex system of schools.

It is important to not only look at what reproduces desired patterns, but to also consider patterns that have been institutionalized and may stand in the way of desired reforms (Anderson & Colyvas, 2021). Focusing beyond idealized practices illuminates how the MoRs for multiple patterns of practice coexist and interact. Looking across continua of patterns that exist within classroom practice allows researchers to capture complex interplay between old and new practices and break down walls that stand in the way of effective reforms.

MoRs take many forms. Anderson and Colyvas (2021) identify categories of MoRs endemic to education systems including policy, stakeholder interests, identities, and roles. MoRs are distinct from the patterns they reproduce and can act at many levels within a complex system (Anderson, 2017). When looking at an undergraduate course, MoRs may act at levels ranging from individual to global. The sustaining force of a MoR can act at a completely different level than the pattern of practice manifesting at the focal level of a study.

The MoRe Institutional Framework provides a roadmap that helps navigate the intricacies of practices and the supports that sustain them. The investigation of both new and old practices creates a unique snapshot that captures change processes within a single timespan. The discovery of the MoRs that sustain patterns of practice creates the opportunity to leverage change efforts where they are most effective at creating lasting change.

Methods

This work examines the methodological implications of a larger study that leveraged case study and action research to deeply investigate practices within a science content course for undergraduate elementary education majors. In this paper, I explore how methods based on the MoRe Institutional Framework serve such an analysis.

The study investigated a physics and earth sciences course for undergraduate students over the Fall 2020 semester. It is part of the requirements for the university's elementary education major, which focuses on teaching

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in urban environments. The university is a large, R1 institution in the Midwestern United States and a minority-serving institution. The course team consisted of two co-instructors and two teaching assistants (TAs). The author was the physics instructor, while the other instructor was an earth science professor with many years of experience with the course. The course had 72 students and was held synchronously online, with three lab sections led by the TAs. Data collected includes course materials, field notes, and course team member reflections and interviews.

The data collected was initially sorted into either *practices* or *supports* for initial analysis. Data analysis utilized iterative coding rounds that created an in-depth account of how patterns manifested across the semester and supports (see Zeller, 2022). I coded the supports data using Anderson and Colyvas' (2021) categories of MoR. Once the initial practices and supports coding was complete, micro-cycles of iteration occurred as supports suggested practices and practices suggested possible supports. The iterative process resulted in final descriptions of patterns of practice and self-activating supports.

Findings and Implications

In the larger study, I investigated the practices and supports of the continua of science representation (Zeller, 2022) and student vs teacher centering practices. In this poster, I discuss the utility of my framing and methods to inform change efforts that came out of this wider work.

Examining patterns of classroom-system practice and the supports that sustain them inform educational change by illuminating the breadth and depth of how practices manifest within the classroom as well as how these practices are supported via multiple levels beyond the classroom. Within the examination of science-representation practices, a variety of patterns were observed. An overall science representation pattern carried across the course as a whole, but variations were found within the different structures of the course, the different disciplines covered, and the assessments as the semester progressed. Supports for these patterns included taken-for-granted, global-level disciplinary norms about what introductory courses cover and the content available to teach. Supports also included the individual-level roles of the instructional team and university-level shared stakeholder interests in the students as future teachers. The detail that resulted from the systematic investigation of science representation practices and corresponding supports created descriptions with both depth and breadth of what sustains practices and led to implications that informed changes made to the course. This shows that the application of these methods for other practices holds similar potential for informing and guiding change efforts.

The systematic examination of patterns and supports also led to the emergence of theory-rich patterns that created deeper understanding and showed opportunity for future work. Within the examination of teacher- and student-centered instructional practices, a pattern of students building more positive relationships with science emerged that was being supported by the student-centering practices observed. This informed how the patterns the study focused on were in turn supporting patterns in shifts of students' science identities. This illuminated an additional level of findings and implications about student-centered practices. A separate pattern related to the learning of the teaching assistants also emerged from the larger study. This emergent pattern pointed towards a potential new line of study of teaching assistant learning that focuses on learning through participation in course design. These emergent patterns further show the utility of systematic examination of patterns of practice and supports using the MoRe Institutional Framework.

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International Society of the Learning Sciences

Imagining Inquisitive Futures for Learners With Developmental Disabilities

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Abstract: Two activists with developmental disabilities designed a learning activity for learners with developmental disabilities. Their talk during design meetings was analyzed using discourse analysis (Gee & Green, 1998) to learn what imagined futures (Gutiérrez & Jurow, 2016) they assumed for the learners. These futures tended towards the inquisitive, and suggest that including activists in the development of learning activities for youth from the communities those activists represent could lead to fruitful new designs.

Introduction

Disabled learners, especially learners with developmental disabilities (DD), are an understudied community of learners within the learning sciences. This community is nonetheless an important part of human diversity, and one whose members deserve justice and equity in the study and design of learning environments, pedagogies, and beyond. One of the central rallying mottos of disability activist movements is "nothing about us, without us" (Charlton, 2000). This motto demands that in order to work justly and equitably, research about disabled people must be led by disabled people (Autistic Self Advocacy Network, n.d.). This study turned to adults with DD who self-identify as activists and have experience working with youth with DD in mentorship and/or teaching roles. Activists with DD are an ideal community of practice with whom to design learning environments because they frequently envision and work towards more just futures for people with DD.

How one imagines potential futures is informed by what has occurred in the past, resulting in imagined futures (Gutiérrez & Jurow, 2016). Therefore, it is important to trace the imagined futures that co-designers of learning activities, curricula, and environments assume learners could take up. Activists with DDs' imagined futures may differ from non-disabled researchers' and educators.'

This poster describes initial findings from a research study that asks: What imagined futures do activists with DD assume while designing a learning activity intended for non-speaking youth with DD? In order to answer this question, an adult activist with a DD engaged in a co-design process with the researcher, themself an activist with DD. This poster describes findings from the meetings between the researcher-activist and participant-activist, while they co-designed an adaptation of an inductive logic game. The researcher-activist and participant-activist are both Augmentative and Alternative Communication (AAC) users. AAC are systems of communication for people who cannot speak, such as text-to-speech devices.

Methods & Findings

In order to trace the imagined futures that activists with DD assume for learners with DD, this research took up discourse analysis, an analytic approach that claims knowledge is constructed via discourse between members of a social practice, rather than existing solely in the minds of individuals (Gee & Green, 1998). Discourse analysis was used to unearth the imagined futures contained in talk during the co-design process. This talk took place across three 90-minute design meetings, which took place on Zoom. The meetings were recorded and transcribed. By engaging in discourse analysis of design meeting transcripts, the researcher-activist learned what imagined futures appear in the co-constructed space between the two designers. Analysis of designers' talk provided a setting within the situated practice of designing for learners (as opposed to methods that occur outside of that process), which afforded unique insight into the activists' assumptions.

The pair designed an activity in which learners can use inductive logic to explore their interests. Design decisions sought to center the learners' ways of being in the world, and position assessment as an opportunity to validate what the learner learned, regardless of how that learning might compare to an external standard.

Data was coded using a grounded theory (Charmaz, 2006) approach. Initial coding delineated the kinds of talk that were present, and which were analytically relevant to the research question. Codes were applied to turns and sometimes to a set of sequential turns, based on emergent themes. While developing these codes, their definitions were recorded in a dictionary of codes.

Next, during focused coding (Charmaz, 2006), the researcher-activist sorted the coded turns into pasts and futures. Turns that did not hold any indication to past or present were left out of this coding step (and this poster). The researcher-activist wrote a memo describing the nature of the past or future contained within each turn and used these to develop a second set of codes describing the types of pasts and futures apparent in the talk.

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This representation revealed stated or implied chronological relationships between codes about the past and the future. This led to the development of several categories of imagined futures assumed in the design meeting talk.

Finally, a member check (Hammel, et al, 2008) was done on this report prior to submission to ensure that the participant-activist was not misrepresented.

Four explicit imagined futures (Validating Futures, Accessible Futures, Inquisitive Futures, and Ableism-literate Futures) and three implied imagined futures (Invalidating Futures, Compliance-centered Futures, Learning-restricted Futures) emerged.

Explicit imagined futures were directly apparent in the talk. For example, in Meeting 3, Turn 32, the participant-activist says, "The one thing I would add to what you wrote is that preferences can change over again, especially depending on how long you call the game to be." Here, they are positioning an imagined learner in an Inquisitive Future, in which the learner might change their gameplay over time to follow multiple lines of inquiry according to their interests and preferences.

Implied imagined futures were not directly described, but were hinted at through descriptions of pasts. For example, in Meeting 3, Turn 7, the researcher-activist says, "Yes. It made me think of algebra class from middle and high school and how much easier it would have been if they explained that stuff [inductive logic] first." This turn was initially coded as "Statements about ourselves that are also about imagined learners," and secondarily coded as "Learning-restricted Pasts." The turn refers to drill-based learning environments the researcher-activist struggled in. A specific future is not named, but the nature of imagined futures as informed by past experiences suggests a Learning-restricted Future.

Discussion

On a whole, the activists in this study imagined validating, inquisitive futures for learners who were given the opportunity to direct their own learning. These futures were explicit in their talk while designing. A number of less-preferred futures were implied, but talk about those futures ultimately fizzled out before it began. Interestingly, the futures that were explicitly talked about had more directly positive overtones, whereas those only implied, through discussion of pasts, tended towards the negative. This is surprising due to the tendency for activists to engage in critical work, pointing out the flaws in the various systems, including educational, that they find or found themselves within. Here, instead, they focused on the imagined futures they preferred, rather than critiques. These explicit imagined futures were embedded in the process of design.

The inquisitive, learner-centered imagined futures explicit in activists' design talk may differ from those non-disabled educators and researchers take up. Working with activists from the non-dominant communities learners are members of may lead to valuable new insights that push educational design towards more hopeful imagined futures.

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International Society of the Learning Sciences

Strategies to manage scientific uncertainties for productive sensemaking: Case studies from Korean and American classrooms

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Abstract: This study aims to explore instructional strategies to manage students' scientific uncertainties in sensemaking activities in the science classroom. Sensemaking activities in four science teachers' classrooms were analyzed for this study, two from Korea and two from the USA. The analyzed data include video-recordings of classroom discourses. Six themes about features of teachers' instructional strategies that supported students' productive management of the uncertainties were identified through analysis.

Introduction and Background of the Study: Sensemaking and Uncertainty

This study aimed to explore features of instructional strategies to support students' management of scientific uncertainties they encounter in sensemaking activities in the science classroom. With a critique on teacher-centered type of classroom, science education studies have widely agreed on enacting practice-focused curriculum in the science classroom (e.g., National Research Council, 2012). The fundamental goal of epistemic practices of scientific communities can be described as sensemaking, which refers to "a dynamic process of building or revising an explanation in order to "figure something out" –to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one's understanding" (Odden & Russ, 2018, pp. 191–192). Researchers have designed curricula and pedagogical strategies to help students make sense of scientific concepts (Schwarz et al., 2021); however, it is not clear whose sense do students make: Is it the scientists', the teachers', or the students'? We notice that students encounter epistemic and content uncertainties entangled together in sensemaking processes. If our goal is to help students develop their own knowledge that makes sense to them so they are capable of explaining a phenomenon, students' scientific uncertainty should be considered as a significant resource in the sensemaking process.

With the view of scientific uncertainty as an umbrella term which includes *content* and *epistemic* uncertainties (Kampourakis & McCain, 2020), this study aimed to examine teachers' supports to manage these uncertainties. Content uncertainty refers to uncertainty regarding *what* knowledge to interpret a phenomenon. Epistemic uncertainty refers to uncertainty regarding *how* to use and generate knowledge to interpret a phenomenon on and *why* the interpretation is valid and reliable (Chen & Qiao, 2020). Building on the definition of scientific uncertainties, we explored the following research question: How can teachers support students to productively manage these uncertainties, which refers to managing uncertainties through meaningful practices in the science classroom? The current study intends to contribute to dealing with this issue by examining scientific uncertainties that emerge in students' sensemaking processes and teachers' instructional strategies to effectively use students' scientific uncertainty as a resource to foster them to make sense of phenomenon, data, and argument.

Research design and methods

This study reflectively analyzed four science classrooms, two in Korea and two in U.S., that adopted sensemaking activities. While two Korean science teachers taught at middle school level, two U.S science teachers were at upper level elementary school. The main data sources of this study were 23 video recordings of the classes and transcripts of discourse in the classes: elven lessons collected from Korean classrooms, twelve lessons collected from U.S. classrooms. In the data analysis, to grasp features of each class, we first iteratively watched the video recordings and read the transcripts. Then, we divided the data into events with the cues of changes in a classroom sessions and discussion topics. The next step dedicated to initial coding of events. Starting from the sign of uncertainty in each event, core concepts, function of uncertainties and teachers' responses were coded. Then, we interpreted processes of managing uncertainties and teachers' responsive supports on these processes. Previous literature and codes were adapted in the coding process (e.g., Chen, 2022; Jordan & McDaniel Jr, 2014). Categories and definitions of the management of uncertainty as a pedagogical resource are shown in Table 1. Last step of the data analysis was to compare the coded events and identify across our database patterns concerning teachers' supports for students' management of scientific uncertainties. We described these patterns as potential themes concerning how science teachers mange scientific uncertainties in sensemaking in the classroom.

Table 1

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Coding scheme for uncertainty management in modeling

Uncertainty Management	Definition
Raising	Raising uncertainty involved any action and utterance applied to elicit students' awareness of an uncertainty to (1) open the problem space, (2) seek multiple alternative opinions, (3) express doubts, (4) state different opinions, (5) disagree with other opinions, or (6) acknowledge non-understanding during discussion
Maintaining	Maintaining uncertainty involved any action and utterance to (1) support, (2) elaborate, (3) rephrase, or (4) increase doubts
Reducing	Reducing uncertainty involved any action and utterance to (1) request more information/an explanation, (2) make a connection between the discussed uncertainty and past experience/prior knowledge, (3) seek a consensus, (4) ask for clarification, (5) clarify doubts, (6) refer to expert resources/authority figures, or (7) suggest a solution
Ignoring	Ignoring uncertainty involved any action or utterance to (1) avoid, (2) disregard, or (3) reject the opportunity to discuss the uncertainty.

Findings

Six themes of teachers' instructional strategies to productively managing scientific uncertainties for sensemaking were identified through our analysis. (a) problematize problems regarding not only what students know (content uncertainty) but also how to explain (epistemic uncertainty), (b) use scientific uncertainty to encourage students to re-collect evidence, (c) use scientific uncertainty to clarify what students learned and construct more sophisticated explanation, (d) encourage students to utilize scientific practices to resolve scientific uncertainties, (e) use scientific uncertainties to reflect on students' reasoning, and (f) use scientific uncertainties to plan further sensemaking processes. Due to limited space, we will present specific explanations of the cases at the conference.

Discussion

This study explored features of instructional strategies to support students managing scientific uncertainties in their sensemaking processes. In the practice-focused curriculum, students are expected to position as agents in sensemaking of the natural world (NRC, 2012). As scientists do, it is evident for students to encounter numerous uncertainties in their sensemaking processes. Instructional strategies are needed to support students to identify, manage and resolve uncertainties. By presenting features of these instructional strategies, this study contributes to developing teaching for students' engagement in sensemaking in the science classroom. Further, this study focused on management of scientific uncertainties, which encompass content uncertainties as well as epistemic uncertainties. This allowed to identify more diverse uncertainties that students struggle to resolve in the science classroom, and add more cases and expand the existing discussions of developing instructional strategies to support uncertainty management in the science classroom.

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Designing to Enhance Academic Buoyancy: A Snapshot of First Steps in a Second Level School Setting

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Abstract: Academic buoyancy generally refers to students' ability to respond to everyday challenges in academic settings. This paper presents insights in to a design-based research pilot intervention that is informed by a multi-ontological framework that included conceptual pillars of: engagement, collaboration and reflection. Preliminary findings are presented, the emergence of co-creation as a core element of the success of the pilot is explored, and next steps discussed.

Introduction and Conceptual Background

Clearly identified by UNESCO as Sustainable Development Goal 4 (UNESCO, 2021) the provision of quality education opportunities is critical to the development of our global citizenship. However, in order to support a sustained engagement with education, student adaptability, particularly in the form of academic buoyancy, has a significant role in how individuals respond to the challenges they will experience (Martin & Marsh, 2009) both within and outside formal educational settings. Consequently, there is a clearly established need to develop innovative pedagogically informed initiatives, programmes and interventions that aim to enhance the academic buoyancy of second level students (Edwards et. al, 2007) as they move ever closer to post compulsory education and the world of work where the link between achievement and buoyancy (Martin et al. 2016) is even closer.

The conceptual framework that underpins this work has three pillars. Firstly, collaborative activity is seen to provide students with opportunities to challenge themselves and to develop the ability to be discerning about ideas and content (Hase, 2015). Second, through such collaborative exchanges students are more likely to demonstrate enhanced engagement with both content and social interaction with their peers (Shneidermann, 1998) creating opportunities for positive learning outcomes (Trowler and Trowler, 2010). The third pillar, reflection, seeks to foster student' capabilities for critical thinking and self-evaluation resulting in a more buoyant learner.

When students actively participate in directing their own learning, agentic engagement can occur (Lawson and Lawson, 2013). As an empowering process this can can have a positive impact on participant engagement with a pedagogical intervention. A core aim of the intervention in this study is to produce lifelong learners capable of working collaboratively, assessing their own learning and monitoring their performance. In conjunction with collaboration, reflective practice provides students with opportunities to develop the capability for critical thinking and ongoing self-evaluation thus improving the likelihood of enhancing their academic buoyancy (Martin, 2013). In order to promote awareness among the students, reflection emanated as a keystone of the intervention. Reflection seeks to foster students' capabilities for critical thinking and self-evaluation resulting in a buoyant learner.

This paper reports on the outcome of a Design-Based Research (DBR) (DBRC, 2002; Barab & Squire 2004) pilot project and an emergent need to develop a pedagogical framework to support a curricular co-creation process particular to the development of academic buoyancy with second level students.

Methods

Employing a DBR methodology, this multi-cycle study seeks to iteratively design and refine an innovative pedagogy that supports the enhancement of second level students' academic buoyancy set in the real-work messiness of a second level school setting (Barab and Squire 2004). Such pedagogy will be a guide rather than a proscriptive learning process. Additionally, it will promote higher order thinking skills and the development of self-regulated learners (Shvarts and Bakker 2019). Given that this was a pilot study and the lead researcher is an in-service teacher, convenience sampling was employed for the recruitment of participants into this study. A data collection plan was designed that included the administration of a pre- and post-questionnaire, students' artefacts, practitioner observations and student reflective journals. A process of data triangulation informed and contributed to a thematic analysis.

The lead researcher implemented the pilot intervention with a cohort of second level female students (N=51) with an average age of 15.5 years enrolled in yearlong an elective programme in an Irish secondary school called the Transition Year Programme. The module was delivered through six, single weekly classes of 40 minutes duration and included an introductory session involving co-creation of the main areas of concern for the group

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and in doing so, establishing learning outcomes for the module that related to key characters of academic buoyancy: metacognition, reflection, goal setting and decision making (Martin & Marsh, 2009).

Preliminary Findings

The conceptual pillars of engagement, collaboration and reflection are used here to frame the results of this pilot intervention. Firstly, we found, particularly through our thematic analysis of the student reflections, that students' perceived usefulness of the module and individual classes influenced their level of engagement. It was evident that this was linked to the role that students played in the co-creation of the module which ensured that the outcomes were reflective of the needs of the students. This was corroborated through the observations of the lead researcher who is an experienced teacher and noted a positive change in the classroom atmosphere, teacher-student relationship and inter-student relationships.

Secondly, throughout the six-week pilot intervention students worked in groups of 3-5, depending on the physical layout and the number of students in the class group. Participating students developed a range of social soft-skills as an outcome of their engagement with collaborative aspects of the module despite social distancing restrictions imposed as a consequence of COVID-19.

Thirdly, triangulated data highlighted a relationship between student agency in the co-creation of the module, student engagement and collaboration facilitating a mechanism for students to meaningfully address and design for their own needs as part of an ongoing process of selective practice.

Discussion

The preliminary findings of this pilot study indicate that the approach taken has the potential to enhance the academic buoyancy of second level students. The initial conceptual framework afforded an opportunity to develop an informed, real-world, experiment and at the same time an opportunity to determine the proximal workings of the design. It has become clear to the research team that students played a pivotal role in the design and development process of this module through their participation in a consultative, student-centred learning experience. This process of co-creation, initially not considered a component of the conceptual framework must notw be considered an essential pillar of its initial success. Therefore, next steps include an explicit enabling of the collaborative social learning environment afforded by the co-creative approach embodied in this pilot study.

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International Society of the Learning Sciences

Student motivation in science learning with embodied Computational Thinking

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Abstract: In an on-going multiple-case study, we investigate the use of unplugged, embodied Computational Thinking activities to learn topics within biology and chemistry. We utilize Educational Design Research in collaboration with 4 teachers at 2 upper secondary schools, focusing on students' experience and how the activities affect their motivation for learning the topics in question. Tentative results indicate that students find such activities fun, allowing them to address curricular content in new ways, but also confusing.

Introduction: Why use embodied Computational Thinking to learn science?

Computational thinking (CT) is argued to be of prime significance for all citizens in the 21st century (e.g. Vuorikari et al., 2016; Wing, 2006). Wing's definition of CT is often cited: "[T]he thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2011). This definition determines CT as algorithmic problem solving without reference to specific domains, implying that CT is a set of abstract skills that can be generally applied – in Wing's words "a "universally applicable attitude and skill set" (Wing, 2006) that can be used to learn and investigate any subject or discipline. Some dispute remains as regards which skills the set comprises, but decomposition, logical data analysis, modeling, algorithm design (including sequencing in step-by-step procedures), automatization, and generalization are usually listed (e.g. Chongtay, 2018; Shute et al., 2017). A large strand within the literature emphasizes that CT can be performed 'unplugged', that is, without the step of coding the designed algorithm into a computer program (Caeli & Yadav, 2020; CS Unplugged). The claimed pedagogical advantage is that students become familiar with the steps of the problem-solving method without the additional complexity of having to learn a code language. This is particularly relevant when CT is utilized to learn other disciplines than computer science. Here, premature introduction of coding may confuse learners and affect their motivation for learning both CT and the discipline in question (Chongtay, 2018).

The mainstream understanding of CT as a set of abstract skills is challenged by research within the fields of learning and practicing arithmetic, logical, and algorithmic thinking. Research in situated learning (Lave, 1988) and embodied cognition (Abrahamson & Bakker, 2016; Johnson, 1987) show that such thinking processes are learned situatedly and crucially involve embodied cognitive processes. As these thinking processes are adjacent to or part of CT (Wing, 2011), the implication is that CT skills are also situated and will concretize differently within different disciplines. It is further to be expected that their development and use within other disciplines can advantageously be supported – both cognitively and motivationally – by involving embodied activities.

In the present on-going multiple-case study (Yin & Yin, 2018), we investigate the use of unplugged, embodied CT-activities to learn topics within biology and chemistry, acknowledged by researchers (e.g. Düsing et al., 2019) and teachers in practice to be particularly difficult for students to learn. The activities engage the CT skills of decomposition, modeling, sequencing, and generalization. We focus on how students experience these embodied CT-activities, and, in particular, how they affect their motivation for learning the topics in question.

Methodology

The advantage of the multiple-case approach is that it provides opportunity to achieve a high degree of both ecological and external validity. Our sample involves four teachers from two urban upper secondary schools in Denmark and in all six classes of biology and chemistry. The average class size is 26 students. The multiple-case study utilizes Educational Design Research (McKenney & Reeves, 2014) and activities are therefore developed in collaboration with the teachers in a series of iterations. Activities are designed for the individual classes' curricular content and the teachers share their materials for inspiration. Content themes are carbon cycle, nitrogen cycle, phosphorus cycle, chemical analysis, protein synthesis, and balancing chemical equations. All tasks address 'algorithmic processes' through unplugged, embodied activities. In the carbon cycle task, for example, students take on the role of a carbon atom and move around different stations to simulate the dynamics of the cycle. This involves decomposition of the carbon cycle, embodied modeling of the dynamics, and sequencing. For instance, from the Atmosphere station, students may be absorbed into a plant leaf and move to the Plant station. During each move, students note stage and form of carbon. Based on the movements outlined in their notes, they produce a diagram of the carbon cycle and the route of the carbon atom through the cycle. Comparing the routes allows

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them to generalize their model. Another task utilizes LEGO bricks to model the balancing of chemical equations. Students decompose the reaction by letting bricks in different colors represent atoms. They then build reactants and products and reconcile reaction equations by counting bricks in each color on both sides. Finally, they list the sequential steps needed to determine the reactions and try to generalize the list for further balancing tasks.

To evaluate students' experiences, we used self-report with open questions supplemented by classroom observations and informal interviews. In the self-report, students were asked about their positive and negative experiences and whether the activity made the content easier to understand. Observations focused on situations in which students were engaged and on situations where they seemed confused or demotivated. In short (1-4 minutes) interviews, students were asked how they experienced a given situation, why it was or was not motivating.

In the analysis, we searched for signs of how embodied involvement impact students' self-reported understanding of the science content and of motivation. In our search for signs of motivation, we did not limit ourselves to one theory but were open to statements being interpreted inductively in different directions, especially interest (Hidi & Renninger, 2006), self-efficacy (Bandura, 2001), and utility value (Eccles & Wigfield, 2020).

Tentative results

The very tentative results suggest that students find embodied CT-activities fun and interesting, allowing them to address curricular content in new ways. At the same time, many students also report that the CT activities are confusing. Students are challenged as regards experiencing the full picture of the processes, as they tend to focus on specific elements. Besides, they are challenged in making connections to textbook content and in generalizing their enacted algorithmic processes. They need support to understand physical models of processes.

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Informing Advanced Digital Technologies' Design for Refugee Language Education in Greece

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Abstract: This paper focuses on needs finding for computer-assisted language learning for vulnerable population living in difficult circumstances. It presents semi-structured interviews with teachers and volunteers working with refugee students in Greece. It explores their needs regarding digital technologies in teaching and learning of Modern Greek as a second language. The findings outline the context of technology and Greek refugee language education, the capacity that teachers have, as well as the challenges within this context.

Context

This paper aims to explore the ways that advanced digital technologies, such as mobile devices and applications, and artificial intelligence tools, can enhance second language learning and instruction within the context of refugees in Greece. Refugee language education in Greece is mostly supported by non-governmental organizations, community-based organizations of volunteers and some training language programs that were designed by Ministries, Municipalities and Universities (Kantzou et. al, 2017). The use of digital technologies in such a context appears to have promising results, according to McCaffrey & Taha (2019) who studied the use of smartphones by recent refugees in the US with the purpose to adapt and make sense of the world moving across places and named languages.

Objectives

The research questions associated with this small-scale study include the following:

- What are the needs of refugee language teachers within the Greek context?
- What technology design features would better support refugee language education in Greece?
- What are the potential challenges for teachers working with advanced digital technologies?

Methods and data

This paper follows a qualitative case study methodology. Four semi-structured interviews of approximately 1 hour each were conducted with teachers and volunteers of elementary or middle school educational background, working in informal settings with refugee students in Greece and having an average of 4.25 years of experience in the field. Teachers were identified through snowball sampling during the Fall of 2019. The interview included questions about: Language course structure and material, Use and access of digital technology tools in educational practice, Use and access to digital technologies crafted for language education. The interviews were analyzed following thematic coding analysis. Member checking was realized for validity purposes.

Table 1 shows the main categories and overarching themes that emerged, supported by sample excerpts.

Table 1

Data analysis categories & overarching themes with sample interview excerpts

Overarching Themes	Categories	Sample Interview Excerpts
Technology use in the Greek refugee language education	Limited access to tablets	*"We have used tablets (...) Not enough tablets for all students."* (Teacher 1)
	Access to websites	*"I was bringing my laptop to the camp to show them images and for sounds on YouTube"* (Teacher 3)
	Use of mobile phones	*"Adult students using their mobile phones"* (Teacher 3)
	Achievement of communicative goals	*"(Technology) provides different ways to communicate with people without a common language (...) Really important to achieve communication"* (Teacher 2)
Teachers' needs and capacity	Minimal or no pedagogical training provided	*"We didn't receive formal training about how to teach Modern Greek in these students. Experience taught us most of the things and we are still learning"* (Teacher 4)

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regarding digital technologies	Availability of digital applications	*"There aren't many applications for teaching Greek as a second language. Comparing to English, for example."* (Teacher 1) *"There are many applications for refugee language education, e.g. AR scan to translate and something like Google translate"* (Teacher 3)
Design features of advanced digital tools	Potential of using AI	*"Yes, these tools seem to be very helpful (…) It would be amazing if we could use them in the class. Students would be very happy."* (Teacher 3)
	AI tools to target communication goals	*"(…) important to focus on dialogues, communicative situations, e.g. dialogues/phrases/words on the super market, when buying coffee, etc."* (Teacher 1)
	Digital tools in native language of the students	*"Some students do not know how to read, so they would appreciate an interface that is visually friendly and that would guide them on what to interact with the tool and complete their tasks in other ways and not with text."* (Teacher 4)
Challenges using advanced digital technologies in this context	Digitally illiterate students	"Although the young kids are familiar with digital tools, there are a lot of adults who don't own laptops, they don't know how to use it (…) I can't imagine them using advanced technologies right now" (Teacher 3)
	Lack of a common language for communication	*"I was using English, but they didn't know/ I was speaking only through the translator (…) but the communication was difficult."* (Teacher 3)
	Instability and population movement in the refugee camps	*"(…) very unstable situation. It is difficult to form relations with students, because they are moving, and they are coming and going."* (Teacher 1)
	High cost of AI-enhanced tools	*"There is not enough funding to buy not only AI enhanced equipment, but not enough funding for computers or tablets. for the large number of students".* (Teacher 4)
	Challenging conditions at the camps	*"At the camps, in the beginning, there were no buildings. We were doing our work in tents. People were living (…) with no electricity, water or any of the comfort of a house (…) These conditions did not make our work easy"* (Teacher 2)

Results

Findings illustrate the current context of technology use in the Greek refugee language education, the needs and the capacity that teachers have, the applicability of advanced digital technologies, and its potential challenges. The findings show that websites, mobile applications, or platforms are used and are considered helpful to achieve better communication. Participants highlighted that digital tools' design should aim in improving everyday meaning making and being accessible in the native language of the users. Teachers reported minimal or no training in incorporating digital tools in their instruction and subsequently, they lack proper information about the availability of digital instructional tools for this specific context. About the potential challenges, they mentioned: digitally illiterate students, lack of a common language for communication, high instability and refugee population movement, high cost of the AI-enhanced tools, challenging weather and infrastructure conditions.

Discussion & scholarly significance

Advanced digital technologies seem promising, beneficial and are viewed positively. However, there are more fundamental needs to be addressed alongside the potential of using innovative digital tools, such as the environmental challenges and the inadequate teacher training. Overall, this paper addresses some design considerations for devices, platforms, and applications of second language learning in complex settings.

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Teacher Discourse in Scaffolding a Knowledge Building Group：A Case Study

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Abstract: In a group of one teacher and 30 students engaged in collaborative knowledge building, the teacher's 165 posts in Knowledge Forum were parsed out for analysis. A coding scheme was developed to categorize the posts into three patterns, namely, *managerial, low order, and high order*. While managerial and low order discourse seemed inevitable, high order discourse was more pervasive. The posts also suggested a shifting role of the teacher in scaffolding knowledge building over time.

Introduction

One important goal of a Computer-supported Collaborative Learning (CSCL) environment is to foster productive discourse among the learners. A wealth of studies has examined the effectiveness of a designed environment through the analysis of student discourse; however, very few studies have examined the role of teacher discourse in fostering productive discourse in CSCL environments.

Knowledge building posits that a learning community shall look ideas as improvable and get them enriched, revised and refined through productive discourse in Knowledge Forum® (KF), a technology-supported discussion platform. However, people often find it difficult to implement the knowledge building approach because there are no scripts to follow. In knowledge building, learner agency is often stressed and the role of a teacher is described as a facilitator or student helper. While a teacher is suggested to shadow its existence and let the students fully play their potentials in progressive inquiry, it is important to investigate how a teacher can achieve such a role. This poses a dilemma particularly in the Asian educational context in which a teacher is often regarded as the authority and expected to assume much responsibility in leading the class.

To obtain productive interaction and quality discourse, teachers should try to ask more high-cognitive-level questions. Wang and colleagues (2016) identified a few examples of teachers' classroom questions that have promoted knowledge building principles. It is also found that higher-order-thinking questions could foster student's deeper thinking and develop their understanding; and when questions are responsive to students' earlier contributions and builds on from them, they can encourage elaborated interaction and promote productive talk activity (Chin, 2006). Traditionally, teachers' questioning practices are exercised verbally with students on face-to-face classroom occasions; however, many CSCL environments are usually mediated by discussion tools where written messages are exchanged and recorded asynchronously. Therefore, it is important to investigate how a teacher may interact with his students in a discussion forum, aiming to prompt the whole community towards collective knowledge advances through productive and deep discourse.

Two research questions are addressed: (1) What characterizes the teacher discourse in Knowledge Forum when knowledge building approach is implemented in a group of Year-1 university students? (2) Are there differences on teacher discourse over time (Semester-1 versus Semester-2)?

Method

This study is based on an earlier knowledge building study in Shanghai, China (Lei & Chan, 2018), which showed students in the knowledge building environment were engaged in productive knowledge building discourse and made collective knowledge advancement. For this study, the teacher's KF posts are retrieved separately for analysis.

Over two semesters and with a group of 30 students engaged in knowledge building, the teacher contributed a total of 165 KF posts, either in the form of a KF note or a KF annotation. A KF note is typical in the forum, i.e. when a post is composed and submitted, it will appear as a tiny square ( ) in the working space where every one of the community could see. While an annotation will not appear in the open space, it is an attached message to an existent note ( ); only when a note is clicked open, the annotation can be seen. All the findings are based on the analysis of the teacher's posts in KF; students' KF notes, especially those prior to or build on the teacher's posts, are frequently revisited in order to understand the interactional contexts.

Findings

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It was found that the teacher wrote 38 notes and 127 annotations over two semesters. Overall, he did not make his presence very conspicuous (posting notes) in KF; he wrote more annotations which were embedded within the students' notes. In other words, student to student interactions were more salient in the dataset.

A qualitative analysis was conducted and teacher's discourse was ultimately categorized into three patterns in terms of its nature and purpose:(1) *managerial*, to encourage and maintain students' KF writing; (2) *low order*, to invoke students' low-cognitive, quick responses; (3) *high order*, to promote knowledge building principles, i.e. involving students' collective responsibility in pursuing new knowledge. Table 1 shows some examples.

Table 1

Examples of managerial, low order and high order teacher discourse

Categories	Examples (excerpts)
Managerial	[Oct 30] Some of the questions concerning technological environment and its impact on business: such as how technology affects employment; how technology helps an industry shift? … [Sep 10] Clive, when you contribute a note, we all see your name under the small icon. So you don't need to indicate your name at the end of the note…; [Oct 05] Yes, I like your explanation and example. Continue your effort on KF. We learn together!
Low order	[Oct 23] How to spell the word "基础设施"(infrastructure) ? [Nov 28] Try to get more solid data to support your ideas and follow the report format [Sep 22] What do you mean "not powerful enough"? …
High order	[Sep 29] You raised a good question – why there is an economic miracle? Could you and the other students find answers from some sources…? [Nov 28] I suggest you read the SWOT note written by Wang Qiaoyan. Also, you can try to summarize the findings … [Mar 29] when you and your group members put the notes together, could you tell us why these clusters of notes are good? Or you can tell us what your group understood previously, and now do you have any new understanding?

Teachers' posts are partitioned into semester-1 and semester-2 discourse according to the date. Table 2 shows the frequencies of managerial, low-order, and high-order teacher discourse in two periods of time.

Table 2

The frequency and percentage of managerial, low-order, and high-order discourse over two semesters

Time \ category	Managerial	Low order	High order	Total (100%)
Semester-1	30 (26.8%)	26 (23.2%)	56 (50%)	112 (100%)
Semester-2	12 (22.6%)	10 (18.9%)	31 (58.5%)	53 (100%)
Whole Year	42 (25.5%)	36 (21.8%)	87 (52.7%)	165 (100%)

Implications

Similar to teachers' classroom questioning, teachers' forum discourse also needs to orchestrate students' inquiry rather than prescribing what they should do (Wang et al., 2016). Traditionally, a majority of teacher questioning is managerial or low-order; however, high order discourse needs to be prevalent in order to stimulate knowledge building principles and productive student discourse. The teacher's posts were significantly decreased in semester-2, which suggested less teacher presence and more student-to-student interactions in the progressive inquiry process. There is a shifting role of teacher and a turning of high level agency to the students over time.

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Grounded Creativity

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Abstract: We used complex conceptual systems theory to analyze conceptualizations of creativity in the context of a course in which students engaged in group projects to develop creativity tests and creativity games. Using semantic network analysis, we were able to identify conceptualizations of creativity and emergent practices. Groups which developed games tended to conceptualize creativity as organic, while groups which created tests conceptualized creativity as an object or state. Different practices were emergent from each conceptualization.

Background

In constructivist perspectives, learning is a generative and creative process. This paper uses complex conceptual systems theory to argue that practices in creativity emerge from conceptualizations of creativity. The Creativity Landscape conceptual framework (Donaldson, 2016, 2018) describes the rich landscape of creativity research by identifying key tenets of the construct of creativity and then categorizing them into four domains: **creative environments** (generativity, playfulness, reduced regulation, and lowered inhibition); **creative mindsets** (perseverance, openness to experiences, tolerance of ambiguity, autonomy, creative self-efficacy, and mindfulness); **creative processes** (identification of problem, framing, preparation, idea generation, incubation, unconscious cognition, insight, and refining); and **creative cognition** (divergent or convergent thinking, including metaphor creation, perspective taking, analogical thinking, frame creation, conceptual combination, abductive reasoning, synthetic thinking, pattern recognition, and elaboration). Each domain is characterized by practices that through their interplay and dynamic interaction help demonstrate how one's *conceptualization* of creativity impacts the subsequent materialization and manifestation of creativity. Optimal facilitation of creativity involves a balance among all four categories, as well as a mix of practices from within each category. The Creativity Landscape framework was applied to analyze a project-based learning task that had groups design unique and original board games or creativity tests. Complex conceptual systems theory (Donaldson & Allen-Handy, 2020) views conceptualizations of creativity as complex systems, and practices in creativity as emergent from different conceptualizations. We investigated the relationship between conceptualizations of creativity and emergent practices, fully exploring how the operationalization of creativity influenced the approaches and actions that were enacted in the genesis of these artifacts.

Methods

Third-year university students in a course for the Creative Studies minor were put in 14 small groups to work on semester-long creativity projects. Half of the groups chose to develop creativity games, and half developed creativity tests. Each group created a document describing in detail the game or test they created, including the creativity concepts and literature which informed their designs. We collected these documents and coded them in MAXQDA for creativity practices as organized through the Creativity Landscape framework, as well as conceptualizations of creativity using categories necessary for complex conceptual systems analysis—namely, metaphorical and non-metaphorical characterizations of creativity. Coding resulted in 257 codes covering 2,331 coded segments. We then calculated correlations between pairs of codes within each category to determine the likelihood that any pair of codes would appear within proximity in the data. We used these correlations to construct symmetrical correlation matrices which we then entered into the UCINET and NetDraw software where we constructed semantic network maps and used Girvan-Newman cluster analysis (Girvan & Newman, 2002) to identify clusters. Clusters of metaphors were interpreted as conceptual metaphors, and clusters of non-metaphorical characterizations were interpreted as conceptual stories. The codes belonging to each cluster were then collapsed in MAXQDA, and correlation matrices were constructed to determine the relationships between conceptual metaphors, conceptual stories, and practices emergent from conceptualizations of creativity.

Findings

Our analysis resulted in a semantic network map of conceptual elements and practices correlated at the $p<0.05$ level, including 5 clusters at $Q=0.324$ (see figure 1). The red cluster frames creativity through a set of four conceptual metaphors (*Creativity is a Living Organism*, *Creativity is Physical Action*, *Mind is a Computer*, *Mind is Physical Action or Enactive*) and one conceptual story (*Evidence-Outcome*). This conceptualization of creativity was most relevant for the creativity games groups. The use of this frame led to the emergence of particular

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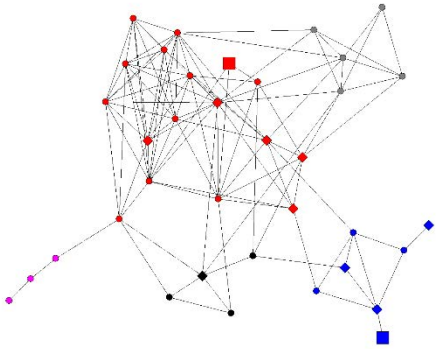
practices. Creative cognitive processes of conceptual combination and frame creation were emphasized. This perspective includes developing a creative environment which promotes generativity, lowered inhibition, and playfulness. The only creative mindset involved here is autonomy. Practices in terms of creative processes were emergent in this conceptualization, including identification of a problem, preparation, incubation, unconscious cognition, and insight.

Figure 1

Network Map of Conceptual Elements and Emergent Practices



The blue cluster was most relevant to the creativity tests groups, and included the *Creativity is Physical or Environmental State* and the *Creativity is an Object* conceptual metaphors, along with the *Contextual-Vague* conceptual story. Elaboration was the only form of creative cognition emergent in this conceptualization. No creative environment or creative mindset practices were emergent, but creative processes of framing and refining were emergent. The black cluster was relevant to both the creativity test and creativity game groups. This conceptualization uses the *Process-Personality* conceptual story, but includes no conceptual metaphors. Emergent creative cognition practices were limited to pattern recognition in this framing of creativity, as well as creative mindset practices around creative self-efficacy along with creative processes of idea generation. The gray cluster was relevant only to the creative games group. This cluster included no framing of creativity through conceptual metaphors or conceptual stories, but consisted of four creative cognition practices (synthetic thinking, analogical thinking, and perspective taking), collaborative creative environment practices, and the creative mindset practice of tolerance of ambiguity. The pink cluster was also only relevant to the creative games group, and included no creativity framing. This cluster included two practices related to creative mindset (openness to experiences and perseverance) and practices to facilitate creative environments which are unregulated or have lowered regulation.

Implications and Discussion

We identified salient themes and significant findings in several domains across both projects. For the creativity games, metaphorical perspectives related to the life-like and organic nature of creativity significantly impacted practices related to creative cognition, processes, and environment. This perspective led to the designing of game-play elements with lower regulation that featured tasks related to generating conceptual combinations along with the eliciting of insight. Analysis revealed different patterns for groups developing creativity tests, with metaphorical perspectives related to the physical properties and environmental elements of creativity impacting practices related to creative process and cognition. The test questions that were designed emphasized framing, refining, and elaboration of responses in a much more structured way. Perspectives related to the creative mindset were apparent in both projects, with practices related to cultivating creative self-efficacy (confidence in one's competence) inherent in responses processes for both. A takeaway from this analysis is that the labels "test" vs. "game" significantly influenced the perspectives of the groups as they designed their projects and influenced the practices that they put into place in the attempt to measure or generate creativity amongst their participants.

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"You Are Not Valued As They Said": Re-constructing A U.S. Higher Education Environment Negotiated By an International Student

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Abstract: This paper responds to the call for examining and promoting a more diverse and equitable education environment by shedding light on an international student's experience in U.S. higher education. Using narrative analysis, the author unfolds the participant's proactive actions and resistant voices. The results also show the hidden "de facto" in the environment that the participant experienced with, further contributing to the education practices by unveiling the limitations of the current U.S. educational system.

Introduction

In the past decade, the number of international students at universities in the United States has grown from 690,923 to 1,075,496, increasing from 3.4% to 5.5% of the total student body population (Institute of International Education [IIE], 2020). Many universities now have a more diverse student body and increasingly emphasize the importance of equitable and inclusive educational practices. Despite this, international students' needs continue to be overlooked, with a growing body of literature suggesting that they persistently experience discrimination, microaggressions, and/or a lack of support from the educational system (Marginson et al., 2010). In addition, scholars argued that much of the research focused on international students has taken up a deficit perspective. Page and Chahboun (2019) noted that much of the current research on international students has been based on the assumption that international students simply serve to "internationalize the curriculum" (p. 873), resulting in little attention being given to the everyday experiences and perspectives of the international students themselves. Xu (2018) also argued that ample research used the acculturation model when studying international students' overseas experiences. Such a model assumes that the goal is for international students to adapt to the host country's culture. Such deficit models serve to overgeneralize international students' motivation for studying in another country, simplify their overseas trajectories, ignore their agency, and minimize the challenges they face.

Despite international education experience is a self-forming process, Tran and Vu (2018) revealed that there is a lack of study in understanding how international students negotiate their agency. They clarified that the achievement of agency is not merely students' effort. It is an inter-relationship among the individual (micro-level), the resources and spaces given by the institutions (meso-level), and the larger structure (macro-level). This study will contribute to scholars' call for unfolding how international students negotiate and express themselves within the U.S. educational system, and also to reveal the hidden norms of the U.S. higher education. The results can also create dialogs for policy-makers, educational practitioners, or scholars who work on higher education study or with international students.

Methods and Data

The data were from my larger project exploring international doctoral students' academic trajectories in the U.S. The study was conducted in a predominantly white university in the mid-west U.S. with 6 participants in total. In this specific study, I focus on Tabitha, a Chinese female international doctoral student's data because (1) the research activities were done in narrative forms; and (2) the research meetings have lasted for a year since August 2020 until now, therefore creating a rather complete trajectory of her academic experience; (3) a similar challenge of funding-searching was identified as a critical event (Mertova & Webster, 2012) that had been consistently emphasized and later changed her personal beliefs and attitudes toward the education environment she locates within. The meetings were conducted in an online format because of pandemic. There were 16 meetings up-to-date resulting in a total of 44 hour's video recording. Tabitha also created monthly diaries with her reflections on her life. Negotiation of funding re-occurred and became critical in the past year in Tabitha's life. I started the analysis with the segments directly related to these events. Data were the video recordings and the written journals on September 21st, 2020, March 1st, 22nd, and April 18th, 2021. Both the videos and her diaries were analyzed using qualitative data analysis software ATLAS.ti 9. Data were analyzed in its original language, Mandarin (the mother language of both the participant and myself), and later translated into English for reporting. As I watched the recording or reading through the journal, I marked the components in the narratives (e.g., characters, events, actions…etc.) and also analyzed the meaning behind the narrator's interpretations, decisions, and reflections.

For each segment, I summarized and generated the following: (1) critical moments: what are the events that are presented as influential in her narratives in that specific period; (2) key persons: what are the critical characters in these moments, what roles do they play; (3) emotion: how does the narrator feel about these

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experiences/interactions; (4) narrator's voice and explanation: how does the narrator perceive these moments and reproduce these moments through her narratives; (5) decision or action: what action does the narrator decide to perform in response to the experience; (6) de jure vs. de facto: what the narrator considers things/the system should be vs. what actually happened; and (7) macro-meso-micro structure: through her narratives and the analysis of the above themes, re-construct the system that the narrator negotiates herself within, the system that allows these experiences happen. Finally, I compared these themes across the four segments/across these time spans, therefore generated a clearer picture of how an international student posits and voices herself in the funding-searching experience under the U.S. higher education system.

Summary of Results

With the seven analytical structures that I proposed in the method section, I was able to re-construct an U.S. higher education environment where Tabitha interacted with by the following findings: (1) individualism seems to be an underlying culture. In the environment Tabitha locates within, many staff and faculty members do not actively pay attention to students' external needs (e.g., resources, academic works) or internal needs (e.g., mental status or personal development). Even when Tabitha requested help, some replied with the most basic, "official" answers while some rejected to give a hand by shirking responsibility. Tabitha described the phenomena using "playboy" as a metaphor, that: "they did not deny my questioning yet they also gave no response; and they took no responsibility" (041821). (2) When university people hiring graduate assistants, there seems to be a hidden pre-assumption and pre-requisition to international students' language ability before getting to know their other strengths. Such as when R (Tabitha's advisor) queried around the funding opportunity at the institutional level, he received a response directly stating Tabitha, as an international female student, is unlikely to get a position. The staff answered without asking for further evidence to support her ability. When Tabitha tried to apply to other positions, she sensed that native-speaker-level English proficiency seemed to be a baseline for many jobs, even the employers do not explicitly stated it on the job post. (3) Mentor/advisor plays a critical role in international doctoral student's trajectory. This strongly influences how an international student perceives the host country's educational culture. Across Tabitha's trajectory, her advisor R's role switched from a powerful protector, a father figure that seems to be omnipotent, gradually to a faculty member that acknowledged and also carried out a certain degree of the norms established by the institution. Tabitha reflected that "In my first year, I thought our program was supportive. Now I started to sense the gap [the problems of it]" (041821). Her perceptions toward the institution changed as time passed and as R started to be bounded by the implicit rules of the rules set by the institution.

On the other hand, Tabitha positioned herself as an active character who fights against challenges. For example, knowing R became the scapegoat that the office blamed on, Tabitha insisted that she will not accept such a result and instead respond with "quitting". Here, "quitting" is a weapon and a voice that Tabitha took to speak out for the unfairness she saw and encountered, which is different from what some literature posits as a passive result and the ending of a student's trajectory. Many reports also tend to position international students as consumers and customers of overseas education (Marginson, et al., 2010). Some universities and scholars assumed that quality education attracts international students. After admission, it is the international student's responsibility to accept and adapt to the host country's educational system. Tabitha's reflection provides another perspective, showing international students are not merely passive receivers: "From the decisions made by the department and the program [on how they decide to support us], we also, at the same time, evaluate if this is the place that worth staying. It is a fair position for both side" (030121).

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International Society of the Learning Sciences

Uplift modeling for educational data

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Abstract: Traditional learner model focuses on modeling students' mastery level of a knowledge component based on their historical learning trajectories. Uplift modeling tries to predict the difference between the treatment group and the control group so that the model can predict the actual causal effect of the intervention. We found that the hint effectively increases the learning gain and learners' prior probability is an important factor affecting the learning gain.

1 Introduction

Adaptive learning systems provide personalized learning supports for students. There are many factors affecting learning, and the mechanism of learning is not clear. It is difficult to carry out research through traditional experimental research, so it is still difficult to track the learning gain of students. However, many student modeling studies only focus on modeling the change of students' knowledge ability level over time, such as Bayesian knowledge tracing and deep knowledge tracing. In contrast, uplift modeling allows for the addition of control groups, designed to clarify the difference in outcome probabilities between the modeling control group and the treatment group, and is therefore more suitable for educational data analysis. The Uplift Model is an incremental Model designed to predict the causal effects of an intervention on an individual's state or behavior. Uplift modeling is receiving increasing attention from the business analytics research as an improved example of predictive analytics for data-driven operational decisions.In this paper, the effectiveness of hints in adaptive learning systems on learning gain will be explored by using uplift modeling. Measuring and predicting "incremental improvements" resulting from interventions (such as hints) in the adaptive learning system reflects the effect of "intelligent tutoring".

2 Uplift Modeling

The uplift modeling is an incremental model designed to predict the causal effects of an intervention on an individual's state or behaviour. The calculation formula of user I's causal effect is as follows:

$$\tau_i = Y_i(1) - Y_i(0) \quad (1)$$

The goal of the uplift model is to maximize τ_i, which is an increment, the gain of the intervention strategy versus the no-intervention strategy, which is simply the difference between the outcome before and after the intervention. In practice, the estimated value of the expected causal Effect of all users will be used to measure the Effect of the whole user group, which is called Conditional Average Treatment Effect (CATE). Mathematically, it can be expressed as the difference between two Conditional probabilities:

$$CATE: \tau(X_i) = p(Y_i(1)|X_i) - p(Y_i(0)|X_i) \quad (2)$$

X_i is the characteristic of user I. τ_i represents the user's intervention measures, which is a binary variable (1 represents intervention, 0 represents no intervention). Y_i represents the user's results (e.g., whether the student got the answer right or not); $\tau(X_i)$ represents the causal effect of the treatment group relative to the control group. Conditional means based on user characteristics.

Formula (2) is the ideal uplift calculation. In fact, it is not possible to observe the output of user I with treatment and control at the same time, i.e. it is not possible to obtain $Y_i(1)$ and $Y_i(0)$at the same time. Therefore, formula (2) can be modified to obtain:

$$Y_i^{obs} = T_i Y_i(1) - (1 - T_i) Y_i(0) \quad (3)$$

Where $Y_i^{obs}$is the output observed by user I. $T_i$is a binary variable,$T_i = 1$ if user intervention is used, $T_i = 0$ otherwise.

Thus, the expected estimate of the conditional mean causal effect is:

$$\tau(X_i) = p\left(Y_i^{obs} \middle| X_i, T_i = 1\right) - p\left(Y_i^{obs} \middle| X_i, T_i = 0\right) \quad (4)$$

However, it should be emphasized here that Uplift modeling has high requirements for samples and must be subject to the Conditional Independence Assumption (CIA) that X and T are mutually independent, that is, user characteristics and intervention strategies are mutually independent:

$$\{Y_i(1), Y_i(0)\} \perp T_i | X_i \quad (5)$$

3 Experiments

In this experiment, Python package Pylift was used for the experiment, and Class Transformation Method was used for uplift modeling. The KDD CUP2010 data set we analyzed came from the research data of adaptive

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learning system. The study was divided into two groups: the no-hints group (as the control group for this study) and the hint group (as the treatment group).Figure 1 shows the QINI curve. As you can see, overall, the treatment group got 0.8% more correct answers than the control group. The Adjusted Qini curve is shown in Figure 2. FIG. 3 shows the cumulative gain curve. The area between qini curve and random line AUUC= 0.29; The area between aqini curve and ideal curve AUUC=0.08; The Cumulative gain curve and the area between the best practice curve AUUC= 0.11. From the experimental results, it can be seen that the hints in the adaptive learning system can improve the learning gain of students.

Figure 1

The Evaluation metrics for the KDD cup 2010 data

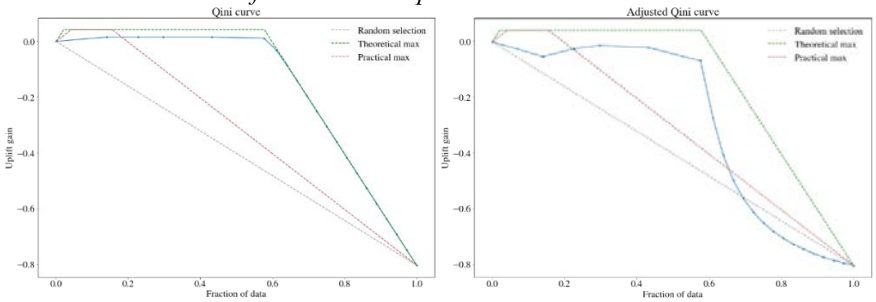


Figure 1-a The Qini curve *Figure 1-b The Adjusted Qini curve*

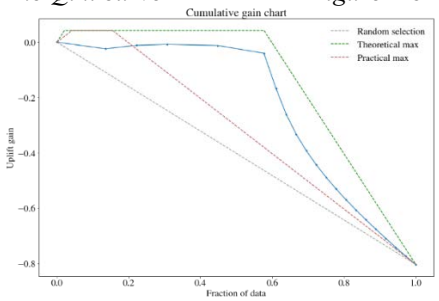
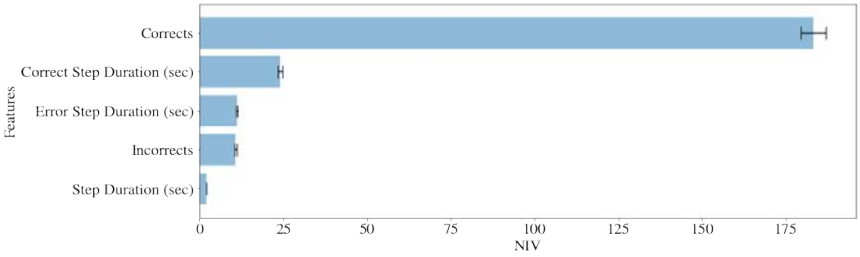


Figure 1-c The Cumulative gain curve

Information value (IV) provides a good framework for exploratory analysis and variable screening of binary classifiers. IV Consider the independent contribution of each variable to the result. The net Information Value (NIV) measures the strength of a given variable. The NET Information Value (NIV) figure obtained after uplift modeling (FIG. 2) shows that "Corrects" has the largest weight. Therefore, it can be seen that learners' initial ability (i.e., prior probability) when entering the system is an important factor affecting learning gain.

Figure 2

The net information value of partially variable



4 Conclusions and future research

This paper uses the uplift model to model the educational data in the adaptive learning system, and explores the influence of the personalized intervention in the adaptive learning system, hint, on the learning gain. The experiment shows that hint is effective, and the learning gain of the treatment group is higher than that of the control group. In addition, we also found that the prior probability of learners entering the system is an important factor affecting learning gain. Future studies will add datasets to explore the applicability of the uplift model in the field of education.

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The influence of an intervention on students' historical arguing skills

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Abstract: Despite the importance of reasoning skills in today's knowledge-based society, students do not appear to possess sufficient arguing skills. This study aimed to examine the improvement of those arguing skills after implementing an intervention in grade 8. In total, 699 students participated, and data was collected using a document-based essay. Results show that students receiving limited and full arguing lessons showed significantly better progression from pre- to post-test compared to students not receiving the intervention.

Keywords: historical reasoning skills, arguing, intervention

Theoretical background

Historical arguing means to formulate and weigh arguments in support of different conclusions to answer a historical question. As part of formulating an answer, students must present arguments in support, counter arguments, and rebuttals. Finally, students must be able to base their arguments on several references found in the sources (De La Paz & Felton, 2010; van Drie & van Boxtel, 2008; Voet & De Wever, 2017). A recent study of Hulders et al (*n.d.*) shows that students in grade 8 (age 14) achieve poor results for arguing. It shows that students do not manage to give a substantiated answer. When answering a historical research question, most students only give their own conclusion and one single argument in support, but have no attention for counterarguments, rebuttals, or references to sources. However, students' arguing skills, as one of the key competences of historical reasoning skills (De La Paz & Felton, 2010), are important to make sense of the information in the 21st century (Wineburg & Reisman, 2015). Because, like to the information today, historical sources are often contradictory (Van Drie & Van Boxtel, 2008). One promising approach to enhance students' historical reasoning and arguing skills is 'inquiry-based learning' (IBL; Voet & De Wever, 2017). So, the aim of this study is to investigate the impact of a new developed lesson series, following the principles of IBL, on students' arguing skills.

Method

Participants

699 students from 42 classes in 18 Flemish (Belgium) schools participated in this study. This sample consisted of 367 boys (i.e., 52.50%) and 332 girls (i.e., 47.50%). Their average age was 14 (SD = 0.42).

Design of the study

An intervention study with pre-post-test design was set up from January until June 2020 (i.e., pandemic). In the experimental condition, teachers implemented a lesson series to enhance students' arguing skills during regular class hours. This intervention lasted for 8 weeks (2 sessions a week, 16 sessions in total). The lessons focused on teaching students how to argue with historical sources (i.e., essential elements of a substantiated answer and many practice opportunities). Teachers in the control condition followed their own curriculum (i.e., business as usual).

Instruments

Data were collected through a document-based essay during the history-lesson (50 minutes), under the supervision of the teacher. This test contained three authentic historical sources about the death of Emperor Claudius. In each source, information about the author and the context was given. After reading the sources, students were asked to give a substantiated answer to the question "Was Claudius murdered by order of his wife? Explain why you think he was or wasn't." The same test was administered as pre and post-test. All teachers had to present the pre-test to their students before the start of the Romans (pen-and-paper-test) and the post-test just after the end of that topic (online test). None of the groups received extra information about the death of Claudius during the intervention.

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Data-analysis

The students' answers were scored using a rubric on the presence of (1) a conclusion, (2) arguments in support, (3) counterarguments, (4) a rebuttal, (5) references to the sources and their value. To answer the research question, a univariate regression with arguing as dependent variable and condition as fixed factor was carried out.

Results and discussion

The condition variable consists of three subgroups. 304 students were part of group 1 who followed the business as usual. Group 2 were students who saw the lessons about arguing in a limited way (e.g., shorter, less exercises, …) and consist of 110 students. 285 students were part of group 3 who engaged in all the arguing lessons in class. Originally only two groups were planned (i.e., control and intervention group), but due to the pandemic not all teachers were able to implement all lessons. However, it might be interesting to include the group of students who saw the arguing lessons in a more limited way, as it could possibly point out fundamental aspects of the lesson series. Students' arguing scores on the post-test and students' progression can be found in Table 1.

Table 1

Students' arguing scores

Condition	Mean score on pre-test /10	Mean score on post-tests / 10	Mean progression
Group 1: business as usual	1.82	1.90	0.08
Group 2: limited lessons	1.72	2.45	0.73
Group 3: all lessons	1.85	3.51	1.66

The univariate analysis shows that condition has a significant impact on students' progression between pre- and post-test in arguing skills ($F_{(2, 698)} = 31.82$, $p<.001$). It shows that students in group 3 have a significantly better progression on arguing compared to students in group 2 ($t_{394} = 5.47$, $p<.001$) and group 1 ($t_{598} = 12.73$, $p<.001$). On the other hand, students in group 1 have a significantly worse progression on arguing compared to students in group 2 ($t_{403} = -3.92$, $p<.001$). Looking more closely at the subskills of arguing of group 3, frequencies show that average response to a historical question consist of (1) an own point of view (96.14%), (2) one or two arguments in support (respectively 58.95% and 31.58%), (3) one counterargument (25%), (4) a rebuttal (20.70%) and (5) several references to the sources (28.95%). This means that students' answers on a historical reasoning question are more elaborated after they received the arguing lessons.

Theoretical and educational significance

In the context of 21st century skills, arguing skills are important (Wineburg & Reisman, 2015). However, research shows that these skills are limited among students (Hulders et al., n.d.). Therefore, this study aimed to improve students' arguing skills. For this purpose, a lesson series was developed. Despite the implementation of the intervention in the pandemic, a significant progression of arguing skills between pre- and post-test was found among the students who had seen the arguing lessons. This is an important finding as it means that teaching materials can be used to improve students' arguing skills. Although group 3 had significantly better progression than group 2, their main score remained quite low. This means that historical reasoning is a complex skill.

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International Society of the Learning Sciences

Data-driven badge design for gamified learning app

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Abstract: Although badges belong to the most used game elements in gamified learning tools, little is known about their optimal design. This poster will therefore discuss a data-driven approach to determine an optimal set of badges based on usage data from the corresponding learning tools. This approach will be tested with actual usage data from a learning app that was used for four semesters in a university lecture.

Introduction

Badges are among the most used elements in game-based learning (Antonaci et al., 2019). However, little is known about their optimal design in the educational domain. Optimal design in this context means that a badge can only be earned by following a learning strategy that leads to better learning outcomes. The inspiration for the design of badges in game-based learning often comes from entertainment games. However, the goals of such games are usually different from those of learning tools used in school or higher education (Loh et al., 2015). This difference also applies to commercial learning apps such as Duolingo. In Duolingo, for example, it is possible to earn a badge called "Weekend Warrior" if you use the app on a Saturday or Sunday and a badge called "Photogenic" if you upload a profile picture (1). These two badges are presumably intended to maximize usage time or identification with the app and are not necessarily aimed at an optimal learning strategy. Since designers of game-based learning tools may use such apps as a blueprint, they run the risk of copying badges that motivate non-optimal learning strategies. To date, no study has empirically investigated optimal badge design in a learning context. Easley and Ghosh (2016) only analyzed optimal badge design with a game-theoretic approach from a general and not an educational point of view. In their literature review, Antonaci et al. (2019) link the effects of game elements on learning outcomes in order to investigate the question of which game elements cause which effects. They find that some game elements can have either a positive or a negative effect depending on the context. The individual effect of a game element seems to depend on the specific setting, the other game elements used and the personality of the students. This result is also confirmed by recently conducted meta-studies (Bai et al., 2020; Huang et al., 2020; Sailer & Homner, 2020). They all report an overall positive significant small to medium effect size of game-based learning on learning outcomes. However, it is still unclear which factors contribute most to the success or failure of game-based learning. In addition, the meta-studies above shed light only on the overall effects of combinations of different game elements. A more in-depth analysis of different designs of badges (or other single game elements) does not exist yet. Facey-Shaw et al. (2017) provide an overview of different badges designs and their functions in various educational applications. Still, they do not link the different designs to the achieved effects on the learning outcomes. The present study will contribute to this research gap.

Data Sources & Research Strategy

The data set used in this study consists of usage data of a gamified learning app that has been in use for four semesters in an accounting course at a large German university. The app's core element is a quiz with over 550 questions covering all nine chapters of the course. In addition to the question types single and multiple-choice, there are also sorting and cloze text tasks. The students can collect learning points in the app to unlock more chapters and earn badges for different achievements. The use of the app is voluntary and no extra credits or advantages for the final exam can be earned by collecting points in the app. The required achievements to earn the badges include specific amounts of consecutive usage days or answered questions. The corresponding goals were developed based on learning theories and practical experiences from past lectures but without any empirical validation. In the four semesters that the app has been used so far, there have been no scheduled changes to the lecture design. The teaching staff, as well as the learning materials have remained identical. However, due to the outbreak of COVID-19, after two semesters the instructors were forced to switch from classroom lectures to online videos. The goal of this study is to use temporal and sequential analysis to classify the app users into clusters and match these clusters with the goals of the available badges. This will help answer the question of whether students who aligned their learning strategy to the given badge goals performed better on the exam. Based on the results, the basic direction (e.g., surface vs. deep learning) but also the levels of the badges will be discussed. For example, the badge for the number of answered questions in the current data set has three levels. The highest level is earned when a student answered 1,000 questions. Unless a large proportion of the top students answered that many questions in the app, you could conclude that the level might be too high. If the level is too high, earning that

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badge could even be a predictor for a bad performance in the exam, i.e., students who answer too many questions might overestimate the app as a learning tool and neglect other learning materials. Past studies have already shown that learning performance does not necessarily increase with learning time (Plant et al., 2005). In addition, the analysis might reveal optimal learning strategies that have not yet been incentivized by any of the existing badges.

Conclusion

The goal of this research project is to find an optimal set of badges for a gamified learning app. Given an optimal set of badges was found, the follow-up question is whether this set is valid for all four semesters. Especially the different teaching conditions due to COVID-19 could lead to changed optimal learning strategies. Prior studies have already shown that the explanatory power of a general model that predicts learning outcomes can differ significantly between different courses (Conijn et al., 2016; Gašević et al., 2016). To further contribute to the topic of portability, the results of the present study could be applied and compared to the settings of other researchers. In the current setting, no data about the personality type of the students was collected. As past studies have already shown that personality traits can play a decisive role in adopting a learning strategy (Matcha et al., 2020), this could also be a promising avenue for future work.

Endnotes

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How a teacher's personal reflections shape her decision making for classroom management

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Abstract: We investigate how a teacher's personal reflection shapes her decision-making process in classroom management. Following open coding, we analyze the teachers' reflections seeking to identify her rationale in the decision-making process during the language arts lessons. Our findings indicated that her thinking was based on the student's behavior, the student's personality, the educational context, her own emotional perspective and condition, her pedagogical knowledge, and her reflective experience. We discuss the theoretical and methodological implications.

Theoretical Framework

Teachers' personal reflection is a powerful professional development tool, which contributes to the improvement of educational practice, leading to positive educational change (e.g., Colwell et al., 2015). It can be adapted in several educational fields, such as classroom management, which is a process by which teachers establish a productive learning environment able to promote cognitive and socio-emotional development of all students (Evertson & Weinstein, 2006). It is described as a complex process, which requires continuous, immediate, and effective decision-making during educational practice (Aho et al., 2010). Adapting reflection in classroom management is associated with strengthening teachers' ability to reflect on their daily teaching work, making informed decisions for classroom management, addressing students' behavior, and it can result in a positive educational change for the school unit (Bilac& Milijkovic, 2017).

Although reflective practice has been recognized as an important element of the effective decision-making process (e.g., Allan, 2018), there is a lack of evidence about how teachers' personal reflection can guide a successful decision-making process (Lloyd, 2019) in classroom management (Aho et al., 2010). Therefore, there is a need to investigate our understanding of teachers' decision-making for classroom management and the elements that consist the teachers' rationale during the process of decision-making. Thus, the purpose of this study was to investigate how a teacher's (the first author's) personal reflection captures and shapes her decision-making process for classroom management during the language arts lessons during a school year, seeking to describe how her rationale in decision making is been constructed.

Methodology

This is a self-case study (Yin, 2017) utilizing action research strategies (Somekh, 2006). The participants were 11 first grade students of an urban primary school. We collected data during the Language Arts lessons for 7,5 months during 2019-2020 school year. The main source of data was 66 teacher's personal reflections before, during, and after teaching, around classroom management issues that occurred during her teachings. The first author identified 112 classroom critical incidents lasting 1-5 minutes during teaching that at the time they seemed interesting and memorable. We broke down the 112 critical incidents into 312 smaller units (sub-incidents) based on a teacher's response to a student's action. Then, we analyzed each line based on the Louca et. al (2012) 3-dimensional scheme structure. We coded the data related in respect to the way in which the first author thought, interpreted, and evaluated each student's action, including data from the first author's personal reflections, multiple readings of critical incidents, her research notes during the actual event, and memos during data analysis.

Findings

The analysis of the teacher's reflections revealed that the rationale of the teacher's decisions for her students' actions was based on six elements: (1) 18.59% of the cases were based on the student behavior (acceptable or non-acceptable); (2) 34.94% of cases were based on the student personal information such as family, language skills, social and cultural background; (3) 6.09% of cases were based on the educational context at the moment of the incident; (4) 6.41% of cases were based on the emotional perspective and the emotional condition of the teacher at the moment of the incident; (5) 23.4% of the cases were based on the teacher's pedagogical knowledge; (6) 10.58% of the cases were based on the teacher's reflective experience which was developed through the reflective process during the data collection period.

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The teacher's reflective rationale focusing on both acceptable or non-acceptable student's behavior included cases in which she thought responding to the issue on a personal or public level, to acknowledge the incident publicly or to publicly provide feedback to the student(s) involved, focusing on reinforcing the particular behavior for the whole classroom. In other cases, it was based on the information available to the teacher at the time of the incident that was related to the personality of the students involved in the incident. The teacher's response to critical incidents was also based on the educational context at the moment of the incident, and on her emotional perspective directly related to her personal characteristics, which guided her way of thinking. In some instances, the teacher's rational was based on her pedagogical knowledge, which included the teacher's knowledge from the relevant literature about classroom management, her previous experiences in managing student behavior, her pedagogical knowledge of classroom management and teaching methodology, as well as her understanding of her personal and professional limitations. Finally, the teacher's reflective rationale was based on her reflective experience which was built through the systematic reflection of her practice during the data collection period and included her knowledge from previous reflections on action (e.g., effective strategies in similar classroom management incidents), as well as her knowledge acquired from the management of a previous event through reflection in action.

Our analysis also revealed that in 13.74% of the total cases, the teacher's reflective rationale about the critical incidents emerged and resolved through a reflective conflict, in which the teacher reflectively examined her conflicting rationale about the way to respond to the incident. These instances included among others, cases in which the teacher misresponded to student's action in a previous incident which had a negative impact on the current incident, a student behavior was identified by the teacher as both acceptable and non-acceptable and cases that the teacher was thinking to respond to either non-acceptable behavior or depending on the teacher's knowledge of student's personality.

Discussion

Although our findings have some similarities with Aho et al.'s (2010) work, our research differs in a methodological and theoretical manner. In a methodological level, the action research strategies we used allowed us to describe aspects of the investigated area that could have not be visible by using other research strategies, leading to the development of better understanding about the process of classroom management (Somekh, 2006). Furthermore, the analytic structure that we used for the data analysis (Louca et. al, 2012) allowed the data to receive a second level of reflection and, thus, a deeper level of analysis, which let more pluralistic and detailed themes to emerge. In a theoretical level, we aimed to direct the attention to the connection among classroom management, the decision-making process involved, and the reflective practice, which lacks evidence. Hence, we contend that the classroom management through the reflective practice lens could lead to more informed, conscious, and student-centered decision-making, and better understanding of the theories and tacit knowledge that guide the teacher's thinking and actions in managing students' behavior.

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International Society of the Learning Sciences

Meeting People Where They Are Can Alter Where They Are

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Abstract: Asking people to "think again" can have unexpected consequences.

A polarized society has become an ever-greater concern. As people continue to confine their interaction to the like-minded, all outside their chosen circle are seen as increasingly more distant, less understood, and less worthy of consideration. Exposure to views of the differently minded would seem the remedy, but it is at its best only modestly successful and risks further polarization, excessive certainty and confidence, and reduced complexity of an individual's thinking about the issue (Fernbach & Van Boven, 2021; Kuhn, 2020; Kugler & Coleman, 2020), in particular the tendency to account for complex phenomena in terms of a single factor (Johnson, Merchant, & Keil, 2020; Kuhn & Modrek, 2018, 2021; Lombrozo, 2007), "explaining away" others if they are considered at all (Lagnado, 2021; Tešić et al., 2020). A more recent approach suggests "meeting people where they are," by engaging them in discussion of their own view on an issue, by reflecting on, exploring, and clarifying this view. Or, as Adam Grant puts it in a New York Times Op-ed, to *Think Again,* the title of his book advocating the approach. It emphasizes careful listening and questioning, getting a person to talk about the specifics and the implications of their position. The objective is to lead them to a more nuanced, potentially less hardened view.

We wanted to try Grant's recommendations for ourselves, hoping to make those we talked to less certain in their commitment to their position and more open to further examining it and considering alternatives, potentially leading to enriched, more multi-faceted thinking about the issue. We sought an issue that did not submit readily to easy, single-factor solutions and chose this: *"What should be done about the problem of young people brought to the US illegally as children; should they be allowed to stay or sent back*? Law-and-order hard-liners can easily justify their *Send-back* position based on the single factor of upholding law. Are progressives more open to thinking further? The very term 'progressive' suggests so. Progressives favoring the *Stay* position must work harder to justify this position, and therefore we chose to talk to this group (who dominated their politically progressive urban locale). *Stay* proponents must bring together two competing sets of considerations –those of the society and its laws and those of an individual who did not knowingly violate them. Single-factor thinking that ignores one of these has not fully addressed the issue. Addressing it requires the richer, more nuanced thinking about a difficult sociopolitical issue that we hoped discussion would encourage. We were therefore surprised by our findings.

Participants were 61 community adults approached in various public places in a large US city. Genders were equally represented and 64% reported having graduated from college. We asked individuals to explain their *Stay* position, encouraging them to elaborate, and included these follow-up questions:

What about their parents who brought them to the US? Should they be allowed to stay?
What about grandparents who want to keep the family united?
What about aunts and uncles and other relatives who would like to stay too?
What about others not related but close to the family?

For half the sample (condition E2), these questions were asked first, before seeking explanations. All were also asked how strongly they felt about the issue and how certain they were regarding this position, each on a scale 1-10.

Contrary to our expectations, these individuals did not tackle the complexity these questions invoke, to arrive at a more nuanced, richer position. Instead, they simplified their *Stay* position. Over 90% favored extending residency to grandparents, over 80% to aunts and uncles, and roughly half to unrelated persons close to the family (Table 1) .

A majority (73%) offered only a single factor or consideration (e.g., "they've worked hard") to support their position. Rather than becoming elaborated and enriched, their thinking became simplified and single-dimensional. Strength and certainty ratings were uniformly high in both Conditions E1 and E2, with median ratings of 10 and negligible change following interviewing.

Two additional groups of 50 participants served as control groups, one from the same community population as the main sample and the other solicited from Mechanical Turk. Both were similar demographically to the main sample, with genders equally represented and 64% and 56% respectively reporting having graduated from college. Control conditions differed from the experimental conditions in two ways. First, participants were asked to indicate

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their position but were at no point asked to justify or explain it in any way, on either the main question or the follow-up questions. Second, they had no interpersonal interaction with an interviewer. In control condition 1, a sheet was handed to passersby in the same locations as those in the experimental condition, asking them to indicate their answers on the sheet and then deposit it in a box that sat nearby. Those in the second (Mechanical-Turk) control condition responded online and were asked only the middle (aunts-and-uncles) question.

Table 1. Proportions of Participants Responding Yes to Follow-Up Questions by Condition

	Condition E1	Condition E2	Control Condition 1	Control Condition 2
Parents stay?	100%	100%	94%	
Grandparents stay?	90%	94%	88%	
Aunts & uncles stay?	83%	81%.	62%.	56%
Close others stay?	43%	55%.	28%	

Why did further contemplation lead the experimental groups to become more positive and generous in their responses to the follow-up questions than they presumably would have been prior to the interaction (as indicated by the control group responses)*?* Why did a majority assert that anyone from the aunts and uncles of undocumented youth to anyone else who knew them be granted residence, a view at striking odds with US immigration policy as well as public opinion? "Did our participants really believe what they were saying?" we wondered.

Coordinating the perspectives of stakeholders who have competing positions on an issue is a cognitively demanding task. In the case of this issue, law-and-order conservatives understandably might be less inclined, but who better than those who champion progress would be more up to taking it on? Yet our politically progressive sample most often took the cognitively easier path of simply extending their *Stay* position to broader and broader groups, rather than invest the mental effort that constructing and justifying distinctions requires. One explanation is cognitive laziness (Stanovich, 2011). Another is self-presentation. Having taken a position and elaborated on why it was the right one, one ought not appear uncommitted or inconsistent, especially to someone unknown.

Our intention had been to enrich more than change people's views. Should our findings be taken as discrediting the strategy of meeting people where they are? We maintain not. Where better to meet them? But we may need to develop more nuanced approaches to the discussions we engage them in. Our findings also have implications for public opinion assessment methods, which may need to become more cautious than is typical.

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How do learners use in-game learning support in digital game-based math learning?

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Abstract: Learners often encounter difficulties in constructing knowledge in digital game-based learning. In-game learning supports offer in-situ guidance for knowledge-constructive gameplay. Yet, how learners use learning supports are still inconclusive. With a mixed methods study, we investigated learners' varied usage of different learning support features in digital game-based math learning. Preliminary findings with 22,615 speech utterances of thirty-four students revealed seven clusters of learning support use.

Introduction and theoretical background

Digital game-based learning environments are open-ended problem solving spaces that can be used as a sandbox for disciplinary practice, experiment, and exploration. In such learning environments, learners are given a high degree of agency for knowledge discovery and construction (Ke, 2016), whereas oftentimes learners encounter problems that lead to unsatisfying learning outcomes (De Jong & Van Joolingen, 1998). In-game learning support and scaffolding that offer in-situ guidance are critical to sustain learners' efforts to regulate planned and systematic discovery, reflections, and sense-making (Chang et al., 2008; De Jong & Van Joolingen, 1998). The types of learning support and its effects have been explored in the literature (Chang et al., 2008; Puntambekar & Hubscher, 2005). However, how learners use learning supports are still inconclusive (cf. Roll et al., 2014), especially in digital game-based math learning.

Without an understanding of how do learners use learning support when experimenting and discovering in digital game-based learning environments, the design of learning support may not meet the learning needs. Thus, this exploratory study aims to address the following research question*: how do learners use learning support features in digital game-based math learning?*

In-game learning support research has been dominantly focused on cognition and meta-cognition by depicting the "*whats*" (i.e., the content knowledge). Using learning supports for knowledge development of *why* and *how* to learn math during gameplay is also crucial to make learning personally meaningful (cf. Jankvist, 2009), yet has been largely underexplored. In this study, we investigate two types of learning supports featuring different knowledge in game-based math learning. *Task planner* is designed to assist learners' systematic and planned efforts for math problem solving, or *hows*. *Math story*, featuring historical stories and real-life applications of math concepts, is a support feature aimed to scaffold the understanding of *whys* of learning math (Jankvist, 2009).

Method

A convergent mixed methods study was conducted to address the research question by validating findings with both quantitative and qualitative techniques (Creswell & Plano Clark, 2018). We collected data from 34 college students who used two types of learning support (i.e., *task planner* and *math story*) in a math learning game called *E-Rebuild*. Each participant completed a two-hour gameplay, think aloud (in-situ gameplay speech), and semi-structured interviewing (gameplay speech and learner experiences) session. The data were in the form of video- and audio-recording; they were then transcribed verbatim by a professional speech-to-text service and reviewed by human coders. These transcriptions were served as text-based speech data for natural language processing and subsequent analysis. The preprocessing raw data consisted of 22,615 speech utterances (208,649 words).

We used unsupervised machine learning techniques with k-means cluster analysis for data-driven exploration of how did the learners use learning support in this study. Toolkits in *Python* (i.e., *pandas* and *sklearn*) were used. For example, speech data were vectorized into computer-recognizable features for extraction and used for nested (clustered) analysis based on the keywords. Qualitative data were analyzed through open coding. The data collection and analysis are ongoing; we present preliminary and tentative findings in this proposal.

Findings

The text-based cluster analysis validated by qualitative analysis revealed seven preliminary and potential clusters that the learners have used and interacted with the learning support features. For *task planner*, learners were found to use it for procedural problem solving, meta-cognitive awareness, and reflection. For *math story*, learners used it for reflection, reasoning, motivational support, and conceptual learning.

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Table 1
The preliminary results of the cluster analysis supported by qualitative analysis for learning support features

Text-based clusters	Text-based cluster instances by key words (*italicized*)
Task Planner-Procedural Problem Solving (20%)	Like sort of *guide* you through those *steps* of how to do it.
Task Planner-Meta-Cognitive Awareness (13%)	I just needed, like *a reminder*, like I haven't ran into similar problems like this before. I just need to see like how to solve it.
Task Planner-Reflection (11%)	I *think* it gives you like the exact math of what you're doing so you can see how the volume of one *relates* to the volume of other, and then how you combine that information.
Math Story-Reflection (19%)	The families one, that's probably where I saw the most *connection,* and the ratios, like the two to one family ratio one and then, how I forgot what it was one of the civilizations that are talking about it was Egypt, how they use the fraction…computations…just like to see the overlap.
Math Story-Reasoning (16%)	It (Math Story) *explains* the different symbols and what numbers they stand for in hieroglyphs…it shows another way of like doing simple math. Like these symbols and everything…students have to go back (to the game) and see what each symbol stands for and multiply that by whatever it's asking.
Math Story-Motivational Support (15%)	It's just *fun* to…like it was just *interesting* to watch it; the math story is definitely *interesting*...it adds to *the beauty of math*.
Math Story-Conceptual Learning (6%)	(Math Story: "completing the square" method) Like the shape revealing algebra…I *don't really know* that *before*.

Discussion and conclusion

In this study, we empirically investigated learners' usage of learning supports featuring different types of knowledge development in digital game-based math learning. Preliminarily, in alignment with prior research findings, learning support of *task planner* was found to support learners' exploration of cognitive and meta-cognitive problem-solving strategies (De Jong & Van Joolingen, 1998). *Math story* appeared to support learners to explain and make connections between the game tasks and math concepts. It also supported learners' motivation to learn and supplement pedagogical values to the existing digital game-based math learning.

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The Power of Gestures: Video Club to Support Teacher Awareness of Gestures as a Form of Multimodal Science Instruction

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Abstract: Teacher candidates attend to many responsibilities and interactions during lesson enactment. Video club (Barnhart & van Es, 2020; Jilk 2016) can narrow reflection to focus on specific aspects of teaching. This study explores the power of video club to develop awareness of multimodal resources, such as gestures. We analyze data from a science methods course, finding that video club makes visible teachers candidates' subconscious gestures and can position gestures as resources for inclusive science teaching.

Objectives and significance

Gestures offer powerful representations of science that promote understanding (Herrera & Riggs, 2013; Johnson & Cotterman, 2015; Williams, 2020). Yet, the complexity of teaching can prevent teacher candidates (TC) from noticing the subconscious gestures that they use to support learning and the gestures that students use to express understanding (Johnson & Cotterman, 2015). To this end, we ask: How can video analysis help science TCs see their gestures and students' gestures as powerful learning tools that support student sensemaking? This paper illustrates the power of video as a reflective tool for TCs to notice and leverage gestures, focusing on how video club (Barnhart & van Es, 2020; Jilk, 2016) can be used to draw attention to gestures as ways to support science learning by: (1) creating safe spaces for students, (2) directing attention, and (3) representing science concepts.

Method

Data for this study comes from a middle childhood science methods course at a large university in the midwestern US (20 students total). As part of the course, TCs participated in video clubs in which they selected short video clips of their teaching (3-4 minutes) from their field placement to watch and discuss in small groups (five TCs and a facilitator from the research team). We use pseudonyms that were chosen by TCs to represent themselves. In this paper, we focus on one video club in which a TC, Luke, shares a video clip. The facilitator (Blue) noticed the significance of gestures in the clip and focused the discussion on the role of gesture. The video was watched one time through without interruption. During the second playback, the video was repeatedly paused for discussion (Johnson & Cotterman, 2015). At the conclusion of video club a brief survey and semi-structured interview captured TCs' key "take-aways" from the experience. Interaction analysis and inductive coding were used to explore how video club supported teachers in noticing how gestures can be used to support science learning (Charmaz, 2006; Jordan & Henderson, 1995).

Findings and discussions

Our analytic focus on gesture emerged from a video club segment where Luke used her hands to talk about tectonic plate movement. She described these gestures as subconscious: "I also talk with my hands, that's just happening, it's subconscious." We show how video club helped Luke and her peers focus on these subconscious gestures as resources for learning that they could leverage intentionally in their future teaching. We propose that video club allowed TCs time and space to slow down and see gestures that they might not have noticed in the moment as they were teaching. Here, we focus on how viewing and discussing the video helped TCs attend to gestures to support learning by: (1) creating a safe space for students, (2) directing attention and (3) conveying scientific information.

First, TCs attended to gesture as a means to create a safe and inviting space for students. Abbey commented "Your body language was really positive. Of just like 'come on up.' I feel like that's kind of underestimated in teachers today, like creating that safe space for kids." Blue built on this comment by asking how body language might affect class dynamics. Elton replied, "I notice what Luke's doing. She's spending more time facing outward, towards them, her arms out giving a very open, welcoming body language." Additionally, Elton interpreted the body language of students as providing valuable feedback to Luke regarding student engagement: "While the students, instead of having their back to her and looking behind their shoulder, they're actually turned towards her. So that shows that

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they're engaging because their bodies are towards her." Second, Xavier noticed that gesture could help students connect to content. He paused the video to note that Luke's body language helped direct students to a pictorial representation of plate boundaries, saying: "I think that sort of positioning (Luke turned towards the screen) gives students a cue to kind of also put their attention on that graphic." Third, Blue explicitly connected gesture to science concepts. She pointed out that Luke brought her hands together to illustrate a convergent plate boundary, then moved them apart to demonstrate a divergent plate boundary, while at the same time verbally emphasizing the prefixes of each word to bridge hand motion to new science vocabulary (Williams, 2020). In this way, Blue offered TCs a lens for seeing gestures as visual representations of science content to support student understanding.

Prior to video club Luke identified her use of hand gestures as being "subconscious." Video club allowed Luke and the other teachers in their group to attend to gestures as resources for learning and to consider intentional uses of gestures in their future teaching. The impact of gestures was evident through its emergence as an analytic focus during the last two video clubs. It also surfaced during interviews where three of the five TCs referenced gestures as memorable. Lindy stated, "Body language was something I recognized a lot in others' videos and my own." Xavier described how he embodied Luke's movement in his field placement, "I am more of, like, a lower energy kind of presence in the classroom. So, like that next week, like I tried to step it up a little bit. You know, I had a little extra coffee and moved around a lot more." Xavier's effort to enact movement in his own classroom is evidence of the impact of video club on his teaching.

Conclusions and implications

Our data demonstrate how video club can help TCs see the power in gestures, elevating them from subconscious motions to resources that can be intentionally used to support learning about science concepts. Video club allows TCs time to pause and reflect on this singular aspect of teaching, even though they may have been attending to other elements as they were teaching. Our findings suggest that video clubs could be used to support noticing and reflection about gestures in this and other contexts (science education courses, professional development), which could support effective and inclusive science teaching.

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Using Electronic Textiles to Visualize the Loss of Tribal Lands Over Time

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Abstract: This poster shares the design and development of a data visualization project that brings together social studies, Indian Education For All, and computing to center understanding of the loss of tribal lands by the Blackfeet Nation in Montana. Students utilize Circuit Playground Express microcontrollers to program LEDs representing the percentage of original (pre-contact) tribal lands still owned by the Blackfeet Nation at various points in United States history.

Introduction

There is growing interest in incorporating data science into K-12 education. When students engage in understanding, analyzing, and making inferences from data and data visualizations, they are developing data literacy skills. While data literacy involves math, science, and computing, it is frequently situated within social studies. In the United States, the National Council for the Social Studies (2015) College, Career, and Civic Life (C3) Framework has a focus on geography, including the construction and use of maps, graphs, and other data visualizations. By the end of fifth grade, students should be able to know how to use and construct maps and other representations of data. In this data visualization project, we are focused on fourth and fifth grade social studies standards in the state of Montana and Montana's Indian Education For All curriculum.

Background & Project Design

Data visualization in social studies can be used to support the factual histories teachers want to engage their students in (Naimipour et al., 2020). Particularly when these narratives are not the dominant narratives in U.S. history data visualization can be a powerful tool to counteract more dominant narratives, such as those of Westward expansion and Manifest Destiny. For students, making sense of second-hand data can still be a meaningful experience connected to one's own sense of race and place (e.g. Wilkerson & Laina, 2018). Further, Lee and colleagues (2021) present a three-part framework for thinking about how students engage data across the curriculum. They suggest that such engagements can be meaningful personally, culturally, and socio-politically.

The goal of the Shrinking Lands Project is to get fourth and fifth graders in Montana to think about how tribal lands were impacted by treaties with the U.S. government and to visually represent the percentage of indigenous lands occupied by each tribe in the state of Montana today. This project is part of a larger undertaking that intends to bring together Montana's Indian Education For All curriculum with the state's new computer science standards through curricular integration across content areas. The Shrinking Lands project is part of a curricular unit focused on the assimilation, termination, and relocation of Montana tribes. Students are tasked with selecting 3-4 significant treaties for one of the 12 tribes in Montana and then using LED lights programmed with a Circuit Playground Express microcontroller to visualize what percentage of indigenous lands remains after the signing of each treaty. For instance, Figure 1 depicts data for the Blackfeet Nation. The small, gray area represents the present-day lands of the Blackfeet Nation and it is such a small percentage of indigenous lands that it does not even merit an LED light. This design method can easily be adapted for other Indigenous nations in the United States and elsewhere in the world.

The quantity of land held by Montana tribes is readily available through the United States Geological Survey and the websites of individual tribal nations. Because some treaties are over 150 years old, most sources only provided maps of lands held by tribal nations before and after treaties. As this project displays the history of lands held by Native American tribes, we used sources available on tribal websites to obtain land treaty maps from 1850 to the present. Maps of each treaty were used to create proportional maps made of felt, and to calculate the area of each land treaty map. Using the land treaty maps for each tribe in Montana, we then superimposed the maps on google earth and used the measure function to calculate the land area in square miles. After calculating the land area associated with each treaty for each nation, we divided the data by nation to prepare the data to be transformed into ratios that can be displayed using LED lights and the Circuit Playground Express.

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Figure 1: Shrinking Lands of the Blackfeet Nation in Montana.

The Circuit Playground Express board features eight programmable ports than can be linked to external lights, which students will use to display changes in land area over time. Using the square miles of indigenous lands as a base, we standardized the ratio for each tribe to be 10/10 and then calculated the ratio of land that remained after each treaty. Because each light represents a ratio of 1/10 of the land area of indigenous lands for that tribe, we rounded each ratio to a whole number. With this standardized ratio, we then took the difference between the area of the indigenous land area ratio and subtracted the land area ratio of the first treaty. The difference between the two land areas equates to the ratio of tribal lands that were lost due to the first treaty. We then performed this same calculation with each subsequent treaty (e.g, treaty 1 land area ratio – treaty 2 land area ratio = ratio of land area taken by second treaty. When this final ratio was calculated, we assigned the corresponding ratio of lights to each treaty land map to display the ratio of land that the treaty reduced tribal lands by.

Educational Implications

Indigenous peoples are an important and overlooked aspect of United States history and that of other settler colonial nations. Developing tools that support youth in thinking through non-dominant narratives is imperative for promoting understanding and empathy across difference. Further, for Montana's Indigenous students, this project provides a way to connect with their own tribal and familial histories.

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Using Delivery Simulation Experiences in Hiring in the Technology Field

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Abstract: Technical assessments and interviews are a unique facet of the technology field. Unfortunately, they have gaps that lead to frustration for candidates and result in companies missing top talent. I propose using delivery simulation experiences to better assess and meet the needs of a modern workforce.

Introduction

The recruiting and hiring process is rife with challenges. Some of the issues are found in all fields; for example, over and underemployment (Kulkarni et al, 2013), inclusion (Nota et al, 2013), and implicit bias (Fisher, 2018) are not unique to the technology field. However, there are some problems that are more unique to the technology field. One such problem is technical interviews. Using the connectivist lens, this paper will examine the traditional technical interview process and a theoretical alternative - the delivery simulation experience.

Why use connectivism

Developing software and the problems being solved within the tech industry are complex problems. As Siemens (2006) points out, with increased complexity, in order to solve problems, the knowledge to do so resides in the collective. Connectivism addresses the pace at which knowledge is constructed and changes in a modern society (Siemens, 2006).

Delivery simulation experiences

Delivery simulation experiences are mock environments where candidates work alongside their prospective team for some fixed amount of time and the work being done reflects the actual work that would be done and problems that would be solved in the job for which the candidate is applying. Table 1 presents a comparison of the traditional technical interview compared to delivery simulation experiences through the lens of connectivist principles.

Table 1

Comparison of traditional technical task/interview and DSEs using connectivity principles

Connectivist Principles (Siemens, 2006)	Traditional	DSE
Decision making is learning. Learning is a network of specialized nodes that requires a diversity of opinions to choose the best approach and knowledge may reside in non-human appliances, and learning is enabled/facilitated by technology.	In take home technical challenges, the candidate may use existing technological resources like previous projects. In in-person technical interviews, the candidate is expected to have all the knowledge to solve the problem or answer the question (Behroozi et al, 2019; Chrupcala, 2021; Morahg, 2021).	Candidates may use any of the technological resources typically used during the team's day-to-day activities as well as tools with which the candidate is familiar. They may also take advantage of the team and specializations (e.g. product specialists and designers) to inform decisions.
Learning and knowing are constant, on going processes (not end states or products). Currency (accurate, up-to-date knowledge) and capacity to know more are the priority and the intent of all connectivist learning activities.	Capacity is focused on and limited to what the candidate currently knows (Behroozi et al, 2019; Chrupcala, 2021; Indeed Editorial Team, 2021; Morahg, 2021).	The intent of a DSE is to assess how a candidate uses and seeks knowledge to fill knowledge gaps. The team and candidate are engaged in the process of learning as they work through the problem together in search of a solution.

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Connectivist Principles (Siemens, 2006)	Traditional	DSE
Ability to see connections and recognize patterns, choose what to learn, adjust to incoming information, and make sense between fields, ideas, and concepts is the core skill for individuals today. The right answer now may be wrong tomorrow.	Technical assessments are presented largely in isolation. The purpose is to test the candidate's individual knowledge. Presented with a problem that gives the candidate an opportunity to showcase these skills, this can be done in a traditional technical interview (Chrupcala, 2021; Indeed Editorial Team, 2021).	The work being done in a DSE reflects authentic work because DSEs are collaborations. There are opportunities for the candidate to demonstrate connections and adjust to new information not only with fields and ideas, but with the hiring team.

Conclusion

Delivery simulation environments can't replace the entire hiring process. They can provide an opportunity for both candidate and team to assess one another on more realistic and holistic terms. DSEs have the potential to be a better fit from a connectivist perspective than the traditional technical task or technical interview. More research is needed in order to explore and collect evidence to better understand what DSEs have to offer.

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Professional Learning to Promote Three-Dimensional Teaching Using Computational Modeling in Remote Classroom Contexts

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Abstract: This study explores how to support teachers in developing and implementing effective pedagogical strategies to promote students in making sense of phenomena through computational modeling in remote contexts. Qualitative analyses of eight teachers' interviews were conducted to characterize their pedagogical strategies to achieve three-dimensional learning. Findings indicate that typical teacher strategies include the teacher and students co-constructing a model and using whole class or group discussions to support students' modeling practices.

Introduction and theoretical framework

The central notion of three-dimensional (3D) learning is that learners should understand science as a specific way of knowing and should develop capabilities to both understand and apply appropriate strategies to solve problems (National Research Council, 2012). We developed a Professional Learning (PL) program by integrating the crosscutting concept of *systems and system models* with the science and engineering practice of *developing and using models* and disciplinary core ideas selected by teachers to support teachers in the complexities of teaching remotely with open-ended modeling tools to support 3D learning. Based on project-based learning theory (Krajcik & Shin, 2022), we posit that teachers are themselves active learners and that they too should employ the same 3D learning goals as their students, especially as they learn new technologies and learning activities to bring to their classrooms. This study investigates two research questions: 1) What PL design principles could be applied to develop a PL program for supporting teachers to incorporate open-ended modeling tools in remote learning contexts? and 2) What pedagogical strategies do teachers adopt and adapt from the PL and use to promote student 3D learning in remote open-ended modeling learning contexts? Seven design principles and associated strategies from the PL program are reported in major findings and discussion.

Methods

The participants were 13 teachers from 1 elementary, 1 middle, and 11 high schools in 3 states from the eastern U.S. The content focus of the PL was on 3D learning using a web-based systems modeling tool called SageModeler (https://sagemodeler.concord.org). Thirteen PL sessions throughout the 2020-21 school year were held over Zoom. We conducted interviews with eight teachers who implemented an integrated computational modeling curriculum in their remote classroom contexts. A thematic qualitative analysis (Braun & Clarke, 2006) was employed to characterize teachers' pedagogical strategies used to promote 3D learning, as well as any adaptations of the PL design principles (DP) behind them. Two researchers discussed all codes to meet 100% agreement.

Major findings and discussion

Strategies associated with DP1, *Use collaborative activities among researchers and participants,* include a) foster collaboration between participants as colleagues with similar or shared goals; b) build community between researchers and participants and among participants; c) engage in collaborative activities among researchers and participants working in small groups (2-3 teachers by subject or grade and 1-2 researchers); d) introduce teaching and learning strategies from researchers ("top down") and encourage participants to share pedagogical tips ("bottom up"). All teachers responded that they highly valued the collaborative activities they experienced, including building system models together, discussing their plans with researchers and peers, and sharing resources with each other. Teachers went on to design collaborative lessons for their students around building models together and giving feedback to peers' models.

DP2, *Demonstrate pedagogical strategies*, and DL3, *Include active construction of tangible products,* are grouped together because the pedagogical strategies focus primarily on teaching about and with models. In

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the PL, researchers were explicit about pedagogical strategies—e.g., describing the "teacher moves" they were making and the reasons for those moves—as they involved the teachers in actively constructing models. All eight teachers used pedagogical strategies they experienced in the PL program, indicating that the explicit modeling of strategies was successful in embodying ways teachers could work with their students. For example, teachers demonstrated the computational modeling process with SageModeler as an example for the whole class by first working together to construct an initial model in a whole class discussion, then having students build their own models (individually or in groups) and holding whole class or group discussions to support students in revising their models. Teachers asked questions to link their students' prior experiences (e.g., lab activities, videos) as they learned key concepts in order to support them in revising their models.

DP4, *Provide individualized support*, DP5, *Scaffold with learning technologies*, and DP6, *Sustain professional learning over time* fall under the common theme of supporting participants' learning. All teachers received individualized support through the PL program by a) working one-to-one with a researcher to meet individual needs as well as working with other participants who have similar questions or modeling challenges; b) receiving just-in-time support; and c) having ongoing support related to their needs for integrating a computational modeling tool into their teaching practices. As they had experienced in the PL, all teachers tracked their students' modeling progress, diagnosed issues or difficulties, and discussed them with the whole class, a group, or individually, depending on the situation. In order to support a wide range of students in classroom contexts, the main pedagogical strategies used across teachers were to avoid framing specific answers as "the correct answer" (e.g., indicating a specific model was "the right one") and to be flexible regarding the kind of model they accepted as "good" (e.g., scientifically appropriate for the phenomenon being studied).

DP7*, Engage 3D learning goals,* and DP8, *Use relevant phenomena,* strategies include inviting teachers to model phenomena relevant to their lives or to their teaching contexts and providing them with driving questions (DQs) to guide their exploration with SageModeler. They also used collaborative documents such as Google Documents and Jamboards to explore DQs during the PL. These activities focus on 3D learning goals to provide opportunities for participants to integrate target DCIs and CCCs with SEPs to explain phenomena. In implementing 3D teaching and learning materials using SageModeler, all teachers used phenomena relevant to students in various ways: daily experiences, lab experimental activities, or field trips to link students' prior knowledge and pique their interest in the learning goals. Teachers reported that starting with a DQ supported a continued focus on 3D learning goals and helped define the system boundaries for the models.

Conclusions and implications

Across teachers we interviewed, they commonly used three pedagogical strategies: 1) questioning students about their models, 2) holding class and group discussions, and 3) grouping students to build and revise models. A common pedagogical strategy to support 3D learning was to facilitate teacher-led or student-centered discussions using student models as referents. However, some teachers disclosed that they need both additional guidance in providing differentiated materials to their students with varied learning needs and examples of high-quality curricula integrating 3D in classrooms. Additional pedagogical strategies (e.g., by grade level and lesson topic) are needed for teachers to be able to support students' revisions through testing and debugging their models.

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Emotion objects: An embodiment of learning socioscientific issues with heart

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Abstract: This multiple-case study examined students' patterns of emotion objects and their learning of obesity as a socioscientific issue. We tracked the emotion objects of four university students over a 12-week general education course on obesity. We found that students with different depth of learning had distinguishable sets of referents of emotions. This paper points out the need to attend to and specify emotion objects as a key variable in future research regarding emotions.

Introduction

Emotions play a role in our learning of an issue and our interpretation of what to do about the issue (Moors, 2014). Emotions are *about* something (Keltner & Lerner, 2010). For example, when we are angry, we are angry *about* a specific referent, such as an event, or something that someone has said or done. Following this logic, there are at least two key elements of emotions in operation. One is the emotion *per se* (i.e., what is the emotion?). The other key element of emotions is their referents (i.e., what is the emotion *about*?). Being specific about referents would help us better understand students' emotions. Although the referents—the *aboutness*—of emotions are known as emotion objects, they do not only refer to physical objects. They can be a variety of phenomena, problems, information, concepts, stakeholders, or experiences.

Foregrounding emotion objects is particularly important in learning socioscientific issues (SSI), which are inherently complex, demand on-going inquiry about ideas and phenomena related to the issues over an extended period of time, and involve perspective-taking. These features mandate that even examining a single SSI involves different phenomena, problems, information, and concepts (Zeidler et al., 2019). When making decisions about strategies to address obesity, students need to consider what is good/bad, just/unjust, and right/wrong from the vantage points of various stakeholders, and reflect on their notions of caring and concern for others. In this sense, having emotions about these emotion objects could be a target of learning (Vea, 2020).

Besides examining students' reasoning (i.e., learning SSI with heads), it is also important to identify the ways that their decisions relate to their emotions (i.e., learning SSI with hearts). The concept of emotion objects allows us to identify a variety of emotions with specific referents, which goes beyond discrete emotions of generic referents. Based on our findings of students' conceptual changes about obesity as an SSI, as manifested in adhering less to a reductionist view about obesity and more to a systems view that consider political, marketing, socioeconomic, technological, and cultural dimensions (Leung & Cheng, 2020), our research question was: "For students with different extents of conceptual change, in what ways did their emotion objects differ?

Method

From a cohort of 114 students who took the university general education course on 'obesity', we purposefully selected two students who demonstrated significant conceptual change and two demonstrated little change. This multiple case study (after Yin, 2018) relied on multiple sources of data to answer the research question.

Weekly reflective journals (time span: 12 weeks)

Throughout the course, the students kept a weekly journal to record their reflections on learning about obesity. Open and iterative coding was performed for emotion objects and the associated emotions. The coding and analysis process involved several rounds of collaborative discussion and refinement. Discrepancies were discussed until consensus was reached.

Follow-up interviews (time: six months after the course)

We conducted individual semi-structured interviews with all those who indicated that they were available. These interviews probed a deeper understanding of the emotions experienced in their learning about obesity. Four cases were selected from these interviewees for the contrasting observations we made of their post-course survey, in which they were asked the extent to which they would assign responsibility for obesity to each of the following categories: government, the food industry, science and technology, society, and individuals. Sylvia and Syrus (all pseudonyms) only assigned 10% of the responsibility to individuals. With the support of other data also, they were regarded as holding a systems-level view of obesity. Reynold and Rebecca assigned 50% of the responsibility to individuals, suggestive of a more reductionist view about obesity. After developing an emotion

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profile for each case, we conducted a cross-case matrix analysis (Miles & Huberman, 1994) to reveal similarities and differences among the four participants.

Major findings

Social phenomena

Sylvia expressed helplessness and worry about phenomena. These negative emotions were often accompanied by her action tendency in response to the concerned issues. A similar pattern was also observed in Syrus.

> I have never imagined the influence of the business sector on policy making or public education and feel helpless about that. As a citizen, I recognize the responsibility to be critical about different information … (Week 3, Sylvia)

In contrast, despite expressing her helplessness about phenomena, Rebecca did not demonstrate any action tendency.

> Such a potential problem does cost a lot to society, undoubtedly some measures are needed to ease this obesity trend ... However, most of the measures are not very effective… (Week 12, Rebecca)

Stakeholders

Another key expression by Sylvia was empathy for the obese, which was also noted in Syrus's reflections, but neither Reynold nor Rebecca expressed such emotions.

> Obese people *suffer* a lot from mental burden owing to our *prejudice and misunderstanding*... Sometimes they have no choice about being obese … but they are *born to be forced to accept teasing* by others ... Respect should also be given to obese people for they are also born to be protected by universal human rights. (Week 10, Syrus)

A key stakeholder within obesity is the obese. While both Sylvia and Syrus expressed empathy for the obese, Reynold and Rebecca expressed little emotion about the obese in their reflections.

Discussion and conclusion

This study found that students who underwent significant conceptual change demonstrated a specific set of emotion objects. These emotion objects included obesity as social phenomena and the obese people as key stakeholders. We found that those who demonstrated little conceptual change did not tend to have emotions about these social phenomena and stakeholders.

In this sense, identifying emotion objects is important not only to enhance our understanding of student emotions but also to make better sense of their learning. That is, emotion objects are a key variable associated with their success of learning SSI. As our data shows, these emotion objects are indicative of what matters to students. The findings of this study offer valuable insights that can guide future teaching on learning SSI with hearts by directing students to specific emotion objects at stake to the SSI.

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International Society of the Learning Sciences

Fostering TPACK via Idea Improvement in Teacher Education

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Abstract: This study examined 38 pre-service teachers' ideas regarding TPACK development in their lesson design during online discussion. Data include all discourse posts and the findings showed three main kinds of idea development processes existing in teacher's discussion. Such results indicate that to help advance teachers' TPACK, teachers' idea development must go through an integration process instead of stagnating at a diversification or elaboration stage.

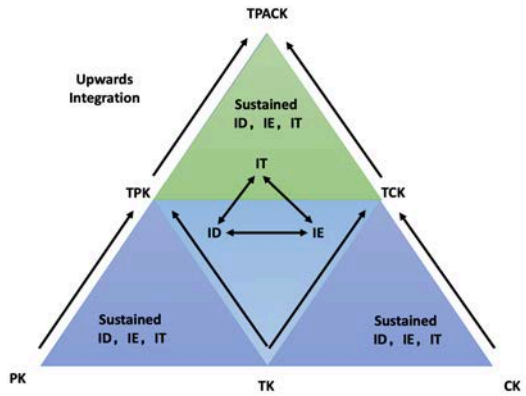
1. Introduction

In many Asia countries with an examination-oriented culture and a rigid administration atmosphere, teachers tend to be teacher-centered and traditionally, covering more concise and pragmatic-use knowledge for school tests or nationwide exams. Lately, there has been an education reform in the curriculum guideline in Taiwan: putting the learner at the center of teaching and encouraging teachers to co-design lessons interdisciplinarily. Teachers now are asked to move away from being merely a lecturer to becoming a designer in organizing and integrating their teaching into a technology-enhanced learning environment in the post-pandemic era. Recent research also suggested supporting pre-service teachers' understanding of the connection between TPACK and their practical development is critical (Tondeur et al., 2020). Therefore, teachers must immerse themselves in sustained idea improvement processes (Hong & Sullivan, 2009) while co-designing lessons. These processes include idea diversification to enrich idea quantity, idea elaboration to enhance idea quality, and idea integration to innovate or rise-above ideas to advance knowledge. However, it is not easy for teachers to suddenly shift their teaching mode in response to the reform due to long-term habits. Under this background, our research aims to reveal how pre-service teachers develop ideas to build on TPACK knowledge. The research questions concern: In pre-service teachers' discourse, what is the idea development process, and what frequency of TPACK related ideas are found? How do they develop their ideas regarding TPACK to design their lesson?

2. Context and Method

Participants were 38 pre-service teachers in Taiwan. They enrolled in a course that required them to work in a group (with 3-4 people) and design a web-based, e-learning lesson to help them develop TPACK more explicitly. As a case study, an online platform called Knowledge Forum was employed for participants to explore, discuss, and design their web-based lessons. This learning environment was guided by three idea-related design principles (Scardamalia, 2002), including (1) idea diversity (**ID**), (2) idea elaboration (**IE**), and (3) idea integration (**IT**) while developing their TPACK (see Figure 1). The research team collected online discourse and conducted discourse analysis through two analytical phases. Firstly, ideas were identified as the units of analysis (see Figure 2 presenting 15 ideas contributed by a group of participants). Secondly, researchers analyzed and quantified each idea to examine its TPACK dimension (see Table 1) and idea improvement activities (see Table 2).

Figure 1.
The design of this study (left) ***and*** *the discussion space on Knowledge Forum (KF) (right).*



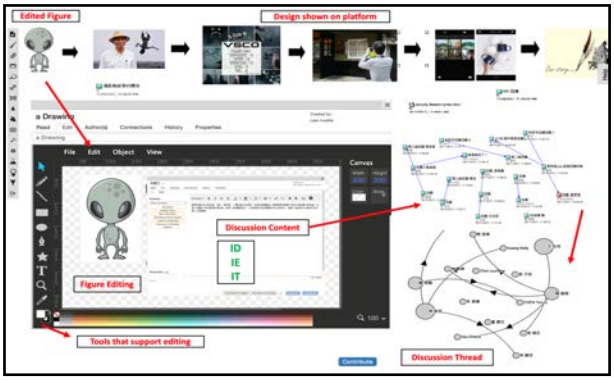


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Table 1.
The coding example for TPACK knowledge

Dimension	Example
TPK	They also set up an extra website [T]. This may lead them *(children level's learners) to* have a clear learning procedure [P] and a more pleasing experience while learning. (S3)
TCK	I feel that more links to related websites, information or videos [T], and picture books about ocean knowledge [C] or courses-related can be put in the course. (S9)
TPACK	You *[the teacher designer)* can consider trying to wrap the learning activities and course contents in a more integrated way with the use of google map so that the learner would know why they need to learn this way [TPACK]. (S26)

3. Result

Primary findings showed that all three idea improvement activities (including ID, IE, IT) were not focusing on TPACK (F=1.079, p >.05; F=1.751, p >.05) (Table 2.), indicating that there is still room for students to deal with more advanced TPACK knowledge and to engage in higher-level idea improvement activities. On the other hand, the discourse analysis showed that ID, IE, and IT were all essential for TPACK development. As shown in Figure 2., students initially proposed many diverse ideas talking websites and videos, followed by elaborating specific ideas and digital materials for presenting target content. Finally, they discussed how to integrate ideas to best create an instructional design in a technology-enhanced learning environment.

Table 2. *The comparison between T-related knowledge and ideas development*.

	M (SD)			F	p-value
	TPK	TCK	TPACK		
ID	1.132 (1.234)	2.711 (3.161)	1.816 (2.649)	3.856	<.05
IE	2.184 (2.078)	1.684 (1.454)	1.289 (1.575)	2.572	>.05
IT	1.132 (1.319)	1.658 (1.632)	1.263 (1.245)	1.437	>.05

4. Conclusion and Discussion

Research on teacher learning is challenging to examine knowledge, practice, and work contexts (Fishman et al., 2014). Pre-service teachers need to develop TPACK knowledge and integrate it with their ideas to strengthen instructional designs toward student-centered learning environments. In this study, we argue the importance of idea development should be considered. We further examined how pre-service teachers interact with group ideas dynamically through ID and IE and build on TPK and TCK. Our results indicate that the IT process is essential to driving pre-service teachers to develop TPACK knowledge. We conclude that to deepen the idea development among pre-service teachers, teacher educators should identify the early stage of idea diversification and elaboration and, most importantly, encourage opportunities for idea integration.

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International Society of the Learning Sciences

Learning and developing positive psychology via knowledge building

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Abstract: This study explores how 56 college students engaging in knowledge-building to advance their knowledge about positive psychology. Data include online behaviors, course evaluation results, and a survey. The findings showed: 1) students were able to work collaboratively to discuss online about two psychological theories; 2) knowledge-building, esp. knowledge-sharing, was significantly related to final course assessment; 3) surveys showed improved well-being scores among students.

1. Introduction

Well-being, as a predictor of psychopathology (Keyes et al., 2010; Wood & Joseph, 2010), has been deemed as important for mental health (Keyes, 2007). In order to enhance well-being, scholars have used positive psychology interventions (PPIs) (Allen et al., 2021; Fordyce, 1977; Seligman et al., 2005) --defined as psychological interventions (e.g., teaching, training, therapy) aimed at raising people's positive cognitions, feelings, and behaviors with the help of positive psychology (Sin & Lyubomirsky, 2009). Layous et al. (2013) suggested that during participants' practice of PPIs, use of a strategy called "peer testimonials" by which students share their life experiences may enhance their understanding of the nature of PPIs and their mental health. Knowledge-building (KB) is a pedagogical approach that regards ideas as basic units of knowledge construction, and values sustained idea generation and improvement to co-construct knowledge (Scardamalia & Bereiter, 2006). Knowledge Forum (KF) is an e-platform to support knowledge building (Scardamalia & Bereiter, 2006) via students' working collaboratively with ideas for in-depth discussion (e.g., about one's testimonials during PPIs) to advance community knowledge. This study aims to explore the influence of developing PPIs while sharing peer testimonials in KF in a positive psychology course. By encouraging students to discuss how to apply positive psychology theories in life, we expect students to be able to design relevant PPIs while sharing their testimonials in KF to improve learning and promote well-being. Accordingly, the research questions are: (1) Can students interact intensively in KB activities, and if so, how? (2) Is there a relationship between KB and students' course assessments/grades? (3) Can KB, with focus on PPIs and testimonials, enhance students' well-being?

2. Method

Participants were 56 Taiwanese college students taking a positive psychology course. The course asked students to discuss 3 topics: (1) PERMA—i.e., using Positive emotions, Engagement, Relationships, Meaning, and Achievements to build "good memories" in life (Seligman, 2018); (2) VIA-IS—i.e., Virtues-in-Action Inventory Strengths (such as using courage, temperance, etc. to share character strengths); and PPIs—i.e., to design PPIs by applying PERMA and VIA-IS in daily life. In terms of study procedure, building on Fredrickson's (2001, 2009) broaden-and-build conceptualization, students engaged in knowledge building in KF to design their PPIs (Figure 1). During the course, students discussed PERMA and VIA-IS and contributed, read, share, and built-on ideas in the form of notes in KF, to develop their testimonials in their PPIs. Regarding the 3 data sources, the first pre-post survey items were taken from: Taiwan Subjective Bell-Being Scale—Short Form (TSWBS-SF) and Taiwan Depression Scale (TDS), with 5 items coming from the TSWBS-SF (i.e., items about psychological well-being, such as "Some people think that life has no purpose, but I don't", and 6 items coming from the TDS in terms of emotional aspect (such as "I am stressed"). Second, online activity logs were concerned with notes created, modified, read, and replied to by students in KF. Third, the final course assessment was a well-established evaluation method required by the university, which was calculated by combining the results of midterm written reports, final audiovisual presentations, and class participation.

3. Result

First, Table 1 shows how students worked interactively online in KF. Students were found to consistently work with ideas by creating, revising, and reading notes over three topics/stages in a semester. The three activities were also correlated (all r's>.69**), indicating the more notes generated, the more also being read/modified/replied. Overall, students were able to collaborate as a class community. Second, regarding relationship, regression analysis showed that the number of notes read had a significant relationship with academic achievement, $\beta = .36$, $p < .001$. But there was no significant relationship between academic achievement (i.e., course assessment) and

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notes created (β = .82, p = .59) or notes modified (β = -.76, p = .62). As the final assessment grades were mainly based on students' knowledge, this indicates that online reading (i.e., idea sharing) plays a crucial role in fostering students' in-depth understanding of the psychological theories learned in this course. Third, the survey results also showed significant differences in the mental-scale (Table 2), indicating KB is related to improved mental health.

Fig. 1 Integrating Fredrickson's broaden-and-build theory into knowledge building activities in KF

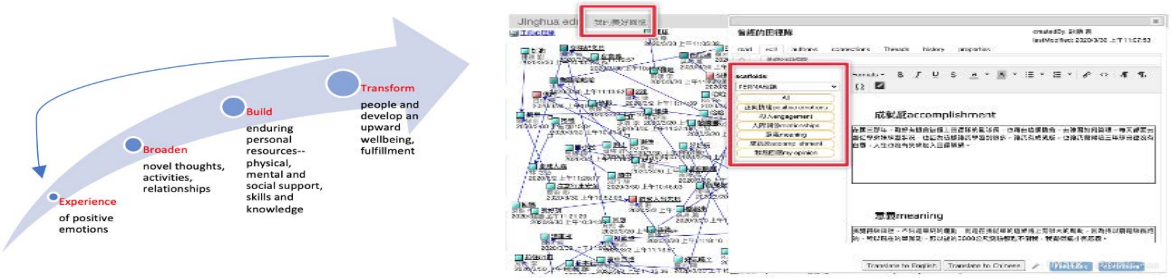

Table 1. Descriptive Analysis of Students' Activities in KF (N = 56).

KF activities	Topic/Stage 1		Stage 2		Stage 3	
Activity frequency	Total	Percentage	Total	Percentage	Total	Percentage
Creation	163	10%	126	16%	307	13%
Modification	423	24%	251	32%	697	28%
Reading	1157	66%	413	52%	1453	59%

Table 2. The Difference Between the Pre-Test and Post-Test of the Mental Scales t-test (N = 56).

Items	M(SD)		df	t-value	p	Effect sizes(d)
	Semester beginning	Semester end				
Psychological well-being	17.13（3.12）	18.07（2.81）	55	-2.12	.038	.32
Depression-emotional	5.82（3.93）	4.86（3.46）	55	-2.37	.022	.26

4. Discussion, summary and conclusion

In contrast to the traditional instructional method that tends to highlight the process of acquiring, understanding, or internalizing theoretical concepts via knowledge-telling in a positive psychology course in Taiwan, this study used knowledge-building theories with the support of KF platform to design a community-based positive psychology course. Students discuss how to apply the PERMA and VIA-IS theories online to developing their testimonials within PPIs, and it was found 1) students were able to work collaboratively to discuss online about two psychological theories; 2) knowledge-building in general, esp. knowledge-sharing (i.e., reading) in particular, was significantly related to final course assessment; 3) surveys showed improved well-being scores among students. In conclusion, the online process of idea-centered discussions to achieve a collective goal of knowledge construction in the field of positive psychology by sharing testimonials via the progressively idea improvement leading to the development of PPIs seems to have served as a way for deeper learning about one's own cognitive understanding and mental well-being. Further data analysis on the actual note content will be performed to triangulate the present findings in this work-in-progress paper.

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International Society of the Learning Sciences

Multiplicity Matters: The Development of Interest Profiles During Dynamic Institutional Transitions

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Abstract: Students pursue multiple interests within their daily lives. The current study aims to describe the development of interest profiles (the total composition of all interests one pursues) in terms of the amount of interests, their domain divergence and developmental stages. Using Latent Growth Models on interest data of 309 students over the course of three years (10 timepoints), we will specifically explore interest profile development, also in the context of institutional transitions and COVID-19 measures.

Introduction

Students pursue multiple interests within their daily lives (Akkerman & Bakker, 2019; Hofer, 2010). Given limited time and resources in daily life, interests develop relative to one another and students may experience competition between interests. For example, a student may have an interest in both playing *tennis* and *hockey*, but may only be able to pursue one of these sports due to the costs involved and the required time investment. This may prompt unconscious or deliberate weighing of tennis versus hockey, forcing a choice to continue pursuing only one or the other. The weighing of interests against each other may also be more subtle, not forced by external factors but by internal prioritization (Draijer et al., 2022). For example, if a student is interested in both painting and drawing because engaging in these interests allows them to express their emotions creatively, they may over time choose to pursue only one of these, allowing them to still express their creativity but simultaneously pursue a new interest serving a different purpose, for example *going out with friends* in order to satisfy their social needs.

Studying the development of interest profiles (i.e., the total composition of all interests one pursues at a certain point in time) is key in understanding the continuation of a single interest. Whether an interest is continued over time may depend on the amount of parallel interests one pursues, the *developmental stage* of these interests (i.e., how novel or developed the interests are), and their *domain divergence*, i.e. the degree to which the interest object is of similar or different domain from parallel interests. The amount of interests one actively pursues may decrease as one grows older due to specialization, possibly enhanced by changing life-wide circumstances. Previous interest studies theorize that, as an interest develops over time, the object of interest becomes more valued and the individual desires to become more skilled or knowledgeable (Hidi & Renninger, 2006), prompting them to spend more time engaging with it. This also relates to identity formation: as a student grows older they increasingly realize who they are and what is important to them, including which interests they want to continue pursuing (Hofer, 2010; Krapp, 2002). This process of specialization may result in a decreasing amount of parallel interests as the growing interest takes up time and resources previously spent on other interests. Domain divergence may also decrease when the objects of interest that remain are similar in content (e.g., someone studying in IT and engaging in various computer games in their spare time). On the other hand, individuals may also drop interests that concern similar domains, so as to retain variety (as in the above example about painting and drawing). Changing life-wide circumstances, such as transferring to tertiary education, likely contribute to interest profile development as the new environment offers new opportunities or takes others away (Hofer, 2010).

The research question we aim to answer is: *How do interest profiles develop over time in terms of amount, domain variety and predominant developmental stages?* More knowledge about intrapersonal interest dynamics can enrich theory on interest development: studying an interest in relation to the student's whole life yields a broader understanding of the value and development of the interest than studying it in isolation. For example, parallel competing interests can aid richer understanding of declining STEM interest (Potvin & Hasni, 2014).

Methods

Participants

Participants of this study concerned 309 students aged 14-30 (M = 19), with 70% female. These students were enrolled in diverse educational tracks in the Netherlands, including (pre-)vocational education, general (professional) and (pre-) university education (in Dutch: *mavo, havo, vwo, mbo, hbo, wo*). All students were sampled in the penultimate year of their current study program.

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Materials

In this study, an ESM (Experience Sampling Method) smartphone application called *inTin* was used to capture (changes in) daily-life interests of the participating students. Students used this application to log their existing and novel (incidental) interests that they experienced within a week. When adding an object of interest to the application, participants filled out six scales about the characteristics of this interest (e.g., how novel the interest is to them). Participants were free to give any name to their objects of interest instead of choosing from pre-existing categories, doing justice to the idiosyncratic nature of interest (Akkerman & Bakker, 2019).

Procedure

Students used inTin for ten waves (consisting of one week) total, spread out equally across three years. For most participants, the transition to another program, gap year or job took place between wave 5 and 6. Before wave 8 the COVID-19 crisis started, which meant that both wave 8 and wave 10 (second COVID-19 wave) were spent in lockdown, e.g., with schools being closed and restrictions on inside sports. All participants signed an informed consent form and for participants who were younger than 16, a parent or caregiver signed an additional permission form. Ethical approval for this study was given by the departmental Ethics Committee.

Analysis

In order to map the development of students' interest profiles, each object of interest is to be coded into one of 21 domains (sports, social, music, et cetera). We will run several Growth mixture modeling (GMM) models for parallel processes in MPlus (Muthén & Muthén, 1998-2017). This allows us to test growth trajectories in terms of amount of interests, developmental stages and domain divergence, also allowing for different types of growth trajectories for different (groups of) students. Linear and quadratic effects are compared for this purpose. To describe domain divergence, we use the amount of domains in someone's interest profile as outcome variable, and for developmental stages we use the ratio of less-developed interests versus well-developed interests (indicating that, for example, someone has relatively many novel interests in wave 1, and fewer novel interests at wave 10). If applicable, follow-up analyses are conducted, for example to get more information on which domains are increasing or decreasing.

Anticipated results and discussion

We anticipate that overall the amount of interests will decrease over time, and that the domain divergence either remains similar or decreases as well. When both the amount of interests in a profile and the domain divergence decrease, this will confirm that processes of specialization take place in interest development over time. Alternatively, when the amount of interests decreases and the domain divergence remains on a similar level throughout time, this will indicate that individuals strive to retain a degree of variation in their daily interest-related pursuits. Results may indicate individual variety in these growth patterns. In addition, results may show that a longstanding interest can indeed fall away during times of transition, but is likely to be replaced with an object of similar domain and purpose. Results are likely influenced by COVID-19 measures, we will discuss the suspected impact of these on interest profile development.

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International Society of the Learning Sciences

The Role of Visual Representations in Impasses During Collaborative Problem Solving in Undergraduate Chemistry

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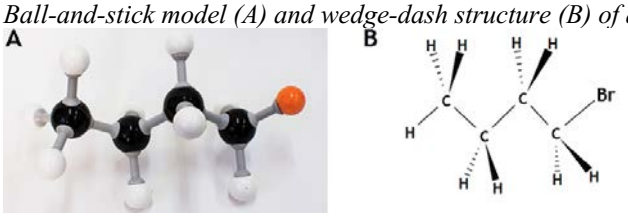
Introduction & Theoretical Background

Visual representations play a key role in disciplinary discourse. They are tools for communicating and problem solving (Wertsch, 1997). Because these representations are part of the community's culture, becoming part of a disciplinary community involves learning representational discourse (Kozma & Russell, 2005). For example, chemists frequently use representations like the ones in Figure 1 to communicate about molecules. STEM communities often use representations in collaborative activities. Representations can enhance the quality of collaboration, and collaboration can help students make sense of how the representations show information (Rau et al., 2017). However, collaboration with representations involves impasses (Strickland et al., 2010).

Impasses are points in a learning trajectory where a student does not know how to proceed because they lack knowledge (VanLehn, 1988). From a cognitive perspective, impasses are learning opportunities if the student receives information on how to proceed (VanLehn, 1988). From a socio-cultural perspective, impasses are opportunities for students to receive guidance on how to align their use of representations with those of more central members of the community (Hutchins, 1993).

Little research has characterized students' use of visual representations to navigate impasses. Hutchins (1993) showed that impasses and the ensuing feedback helps students to gradually align their representation practices with the community's norms. Strickland and colleagues (2010) found that representations can make impasses visible my revealing divergent views on how to solve a given problem. However, it remains unknown how students' use of representations during impasses differs from their use of representations during regular problem solving. To address this gap, we investigate: What is the unique role of visual representations during impasses students encounter during collaborative problem solving?

Figure 1
Ball-and-stick model (A) and wedge-dash structure (B) of a chemical molecule



Methods

We conducted our study in the context of an introductory undergraduate chemistry course. Our study occurred in week 5 of the course, which covered chemical isomerism and used the representations in Figure 1. We randomly selected seven student pairs (n = 14 students) from five lab sessions. All interactions were video-taped.

Students completed ten problems that asked them to construct a ball-and-stick model (Figure 1A) of a given chemical molecule. Then, students modified the ball-and-stick model to show its isomers (i.e., groups of molecules that have the same molecular formula but with different atom arrangements). For each, students had to draw a wedge-dash drawing (Figure 1B). Students collaborated with a partner for about 2.75h.

Videos were transcribed and segmented by turn-of-talk, yielding 8,054 turns of talk. In addition, manipulations of representations and gestures relating to the representations were transcribed. To investigate the role of representations during impasses, we first combined qualitative and quantitative approaches do develop a coding scheme that described students' use of representations and impasses; interrater reliability was Kappa = .90 on 18.6% of the transcripts. Second, we used sequential pattern mining to identify frequent sequences of codes in the transcripts. We defined frequent sequences as those sequences that occurred in at least 65% of the transcripts (i.e., met a support threshold of .65). We ran the sequential pattern mining algorithm separately on the portions of the transcripts that involved impasses (n = 2,731 lines of the transcript) and on the portions without impasses (5,322 lines). This yielded a set of frequently occurring sequences of interactions with representations that characterized interactions with representations during regular problem solving and during impasses. Third, we

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examined the frequent sequences that were unique to impasses using a qualitative approach. This yielded an understanding of students' unique ways of interacting with representations when they encounter impasses.

Results

The grounded theory approach revealed four ways in which students used visual representations during collaborative problem solving. First, students used representations for EXPLORATION when they manipulated a representation while directing their attention to the representation without verbally describing the representation. Second, students used a representation for JUXTAPOSITION when they held the ball-and-stick model adjacent to a wedge-dash drawing for comparison and directed gaze between the representations. Third, students used a representation as a tool for MEDIATION among the collaborating students or between the students and the TA when they manipulated representations while describing related concepts. In these cases, manipulations of the representations were not duplicated verbally. Fourth, students used representations as a REFERENCE to support their arguments when they pointed at a representation. In these cases, students verbalized aspects of the representation. Students most frequently used representations for MEDIATION, followed by REFERENCE and EXPLORATION. Students used representations for JUXTAPOSITION relatively infrequently.

The sequential pattern analysis identified frequent sequences of codes that described students' use of representations. All sequences were unique to either regular problem solving or to impasses. For regular problem solving, we found two sequences: EXPLORATION followed by MEDIATION, and MEDIATION followed by EXPLORATION. During impasses, we found eleven frequent sequences. Six sequences started with REFERENCE (alone or combined with MEDIATION), followed by one to three interactions coded as MEDIATION. Two sequences started with MEDIATION followed by REFERENCE (alone or combined with MEDIATION). The three remaining sequences included two to four interactions coded as MEDIATION and involved no other codes.

Our qualitative inspection of the frequent sequences found for impasses revealed that impasses were usually characterized by one or two students having difficulties interpreting how a wedge-dash structure showed a specific chemical isomer. To resolve the impasse, students used a ball-and-stick model to illustrate the isomer and make sense of isomers by establishing connections between the two representations. In this joint sense-making process, they used both representations as REFERENCE and MEDIATION tools to connect the representations to the underlying concepts until both were satisfied.

Discussion

Taken together, our findings shed light into how representations help students navigate impasses during collaborative problem solving. We found that students use representations as mediators that illustrate aspects that are difficult to describe verbally and as references that disambiguate their verbal descriptions. Using representations in these ways allows students to identify the source of an impasse and to jointly resolve it. Our findings illustrate that impasses engage students actively in joint meaning making with the representations. Future research pending, our findings suggest that joint representation tools may help students learn during impasses.

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International Society of the Learning Sciences

Brazilian Educators' Perceptions of STEAM Education

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Abstract: This paper investigates the perceptions of Brazilian educators of STEAM education. The analysis was based on an online survey of participants of the STEAM TechCamp Brasil program. We analyzed two open questions using the Discursive Textual Analysis method. Results indicate that participants perceive STEAM as a pedagogical approach, but have a restricted view of the sciences. This discussion contributes to the current understanding of STEAM in Brazil and to the evolution towards a self-contained conception.

Introduction

In Brazil, STEAM education practices are still embryonic. In a survey of STEAM approach experiences, developed and published in the country, the few records found by Maia, Carvalho & Appelt (2021) indicate that they are concentrated in four Brazilian states that are more economically developed. Research shows that, considering Brazil's social, cultural, and educational specificities, it should follow the example of other nations that implemented the STEAM approach in their curriculum and have achieved promising educational results. Therefore, innovative pedagogical practices need to be developed throughout the country, which has continental dimensions, cultural diversity and deep social inequalities. Brazil demands the design of specific STEAM environments and not just the reproduction of models from other countries.

In search of a self-contained STEAM approach, that is, connected to the reality and educational needs of Brazilian youth, some initiatives are being developed by educators and institutions. One of them is the STEAM TechCamp Brasil, which aims to create a network of teachers and education professionals to articulate and improve actions aimed at active learning of STEAM in public K-12 networks in Brazil. The STEAM TechCamp has a strong potential for disseminating STEAM experiences in the country.

This article aims to investigate the perceptions of participants about STEAM practices that are being developed in the country and how they contribute to the construction and dissemination of a unique STEAM concept connected to Brazilian reality.

The STEAM Education as an Approach

Some STEAM experiences do not innovate in education, nor do they change learning experiences. In these experiences students are asked to learn and memorize information presented by their teachers or to develop projects defined by their schools or teachers. They are asked to reproduce experiments, instead of observing, identifying problems and creating solutions. Nevertheless, the STEAM approach may reinforce agency, creativity and critical thinking. It is about pedagogical practices that stimulate students to identify problems, develop projects, test hypotheses and present solutions to the problems they identified. These problems are commonly related to the students' context. As Sawyer (2014, p.2) highlights, to work in today's knowledge economy, more than memorizing facts and procedures, people "need a deep conceptual understanding of complex concepts and the ability to work with them creatively to generate new ideas, new theories, new products, and new knowledge".

Methods

This preliminary study is based on an online questionnaire sent to the 80 participants, responsible for 41 projects that received small grants to implement projects related to the STEAM approach. All Brazilian states were represented and awarded the resources. We received 29 responses from 15 states, ensuring representation from all 5 regions of the country, and participants from each of the 4 cohorts of the STEAM Tech Camp (2018-2021).

We emphasized the questions in which respondents showed their conceptions of the STEAM approach. Two open questions were selected and their answers analyzed with elements of Discursive Textual Analysis (DTA), which is a technique that intends to verify different perspectives presented in the respondents' discourse, based on meaning units (Moraes & Galiazzi, 2011). The answers about: "How do you define STEAM?" and "How do you understand the 'S' in STEAM?" were categorized into meaning units and analyzed.

Thus, as indicated by the DTA procedures, we selected extracts of the participants' responses as context units, which are fragments of the respondent's discourse considered central and representative of the response. Then, we identified and categorized these units, with the intention of grouping them into categories that allow

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counting their frequency. At the end, we defined the thematic axis of these responses. These DTA methodological procedures favor the categorization and analysis of the discourse in the responses so that we can make inferences about the data in order to make it more understandable and capable of formulating evidence, based on the objectives of the study and the theoretical framework adopted.

Results

Regarding the first question, which aimed to understand the STEAM TechCampers' conception of the definition of STEAM, we organized the 29 responses, condensed into 4 thematic axes (*educational approach; educational innovation movement; teaching and learning methodology; meaning of the acronym*) from 10 units of meaning (*approach; movement; methodology; science, technology, engineering, arts and mathematics; strategy system didactic-pedagogical actions; new way of interaction; innovative and inspiring; way of thinking education*).

A high frequency of respondents defined STEAM as an educational approach (n_i = 12) or even a movement (n_i = 4) that seeks educational innovation through pedagogical practices based on interdisciplinarity, investigative spirit and creative learning. This suggests that most of the STEAM TechCampers are not disseminating STEAM as a mere educational technology fad. The thematic axis – Education Approach and Educational Innovation Movement – together, corresponds to 69% of respondents.

With regard to the second question, there was a predominance of the indication of "sciences," due to the meaning in the acronym, followed by two occurrences related to the "scientific method." We managed to group the 29 responses into 4 axes, namely: Natural Sciences, Subject, Scientific Method and Broad Sense. There is a balance between two conceptions of the "S" in STEAM: i) the one that understands the concept of "S" as restricted to natural sciences (34.5%), that is, a very limited view of doing science which excludes other areas and paradigms of science; and ii) one which highlights the scientific method (34.5%), or the methodological procedures inherent in investigative practice. This data shows us that the second perspective, although expanding the compression of "Science", it was not possible to perceive whether the participants understand the methodological procedures of other areas of Science like Human Science or Social Science. This view of science in a broad sense was evident in the speech of 21% of respondents.

Conclusions

The results show that most participants understand STEAM as an interdisciplinary pedagogical approach or even an educational innovation movement that intends to develop learning practices focused on the learner, based on scientific, investigative, creative and real-world thinking. This concept is in line with what is expected and desired for the Brazilian reality due to its educational, economic and social development demands.

As for the conception of science, it is necessary that educators, including STEAM TechCamp Brasil participants, expand the scope of the areas that make and produce scientific knowledge. The restricted or more specific view of natural or exact sciences, represented mainly by subjects related to science and mathematics in schools, is probably due to the technicist perspective present and for a long time perpetuated by STEM. Because of this, the examples usually brought as application of STEAM experiments focus on projects with procedures and fundamentals from physics, chemistry, biology and mathematics to the detriment of social science and humanistic subjects. The inclusion of the arts, in addition to the concern with design and development of pertinent soft skills, should include application in the real world, with attention to living beings and the environment, objects of study in the human, social and health sciences.

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International Society of the Learning Sciences

A Growing Problem: Student-Worker Retention at an Urban Farm

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Abstract: We investigate student-workers' motivation at an urban farm situated on a Historically Black College's campus. This is one phase of research embedded within the beginning stages of a larger research practitioner partnership (RPP). This paper aims to address: How do student-workers stay motivated to continue their work placements at an HBCU's urban farm in the Southwest US? The basis of our analyses are interviews, observation field notes, and artifacts collected over the course of this research. We examined the data to identify recurring themes which led to student-worker turnover and discuss opportunities for improvement of student-workers' learning motivation. As a whole, we seek to support key partners, as the ICLS 2022 calls for, by investigating innovative learning environments.

Introduction

Consistent with the "investigating innovative pedagogies, technologies, and learning environments" theme for ICLS 2022, researching innovative learning environments plays an important role to diversify educational experiences. To achieve these new educational experiences, we must look at new systems for marginalized communities and individuals to access systems of power. We report on a budding research practitioner partnership (RPP) between the researchers and an HBCU's urban farm, to examine and address student workers' motivation to learn at an urban farm. The purpose of this place-based research alliance was formed to investigate and understand the overall driving question for this RPP: How can we strengthen the connections between learning and student engagement in perceived community spaces? The research questions were co-designed with stakeholders using Penuel and Gallagher's (2017) RPP framework of finding questions of mutual concern. The overall study aims to answer the following research questions: How do student-workers stay motivated to learn in their work placements at an HBCU's urban farm? What are organizational strategies that are used by the university and urban farm to allow for continued collaborations between student-workers and community partners? What does the process of learning look like for student-workers at an urban farm, and how do the expert-novice roles come into play? This paper will focus on question one.

Theoretical Framework and Methodology

We found using an RPP framework beneficial to look at the initial stages of this project, with goals to become a long-term and sustainable RPP. There is a wealth of literature on informal and interest-based spaces (Rogoff et al., 2016) from amateur and hobbyist astronomers (Azevedo, 2013), middle school field trips to science museums (Whitesell, 2016), and adult social events at children's museums (Harris et al., 2016). However, there is a dearth of research within the learning sciences surrounding food-based spaces. This research is also informed by studies related to students and adults' motivation to learn (Coker, 2003;)

This budding partnership is comprised of the researchers, the college's urban farm, the community, and a local National Football League (NFL) franchise. The researchers include a professor and two doctoral students in STEM education. The college is a HBCU work-study college in an urban setting. In 2010, said HBCU converted one of its sport fields into a four-acre urban farm which began to and continues to grow seasonal vegetables. The community members involved with the partnership are local benefactors of the farm – representatives of local food banks and community centers. The final partner, a local NFL franchise, works with the farm to purchase locally grown produce to supply their restaurant, both at their training facility and their stadium. The research problem and question were jointly identified by the key stakeholders, who took a participatory design approach by listening, specifying problems of practice, mapping systems, and identifying shared values (Penuel & Gallagher, 2017).

The urban farm is situated within an informal learning and interest-based participation setting (Azevedo, 2013; Rogoff et al., 2016). This participatory research study was conducted at a historically Black work-study college's urban farm in the Southwest U.S. The participants of this portion of the study include three staff members of the college, three current student-workers, and two former student-workers. The researchers worked at the urban farm site to build trust and establish a rapport with the partners. All research activity and materials were supported by the stakeholders. Data collection included participating on the urban farm, observations, microethnographic field notes, interviews, and artifacts. Rigorous data was collected until saturation was met. The

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researchers were complete participants to establish rapport and assist with necessary farm duties (Creswell & Poth, 2018). All names listed in this paper are pseudonyms.

Findings

In analyzing the qualitative data related to student-workers' motivation and retention, it was apparent that there were both student-level and organization-level challenges and successes. Student-worker interviews identified reasons for leaving their positions and staying in their positions. First, student-workers discussed complications that prompted their peers to leave. The time and amount of work involved at the urban farm was much more strenuous and demanding compared to other on-campus positions for the same financial incentives, which prompted students to take advantage of the less stressful job sites. Additionally, there was always a shortage of student-workers to help on the farm, leaving the remaining students and staff responsible for the ongoing demands of a working urban farm.

Second, students proposed reasons for staying on the urban farm, despite the implications offered in the above section. There were two primary ideas that were raised in the first round of coding: interest-based motivations and gaining new skills. Student-workers mentioned their desire to expand their experiences by learning new transferable skills related to farming and gardening. Also, student-workers disclosed how they gained necessary 21st century skills that will prepare them for the workforce. One student-worker, Jane, said, "[the farm] taught me patience and trusting the process," by:

> Working on the farm and gardening, we take the process of planting a seed, you have to trust the process of watering it daily, giving it what it needs to be fed, the nutrients, so it can become a sprout and flower or fruit or vegetable or whatever it is you're trying to grow. It's not going to happen right then and there on the same day. It's going to take time.

These skills were deemed important to this student worker to stay in their placement at the farm so they could continue to grow as learners. This unique learning environment, which is situated within a formal context provides a complex layer of the site.

Scholarly Significance

The initial findings from this study parallel the learning motivation in similar studies. For example, Coker (2003) examines Black females adult learners' motivation. She finds that black female adult learners continue their educational journey for self-development, family development, and community development. Similar to Coker's (2003) study, the current student workers continue their work placements to further enhance their self-development by becoming more marketable in the workforce and inspiring confidence. Additionally, the student-workers have found a sense of purpose working on the farm by positively impacting their community, which is echoed in Coker's (2003) research. This study will start the process of studying agriculture and food systems using research and theoretical tools from a learning sciences perspective. The initial findings from this study can continue to advance and contribute to the RPP literature about student-worker's motivation to learn within an urban farm context.

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International Society of the Learning Sciences

Growing Student-Workers as Informal Learners

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Abstract: We investigate an urban farm as an informal learning setting and the interactions between experts and novices using situated cognition as our framework. The poster is situated within a large research practitioner partnership (RPP). Initial findings are reported as they relate to learning in a novel environment, and that it relates to the 2022 ICLS theme of "elucidating theories and processes of learning and teaching."

Introduction

Consistent with the "elucidating theories and processes of learning and teaching" theme for ICLS 2022, researching innovative processes of learning plays an important role to diversify educational experiences. This research is part of a broader project to understand how an urban farm can strengthen the connection between student learning and engagement in perceived community spaces through a research practitioner partnership (RPP). In this poster, we present the first phase of our analysis, which: (a) identifies informal learning that occurs at an urban farm embedded on a university campus; and, (b) initiates the discussion for interactions between the expert(s) and novices on the urban farm. The research questions guiding this poster is: What are the characteristics of learning embedded within the urban farm project?

Theoretical Framework and Methodology

There is a wealth of literature on informal learning, interest-based spaces, and expert-novices (Azevedo, 2018; Harris et al., 2016; Hmelo-Silver et al., 2007; Rogoff et al., 2016). However, there is a dearth of research within the learning sciences surrounding agriculture and food-based spaces. Additionally, this research is guided by literature focusing on the Black lived experiences and how that influences their learning (Vue et al., 2017). This research is grounded using situated cognition as a theoretical framework. This framework states that learning is situated in a particular context, social in nature, and distributed across the individual, other people, and tools (Brown et al., 1989). The urban farm is situated within an informal learning and interest-based site, the learning involves multiple participants (farm staff, student-workers, and the researchers), and the knowledge is distributed across the individual, other farm workers, and the tools being used at the farm.

This participatory research study was conducted at a historically Black work-study college's urban farm in the Southwest U.S. Participants included two staff members of the farm and seven student-workers. The researchers' data collection included observations, microethnographic field notes, semi-structured interviews, and artifacts. The first round of data analysis included inductive coding using situated cognition (Brown et al., 1989) and expert-novice frameworks (Hmelo-Silver, 2007). Future iterations of analysis and this research will aim to pull from literature of lived experiences of the Black students, and how that influences their learning.

Initial Findings

Learners – staff and student-workers – fully participate on the farm, from planting crops, tending to the raised beds, harvesting crops, marketing, and delivering the produce to clients. Additionally, the more novice student-workers collaborate with the more expert farm staff to ask clarifying questions related to different aspects of the farming cycle. Student-workers can apply their existing knowledge of gardening/farming, biochemistry, or business with their experiences at the farm. One student-worker worker was able to utilize their experience with growing peppers to experiment with different types of soil and growing methods, to identify what works best for their operation.

In Figure 1, a farm staff member presents the proper techniques to plant collard green seeds. The situated and distributed nature of the learning is presented by first showing the student the steps and providing a verbal explanation of the steps and justification. The student then demonstrates his understanding by verbally restating the steps while practicing the planting.

Discussion

Learning in a garden-based setting was examined by Dewey (1916), and he argued that in occupational and vocational education, there is a focus more on the trade or skill which, inhibits and perpetuates the existing industrialized complex (Dewey, 1916; Kliebard, 1987). Focusing solely on the trade or skill, limits the more

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expansive and holistic type of learning that can occur. For example, during the planting process, there is a missed opportunity for the expert to discuss the importance of the larger science concepts and processes that are and will be at play, such as, biology, chemistry, and physics. However, during an interview there was an example of vocational education stepping beyond the intended industrialized idea of social control and occupational training. A student was able to use the agricultural science knowledge from the farm and apply her skills obtained from her classroom instruction to develop and implement a marketing plan for a community farmers market. This parallels the expert-novice literature, such as Hmelo-Silver and colleagues (2007), which asserts and points to more productive learning gains in not only the procedures of farming but also the STEM topics embedded in such activities (soil composition, growing cycle, chemical components of fertilizers, biomass growth). The situated nature of the learning between the experts and novices at the urban farm provide an interesting insight to the learning and knowledge building for those involved. To reiterate, this is only at the beginning stages of analysis and will continue to build the situated nature between the experts and novices, as well as using Dewey's work to move forward and beyond vocational and occupational learning of a skill.

Figure 1
Interaction between expert and novice

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International Society of the Learning Sciences

Biology Isn't Black and White: Deconstructing Biology Instructors' Knowledge Networks of Biological Processes to Explore Nuance

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Abstract: To fully appreciate the intricacies of biology, undergraduate students must understand how the components and processes of complex biological systems relate to each other over space and time. However, building normative knowledge networks and transferring across biological contexts is a challenge. In this study, we sought to identify the features of a model describing the relationships between three fundamental processes in biology: cell-cell communication, gene regulation, and phenotypic expression. Through interviews with six biology instructors, we found a diversity of knowledge networks relating the processes. Further investigation revealed that their knowledge networks are influenced by their definitions of phenotype, their biological disciplines, and accumulated professional experiences. Our data reinforce the idea of situated cognition and suggest that a single, acontextual knowledge network is difficult to transfer across biological contexts. We suggest educators invite students to critique models and to engage in explicit instruction about how and when to use them.

Understanding complex systems in biology

A core concept in undergraduate biology education is for students to understand 'Systems,' which describes how organisms "integrate internal and external information, incorporate feedback control, and allow them to respond to changes in the environment" (Brownell *et al.,* 2014, p. 208). Cell-cell communication (CCC), gene regulation (GR), and phenotypic expression (P) are three relevant biological processes cells and organisms use to interact with and respond to their environment. To explain how biological phenomena occur, it is important for biology students to understand the relationships between these three processes and how to apply them to understand a complex system. The theory of knowledge integration serves as a useful framework to investigate how individuals relate the three processes. During knowledge integration, learners process new information, organize these ideas or facts, and then integrate their thoughts into a network of knowledge (Clark & Linn, 2003). Ideally, a knowledge network built in one biology classroom can be transferred and utilized in another biology classroom. To facilitate the construction of knowledge networks and their transfer across contexts, educators can use simple frameworks as a tool to scaffold student learning (*e.g.,* Hmelo-Silver & Pfeffer, 2004). Therefore, to aid students in their learning of biological systems, we sought to derive a normative model regarding the relationships between CCC, GR, and P. We leveraged the theory of knowledge integration to reveal and describe instructors' knowledge networks and answer an overarching research question: What are the features of biology instructors' knowledge networks in regards to three foundational processes in biology (*i.e.,* CCC, GR, and P)?

Methodology

Population. We recruited 6 biology instructors from a large public Midwestern university with very high research activity who had previously taught introductory courses to biology major students. (IRB #1806020745)

Procedure. These data come from a larger study aimed at revealing knowledge of and the connections between the three biological processes: GR, CCC, and P. We used semi-structured, think-aloud interviews guided by the theory of knowledge integration to elicit and characterize knowledge networks such as definitions of the processes and what ideas they use to describe connections between the processes. In this paper, we present results from the question, "How are these three processes related?" in which instructors diagramed and explained their knowledge networks. The interviewer also asked follow-up questions to fully explore participant ideas.

Analysis. We used knowledge integration as an analytical framework and built models (*i.e.,* knowledge networks) to represent how the participants connected the three processes based on the participant-drawn diagrams and conversations. The diagrams drawn by each participant were used as the foundation of the relational models, and features of the models were described using field notes and thematic coding (Creswell, 2013). Through an iterative process involving independent coding, consensus discussions, and revision, a final codebook was developed to describe the knowledge networks. Finally, coding of the full dataset by the first author and an outside reader was conducted. All coding was discussed to complete agreement.

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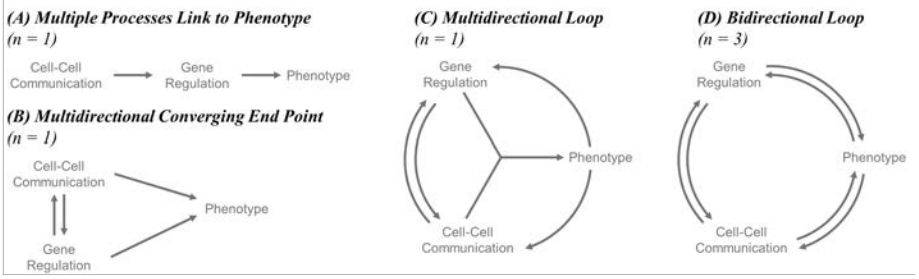
Results and discussion

We categorized the 6 instructors' models relating the three processes into four groups (Figure 1).

Figure 1

Knowledge networks of instructors



Variations in definitions and the importance of context

Most of the instructors (4/6) described phenotype as an *effect or the outcome* of the genotype or as an end product of gene regulation. In contrast, some instructors (2/6) *loosely defined* phenotype and viewed it as any physical or measurable characteristic of the cell, not strictly coming from gene regulation. We found that instructors with the *loose* definition described P as interconnected and intimately involved with CCC and GR (Figure 1D) whereas instructors with the *outcome* definition did not (Figure 1A, B, and C). With further probing of the 4 instructors who viewed phenotype as an *outcome*, 2 instructors declared that they could not conceptualize P as having any feedback to GR or CCC, but the other 2 instructors conjectured that there are certain contexts where P could affect GR or CCC. Indeed, most instructors (5/6) acknowledged that the relationships between the three processes can be drawn differently in other biological contexts, for different purposes, and depending on the individual (*e.g.,* personal definitions, expertise). To this point, we found two instructors who chose to describe their knowledge networks in the context of their disciplinary backgrounds.

Conclusions and implications: appreciating the nuance

In our study, we did not identify a single, normative relational model of the three biological processes. Although educators desire to give students common frameworks that they can transfer and apply to multiple subjects, it is clear that the relational model in our study is strongly context-dependent and its transferability is limited. The issue is that transferability neglects the nature and circumstances in which the specific knowledge content was built (Brown *et al.,* 1989). While practicing application of the acontextualized model across biological contexts could still be beneficial, a more useful approach would be inviting students to reflect and critique the model and engaging in explicit instruction about how and when to use the framework (*e.g.,* layering on detail, exceptions, uncertainty, nuance). Biology is a complex subject with few rules and boundless flexibility. This same flexibility needs to be applied when teaching and reasoning with foundational processes.

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UTeach/NYC: A Research Practice Partnership to Expand and Improve Computer Science Education For All

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Abstract: This 3-year Design-Based Implementation Research (DBIR) study focuses on a Research Practice Partnership (RPP) that encourages broad student participation in computer science (CS), looking at underrepresented urban youth in New York City. In particular, the research examines what organizational conditions, processes, and supports are associated with improved participation by Black and Latino/a students in CS, as measured by the diversity of students enrolling in CS courses. Results indicate an increase in trust has been reliant on the strides made from the partners involved, as well as building upon the RPP framework. Improved communication has resulted from continuity of meetings, regular exchanges of email, and having detailed agendas and expectations for the partners involved.

Introduction

Key to this work is imagining new ways of conducting inquiry; cultivating partnerships, working with communities as authentic partners and engaging in larger-scale research practices, such as multi-sited ethnographies, accessing population level data, utilizing new forms of data and data analytics, integrating data sources that intersect with education and developmental stages to inform the design of classrooms, schools, and systems in the service of equity. We report on a Research Practice Partnership (RPP) between The University of Texas Austin (UT Austin) and New York City (NYC) public schools to examine the degree to which co-design of curriculum, instructional practices, and teacher supports can build organizational capacity to support equitable computer science (CS) teaching and learning as called for by the CSforAll national movement. This study focuses on remaining questions about the organizational conditions and instructional practices that encourage broad student participation in CS, looking at underrepresented urban youth. This paper will focus on the first of the research questions from the grant: What organizational conditions, processes, and supports are associated with improved participation by Black and Latino/a students in CS, as measured by the diversity of students enrolling in CS courses?

Perspectives/Theoretical Framework

Education researchers have long attempted to bridge the divide between research and ongoing challenges of practice faced by educators through pedagogy, technology, and methodology innovations (Anderson 2012; Koehler et al., 2007). Impediments to the successful development and implementation of innovations have hampered and stifled innovations from being adopted to support students (Potvin et al., 2018). Most obviously, educators and administrators in K-12 schools and districts may lack the expertise to properly implement technological innovations to the rationale that stems from research for improving teaching and learning (Louie & Buffington, 2018).

Methods

Methodologically, a Design-Based Implementation Research (DBIR) approach was employed to address the three overarching research questions. In addition, using Penuel and Gallagher's (2017) design template to effectively design curriculum adaptively across levels and settings, partners developed curriculum using an iterative and collaborative design process from joint feedback between UTeach CS teachers, NYC DOE, UTeach curriculum designers, and researchers.

The project implementation and impact section aimed to capture significant accomplishments over the last academic year, including a success story and major activities completed within the year. The next question addressed whether or not the professional development and/or the curriculum was changed for the past academic school year, including changes made to address diversity and inclusion. The third question in this section asked to describe the relationships among RPP members, specifically, a sense of trust, open communication, and working together to build the capacity of educators and researchers. The fourth question in this section aimed to answer whether any other outcomes have resulted from the project to date. The fifth question in this section addressed primary barriers and challenges in the project, and how they were addressed - both outside of COVID-

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19 and related to COVID-19. And lastly, the evaluators aim to understand the plans and goals for the next year of the project.

The Starting Strong unit is used to introduce the course to students, embed non-cognitive strategies, activities, and supports in the curriculum, provide for more student choice in course activities and projects (more differentiation) and add career content to course materials. Starting Strong teacher materials prepare them for the course, classroom set up, strengthen how culturally-relevant pedagogy is addressed, provide more examples, how-to videos, and student work examples spanning range of performance, improve pedagogical support content for teachers, especially Project- Based Learning (PBL). Embedding CS background content in teacher materials strengthen opportunities for students to address personally relevant problems, and improves access to course content for English Language Learners (ELL) students (specifically in Big Data and Internet units). Additionally, teachers participate in an intensive, in-person, summer PD, and are provided in-person support sessions throughout school year, designed to foster community- building, create opportunities to collaborate, and provide on-demand supports. Researchers are collecting data on student interest, engagement, and mindset and data are immediately returned to teachers so that they can adapt instruction accordingly. Researchers also facilitate unit debrief sessions with teachers to review and discuss student data and outcomes.

Results

Three years of Advanced Placement (AP) CS exam results, provided by the College Board, show that students in UTeach CS Principles courses nationwide include more females and other underrepresented students and these students performed slightly better than national averages. In total, 75% of UTeach students passed the exam compared with 72% nationally, and female students passed at a rate of 75% compared with 69%. Pass rates for African American and Hispanic students in UTeach were 43% and 57%, compared with national pass rates of 41% and 55%. Finally, 62% of underrepresented students overall in UTeach courses passed compared with 55% nationally. Both females and underrepresented students comprised a higher proportion of the total number of exam takers in the UTeach CS principles (CSP) group compared with national participation rates.

The progress made over the course of the RPP is reflected in the interview/survey responses from the third-year evaluation. Respondents noted that there is an increase in trust from all key stakeholders, overall positive responses, improved communication, and "more of a solid team." An increase in trust has been reliant on the strides made from the partners involved, as well as building upon the RPP framework (Penuel & Gallagher, 2017). The improved communication of has resulted from continuity of meetings, regular exchanges of email, and having detailed agendas and expectations for the partners involved. An increase in flexibility throughout the 2020-2021 academic year was outlined by the respondents in their role of supporting teachers during this unique year. Additionally, respondents provided recommendations for the upcoming academic year: to elevate the role of the practitioner, continue to receive and enact PD feedback, and for the practitioners and researchers to continue to work closely together.

Significance of the Study

This project will contribute to knowledge about effective organizational conditions, as well as instructional interventions to promote participation, engagement, and learning across diverse groups of students in AP CS Principles, the professional learning and support necessary to prepare teachers with diverse content backgrounds to teach CS, and the strategies employed to address problems of practice through collaborative, iterative design.

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International Society of the Learning Sciences

Embodied Cognition in Virtual Reality to Support Learning of Scale

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Abstract: This work-in-progress poster reports on the development process of a virtual environment to support embodied cognition about the scale of scientific entities from subatomic particles to galaxies. Research shows that learners struggle to comprehend the sizes of entities beyond human scale. In order to determine specific entities to use in the virtual environment, a document analysis of US K-undergraduate science education standards was undertaken. Entities, categories of entities, and ranges of sizes were identified.

Introduction

The US Next Generation Science Standards propose "scale, proportion, and quantity" as a crosscutting concept that pervades science and can aid students in making connections across topics, disciplines, and grades in order to construct a more robust understanding of science (National Research Council, 2012). While cutting-edge STEM is being conducted at extremes of scale, research shows that learners of all ages hold inaccurate ideas about the size of scientifically relevant entities (Delgado et al., 2015; Magaña et al., 2012; Tretter et al., 2006a, 2006b). Science standards require that students consider scales that exist beyond their direct everyday experience. To address this issue, our research project is developing a virtual reality (VR) in which students shrink or grow to the size of atoms or galaxies, and experience scientific entities directly and in an embodied manner through VR. This paper reports on our process of selecting entities for the Cave Automatic Virtual Environment.

Theoretical Background

The theory of embodied cognition holds that understanding the mind requires acknowledgment of its inextricable relationship to a "physical body that interacts with the world" (Wilson, 2002). Virtual reality has the power of creating vivid three-dimensional representations of entities that cannot otherwise be experienced directly. The multimodal immersive experiences of VR may enhance a learner's experiential lexicon of scientific *entities* through embodied interaction and cognition — "[a]n entity is an iconic thing, a meaningful whole on its own," which instantiates a concept (Peterson et al., 2021, p. 321). This embodied cognition may support the learning of well-developed, accurate conceptions of scale. We posit that this understanding of scale can help fulfill the promise of crosscutting concepts in supporting the development of connected understanding of science. The entities selected to populate the virtual environment will play an important role in student learning, ideally becoming scale landmarks (Tretter et al., 2006b) that serve to anchor a mental number line for scale. Entities mentioned in the standards likely appear in the curriculum, and may become landmarks in student cognition.

Methods

We conducted a document analysis of the K-12 (NGSS Lead States, 2013) and college science standards (College Board, 2009) to determine what entities are referenced. The first author, a doctoral student in science education, analyzed the standards, using a constant comparative method (Corbin & Strauss, 2008) with an *a priori* code of named entities (e.g., sea otter, amoeba). Upon analysis of the initial list, the team determined that the standards frequently referenced *categories* of entities (e.g., microorganisms, autotrophs) rather than specific instances, or phenomena that span a *range* of sizes. A category is a group of entities with a small variability in size; a range involves groups of entities or phenomena that spanned several powers of 10. We incorporated categories and ranges as emergent themes into the analysis. We again reviewed the standards, coding for categories and ranges. Some entities were not included because they were pieces of a whole (e.g., human foot, head of a pin). Some groups of entities were not included because ranges could not clearly be defined (e.g., mentions of "all objects"). We then determined the absolute size of each entity using the largest measurement in any given direction. We foresee productive discussions with colleagues from other countries with different educational standards, who may have different insights as to what entities, categories, and ranges are important in science.

Findings

The analysis of the standards yielded 251 entities, 194 categories, and 14 ranges. Examples of each are presented in Table 1, for a subset of sizes (10^{-10} to 10^{2} m). The largest named entity was the Milky Way Galaxy (10^{21} m) and

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the smallest was the electron (10^{-18} m). The categories spanned large portions of the scale with the smallest being subatomic particles and the largest being galaxies. Ranges were limited in quantity but also spanned the entire range; they included gamma rays on the lower bound and solar system bodies on the upper bound. The named entities are concentrated within ranges of the scale with approximately 53% of entities falling between 10^{-2} m to 10^{1} m, approximately 23% between 10^{-10} m to 10^{-9} m, and approximately 7% appearing above 10^{2} m.

Table 1
Sample Entities, Categories, and Ranges for 10^{-10} to 10^{2} m

Size, m	Named Entities	Categories	Ranges	
10^{-10} to 10^{-9}	Water Molecule		X Rays	Electron and Scanning Probe Microscopes
10^{-9} to 10^{-8}	Chromosome	Cell components		
10^{-8} to 10^{-7}	Plasmodesmata		Ultraviolet/Visible Light	Optical Microscope
10^{-7} to 10^{-6}	HIV virus	Viruses		
10^{-6} to 10^{-5}	Mitochondrion, Bacteria	Cells		
10^{-5} to 10^{-4}	Animal Cell		Infrared Radiation	Visible
10^{-4} to 10^{-3}	Amoeba	Insects		
10^{-3} to 10^{-2}	Drosophila (Fruit Fly)			
10^{-2} to 10^{-1}	Bumble Bee		Microwaves	
10^{-1} to 10^{0}	Chipmunk	Mammals		
10^{0} to 10^{1}	Sea Otter			
10^{1} to 10^{2}	Box Elder	Vehicles	Radio Waves	

Discussion and Implications

Document analysis of US science education standards suggested a set of entities, categories, and ranges that can be used purposefully in a virtual environment to support embodied cognition and learning about scale. The emergent finding that categories of entities and ranges of entities or phenomena are prevalent in the standards widens the variety of entities to be conceptualized in terms of scale. Exemplars from categories can be selected based on our experience with science curriculum and their feasibility in the virtual environment. Ranges might correspond to multimodal cues; for example, entities in ranges below the reach of optical microscopy might be rendered in grayscale. Preliminary research with a prototype virtual environment shows that undergraduates and teachers find it helpful in developing their conceptions of scale.

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International Society of the Learning Sciences

Science Teachers' Ideological Shifts about Multilingual Learners

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Abstract: Drawing on theories of ideologies in interaction, this poster considers the extent to which professional development supported elementary teachers' rearticulations of monolingual ideologies toward expansive views of young multilingual learners' capabilities in science.

Motivation and conceptual framework

In STEM classrooms, leveraging multilingual and multimodal resources can contribute to more equitable learning environments for multilingual learners (Pierson et al., 2021). However, learning is shaped by dominant ideologies that privilege "standard" language varieties such as (academic) English, positioning minoritized language varieties as deficient (Flores & Rosa, 2015) and limiting opportunities for meaningful sensemaking. This study considered the extent to which a professional development (PD) project supported teachers in rearticulating monolingual ideologies that constrained learning for multilingual learners in science.

We conceptualize ideologies as powerful and politically non-neutral lenses used to interpret and make sense of students, classrooms, and society (Louie, 2020; Philip, 2011). Ideologies can be constraining, reproducing the status quo, and they can be expansive, challenging and disrupting dominant beliefs about the way things should be. Furthermore, ideologies are complex, fluid, and contradictory, rather than static across contexts (Louie, 2020; Philip, 2011). They can also be rearticulated through interaction (Philip, 2011; Philip et al., 2018).

Method

This work builds on a larger research study supporting elementary teachers in implementing model-based science learning sequences. Yet equitable teaching may have been constrained by pervasive monolingual ideologies (Daniel, 2021). To trace teachers' ideological sensemaking, we drew on Philip's (2011) concept of stance—verbalized sensemaking dependent on the positionality of the speaker. Using interaction analysis (Jordan & Henderson, 1995), we analyzed moments of stance-taking in ideological discourse. We focus on an illustrative case of Marie M., who shifted toward expansive ideologies in the context of our design.

Findings

We compare two moments from our PD. In both moments, Marie (all names are pseudonyms) shared with colleagues a narrative about her 4th grade student Mila's participation in a science lesson on rainbows and light. Mila was a multilingual learner who spoke Swahili and had limited experience with English. We argue that significant shifts in Marie's retelling of the narrative illustrate rearticulations of language ideologies in our larger PD community (see Figure 1).

In our design, our research team initially failed to develop shared language around multilingual learners. As a result, our teachers most often used the term "English Learner" or "EL," the label assigned to students by the school district. However, the use of the label was often expanded beyond students who received district language services. Marie used "EL" in her first narrative (February 2020) to refer to any student who spoke a language other than English. To address this limitation of our design, we spent time in June 2021 discussing systemic labels and how they cast multilingual learners and their language resources as deficit. These conversations were reflected in Marie's second telling of her narrative (June 2021). She noted that some of her students were labeled ELs by the district, and some had exited out of the program, but all students were bilingual. Her clarification demonstrated a shift in her understanding of the EL label by discussing multilingual learners with greater nuance and a greater awareness of bilingualism as a resource (Menken & Sánchez, 2019).

A second shift highlighted how through their interactions as a community, teachers took up more expansive ways of thinking about science sensemaking for multilingual learners. In February 2020, Mila's participation was positioned by Marie as looking, emulating, and copying, assuming that Mila did not understand what she was doing. This was taken up by the group as "step one". The teachers recognized Mila's participation but did not necessarily acknowledge that participation as science sensemaking. By contrast, Mila's participation was framed in June 2021 as one of understanding and engagement. Mila's actions of looking and copying were transformed into seeing and observing, actions that allowed Mila to "catch onto things", leveraging her own

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abilities to draw and her peers' thinking to engage in her own sensemaking. Rather than merely emulating, Mila's participation was reframed as an active effort to draw on multimodal resources to communicate her understanding. The teachers' (re)construction of Mila's participation in the science activity suggests a shift from more constraining to more asset-based ideologies around science learning for multilingual learners.

Figure 1

Science Teachers' Ideological Shifts

Shift 1: Redefining the "EL" label		**Shift 2: Reframing science participation**	
February 2020	**June 2021**	**February 2020**	**June 2021**
Marie: [T]hat's something I've learned this year, because this is my first year working with ELs…my whole class is ELs except for one student, so I have 22 out of 23 students	**Marie:** [Looking at student work] Well, I was trying to, I was trying to determine if they were EL students, but I don't believe that any of these students were. They're all bilingual. But…I think they had tested, they'd exited.	**Marie:** And even…my one little student, my little Mila who has no language, and she does not speak Spanish, she speaks Swahili, she was able to draw a picture just from seeing what the other kids were doing. So, she was able to participate… [S]he can look. And she can kind of emulate what the kids are doing. And sometimes, you know, she can copy…She doesn't know what they mean…But she's learned how to just like copy. **Toni:** Step one. **Sarah:** Step one. **Marie:** Step one, yeah.	**Marie:** [Mila] could see **Sarah:** Right **Marie:** and she could draw. **Kourtney:** [Overlapping] She still had ways to communicate. **Marie:** and she still had ways of also observing her peers….[S]he just observed and was able to just kinda catch onto things.

Discussion and implications

The examples presented here illustrate the rearticulation of ideologies about multilingual learners. We acknowledge that beyond our PD, other factors contribute to these shifts. For example, Marie was seeking EL certification in summer 2021, influencing the ideologies that frame teachers' participation in our PD. We also acknowledge that deficit ideologies such as hierarchical views of language varieties and a privileging of academic vocabulary persisted in our PD discourse, despite activities designed to surface and challenge these ideologies. Further research is needed to understand how PD can support ideological shifts toward equitable science teaching with elementary multilingual learners.

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International Society of the Learning Sciences

Visualizing Family Engagement in Museum Settings

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Abstract: The purpose of the study is to explore the affordances and limitations of information visualization for analyzing video data of small family groups in museum settings. In this paper, we analyze visitor engagement by visualizing space, time, and group interactions. Using observational video data from a museum exhibit, we designed three visualization techniques: *transcript variations, floor plan diagrams,* and *infographic charts*. Using variations of these techniques, we examine each approach's affordances and limitations.

Visualizing visitors' interaction in museum settings

Information visualization involves telling graphical stories, using data for effectively presenting and conveying their meaning, and capturing their patterns in a comprehensive way. Although most visualizations have been utilized heavily in quantitative research, there is still a lack of research on how the method can analyze qualitative data including videos and interviews (Shapiro et al., 2017). High-quality information visualization helps researchers, museum curators, and learning designers understand and analyze visitors' engagement and interaction of the learning process. In this paper, we develop visualization techniques to support analytical processes. We focus on family groups in museum settings due to their complexity but explore applications more broadly for educational research. For the purposes of this research, we created three unique visualizations using video data from a designed museum exhibit that included space, time, and social group interactions. We then evaluate the effectiveness of the visualization techniques by analyzing how those visualizations afford an understanding of visitors' interactions.

Methods

Our research was built on secondary data analysis of *The Walk* exhibit that has been installed in a science museum in the Midwestern United States. The exhibit was developed to support data visualization literacy by allowing visitors to generate and navigate visualization with embodied (i.e., walking and running) interactions at the exhibit (Börner et al., 2016; Peppler et al., 2021). *The Walk* exhibit provides three distinct stations for the experience: a) a *data input station* where visitors can enter their personal data (i.e., height, age, zip codes, favorite activity) on the touch screen, b) a *walk station* where visitors walk towards the finish line for generating embodied data in seconds, and c) a *MAV data output station* that displays data output from previous stations as an interactive data visualization in various styles (i.e., scatter plots, tables, geo-map).

We observed a total of 74 visitor groups and selected three groups, including youth ages 7 to 13. The three groups engaged at the exhibit for more than 8 minutes (i.e., over the average time of 8 minutes) to visualize their interactions. We used three different types of video data across the exhibit: a) videos captured by the *data input station*, b) the *broader view* camera, and c) videos from the *data output screen*. We used the video recordings to track visitors' movement in the exhibit as well as to measure the time spent at each station. We focused on the MAV data output station video to examine visitors' conversations, alongside semi-structured interviews that one of our researchers collected while visitors navigated the MAV data visualization screen. We also used the broader view videos to map visitors' experience at the exhibit by tracing each member's movement and track time spent (i.e., dwell time: how long they stay at the exhibit) at each station along with the layout of the exhibit (Peppler et al., 2021).

Creating visualization techniques

We iteratively developed visualizations to show different aspects of the visitors' engagement. There are three parameters to consider when analyzing the visitor's engagement: 1) visitors' *time*, as a measure of their attention span (Shapiro et al., 2017), 2) visitors' *interaction* (i.e., conversation across the space), and 3) visitors' *movement*. These three parameters apply time and space to represent engagement through the behavior of people. Our visualization techniques include using symbolized icons and graphical illustrations to represent quantitative (i.e., time) and qualitative data (i.e., text, image).

We designed the three categories of visualizations to explore different ways of representing visitor engagement: First, we used transcript variations, typical qualitative research tools used in the learning sciences that show various forms of engagement (Shapiro et al., 2017). We illustrated transcript variations in a table format, which described the observations in each cell as sequences, to evaluate visitors' behavior across the exhibit (see Figure 2a). Second, we generated floor plan diagrams, which presented a layout of the spatial settings across a range of angles in the exhibit. We

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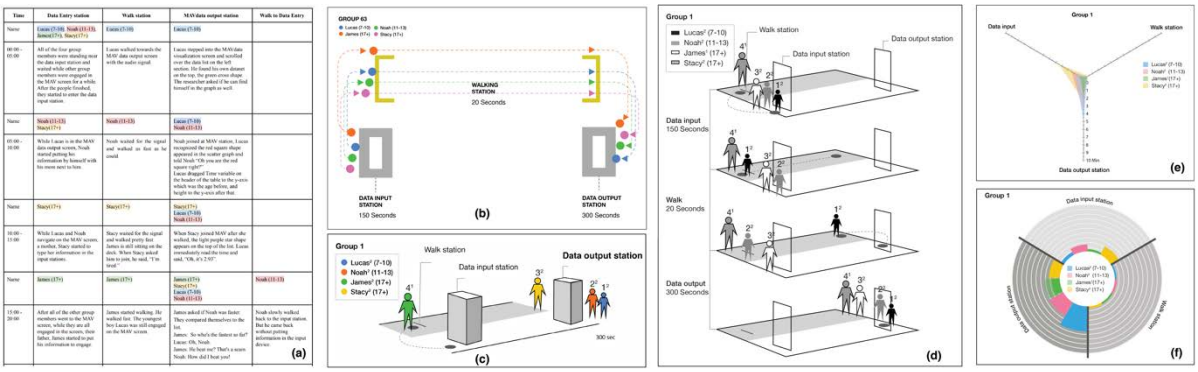
created the floor plan diagrams to illustrate visitors' movement and trace their migration patterns (see Figures 1b, c, d). Lastly, we created infographic charts, which are used to efficiently communicate by creating simplified graphics with design elements using complex data (see Figures 1e, f). The infographics visualization techniques focused on the numeric values such as the *time* spent and the *number of trials* (i.e., some of the visitors tried the exhibit several times).

Findings and Evaluation

We argue that each of the visualization techniques—transcript variation (1a), floor plan diagrams (1b, c, d), and infographics (1e, f)—possesses strengths in one of the three data variables 1) visitors' group interaction, 2) spatial settings, and 3) dwell time. Our findings showed that the *transcript variations*' advantage is to highlight visitor groups' verbal and gestural *interaction*, because it provides textual descriptions on how visitors' make sense of the exhibit. *The floor plan diagrams* focus on visitors' movement across the museum floor, and the layout of the exhibit shows movement patterns. For example, from the top-down bird's eye view floor plan, we can see where each person is located and how they navigated through the exhibit by following the lines. The arrows help make sense of the directions and flows of peoples' movements. The advantages of *infographic charts* (see Figure 1e, f) are in highlighting quantitative values (i.e., dwell time) with the graphical elements (i.e., shapes, colors) with the simplified, symbolized data variables such as individuals, time, and locations. The visualizations are like graphics such as bar charts and scatter plots.

Figure 1

Representative visualization variations under the visualization techniques



Discussion and Implications

This project was conducted through the lens of learning scientists involved with designing information visualization of group interaction in a learning environment. The combination of these three types of visualization techniques will be helpful for showing different perspectives on the visitor's experience in the exhibition. Further, the study shows the potential of using these visualization methods in diverse settings such as schools and homes to review, reflect, and evaluate people's experiences (Shapiro et al., 2017). Approaches of ongoing works around visualizing group interaction can enhance collaboration across data visualization, education, and museum studies. Researchers and museum practitioners will benefit from new opportunities with the visualization techniques in examining and understanding people's engagement in space.

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International Society of the Learning Sciences

Co-Design of AI-enhanced Learning Analytics: Considerations for Ensuring Diversity, Equity, Justice

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Abstract: The majority of the participatory/co-design research has somehow ignored the considerations tackling the diversity, equity, and justice challenges in the design process of learning analytics. We suggest four considerations: (1) while determining the needs and expectations of targeted learners, consider all subgroups of populations (2) determine the transparent and inclusive algorithm for meeting the needs (3) consider diversity and equity for model training data (4) consider heterogeneous participants while testing prototypes of learning analytics.

Introduction

Although learning analytics has huge potential in serving personalized learning opportunities, there are also prevalent concerns on crucial ethical issues such as discrimination and fairness. Specifically, these concerns are related to the degree to which learning analytics can provide different learners from numerous socio-cultural and economic backgrounds with fair intervention (Hansen & Reich, 2015). Due to the integration of artificial intelligence (AI) into learning analytics, algorithms and automated computational methods have been widely utilized. In this regard, algorithmic decision-making of learning analytics has raised some questions on inclusiveness and discrimination levels of these algorithms (De Cremer & De Schutter, 2021).

In order to effectively overcome diversity and equity challenges, the possible solutions require an interdisciplinary collaborative approach involving all stakeholders who benefit from AI-enhanced learning analytics systems (Dollinger & Lodge, 2018). This approach is closely related to the participatory/co-design process. Although important research and initiatives are focusing to (co)- design effective and efficient learning analytics systems with particular learners, the majority of this participatory/co-design research has somehow ignored the considerations /demands of tackling the diversity, equity, and justice challenges in early design and testing process of learning analytics systems (Holstein & Doroudi, 2019). The purpose of the current paper is to determine considerations for ensuring diversity, equity, and justice in the co-design process of AI-enhanced learning analytics. Researchers and developers have utilized the co-design approach to give a voice to learners. Nowadays, co-design has become a well-established approach to facilitate the inclusion of the different stakeholders` needs in the design process. In the current study, the main components of co-design are shown in four iterative steps. The relevant components with descriptions are as follows: *Empathize & Problem Definition (1):* identification of target learners, description of contextual factors *Ideate (2)*: decision on learning approach, identification of learning variables and data modality, determination of AI methods, role of AI methods in the learning analytics tools. *Development of Prototypes (3)*: selection of low fidelity and high-fidelity prototypes. *Test (4)*: implementation of usability test, deployment of LA tools in a real classroom setting.

Methodology

The considerations for co-design of AI-enhanced learning analytics were determined by reviewing literature from various disciplines namely learning analytics, responsible AI use in education, and co-design process for educational technologies. Through the review of related literature, the consideration was selected based on the diversity, equity, and justice from the well-known publications in each research area. The considerations for co-design of AI-enhanced learning analytics were determined by reviewing literature from various disciplines namely learning analytics, responsible AI use in education, and co-design process for educational technologies. Through the review of related literature, the consideration was selected based on the diversity, equity, justice from the well-known publications in each research area (e.g., Hernández-Leo et al., 2019).

Results

The preliminary results as considerations are presented in this section. Initially, we determined four important considerations (C1, C2, C3, and C4).

C1: While determining the needs and expectations of targeted learners, consider all subgroups of populations

As researchers and developers interview or meet with learners to grasp their needs, the participants should represent all learners for equity. In this step, the gender, race, socio-economic characteristics of groups should be formed as equal as possible. C1 can be tackled in the empathize & problem definition (1) step of the co-design process.

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C2: Determine a transparent and inclusive algorithm for meeting the needs and expectations

The prediction results of algorithms should be checked not only for accuracy but also inclusiveness. Transparency of algorithms is also important for justice. Transparency is one of the common ethical use principles and considerations of many AI-based systems (Kitto & Knigt, 2019). Transparency makes AI algorithms of learning analytics more accountable and, thus, the outcome of learning analytics such as adaptive feedback might be more visible and measurable (Ananny & Crawford, 2018). C2 can be performed in the ideate (2) step of the co-design process.

C3: Consider diversity and equity for model training data

In order for AI algorithms of learning analytics to make fair decisions, training data should properly represent targeted learners. Before training AI algorithms based on the data, developers must know how the learners are distributed in the training data set (De Cremer & De Schutter, 2021). The discrepancy could stem from an unbalanced training set within some subgroups due to historical bias. Also, it is more likely that researchers might be biased when they focus conclusions derived from skewed data privileging behavior patterns of more prepared, lower need students (Meaney & Fikes, 2018). C3 can be applied in the ideate (2) and development of prototypes (3) steps of the co-design process.

C4: Consider the heterogeneous participants while testing prototypes of learning analytics

In the testing step of the co-design process, the first versions (prototypes) of developed learning analytics are utilized by learners. Deep understanding is needed to improve prototypes; therefore, the participants testing prototypes should be as diversified as possible. If any learners from different sub-groups have no chance to provide comments, the last version might be lacking their views, intentions and expectations. C4 can be employed in the development of prototypes (3) and test (4) steps of the co-design process.

Conclusions

Personalized and adaptive approaches of learning analytics highlight the advantage of enhancing the equity of learners at different stages. For maximizing this advantage, researchers and developers should perform some co-design considerations. In the current study, we defined four preliminary considerations for ensuring diversity, equity, and justice in the learning analytics systems. Learning analytics developers might integrate these considerations when they carry out the co-design process.

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International Society of the Learning Sciences

Towards a Theory of Dialogic Play for Learning

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Abstract: In this paper, we argue that differentiating dialectic from dialogic play can illuminate important differences between current approaches to game-based learning and can suggest new directions for the field of game-based learning. Expanding on Vygotsky's work on imaginary play, we work towards a theory of dialogic play with particular focus on the role of vulnerability in learning and propose it as an alternative to prior approaches that emphasize content learning or tool-mastery. Because it encourages curriculum that supports new ways of relating to difference and otherness, we believe that dialogic play is important to consider in play-based learning, as it more closely aligns with sociocultural approaches that address issues of power and may be useful in the design of related curriculum.

Introduction

Play is regarded as an important part of learning and child development (e.g., Golinkoff & Hirsh-Pasek, 2006) and has a long history of integration in education (e.g., D'Angour, 2013). In the learning sciences, studies have begun more recently to explicitly explore its role in learning. For example, Saleh et al. (2019), define collaborative inquiry play as: 1) rule-based imaginary situations that provide challenging problems and 2) experiences that present agentic multiplayer interactions and DeLiema, Enyedy and Danish (2019) studied the way play-based practices can drive an inquiry activity, examining how best to support these practices. From these studies, we are better defining and understanding the particular types of play that are good for formal and informal learning, the different contexts in which it occurs, and gaining a better understanding of how that play can be supported. In this paper, we begin to articulate a theory that differentiates two ways to view play - dialectic and dialogic - and argue that this difference can illuminate important differences between current approaches to game-based learning and can inform the design of educational games that are focused less on mastery learning (especially regarding in-game systems and symbols etc.,) and more on players' socially situated and developing identities as well as their relationships with other agents involved in the game (e.g. designer, player). Games and play viewed from this perspective, we argue, can better incorporate a concept of learning as relational and ecological, making them suitable for learning domains that are particularly difficult to teach in higher education, such as ethics (Nardo & Gaydos, 2021). Prior research has noted the importance of post-game discussions for learning (Bado, 2019), and has developed theoretically sophisticated models of the role and relationship between dialog and play (e.g., Chee, 2011). Our theoretical work is different in its focus on the nature of play itself and is rooted in (but departs from) Vygotsky's conception of play-based learning as predominantly dialectic.

Revisiting Vygotsky's Theory of Play

To Vygotsky, play is an important driver of learning and development as it enables children to separate their field of vision from a field of meaning. He points out that it is often mischaracterized as 1) predominantly symbolic action or 2) as simple pleasure-seeking behavior; he rejects both. First, Vygotsky argues that considering play as symbolic action or taking a predominantly cognitivist perspective (e.g., players as algebraists) misses the emotional and motivational components that undeniably drive (especially childhood) play. Second, he maintains that while play includes players taking motivated action to seek pleasure, there are many other activities that children engage in that are more consistently pleasurable (e.g., sucking a pacifier) and that don't include the sometimes-strong negative feelings that accompany play (e.g., losing a game). Play thus seems to involve something distinct from symbolic action and simple pleasure-seeking behavior.

In Vygotsky's conception of play, the child creates *imaginary situations* – play is "the illusory realization of unrealizable desires." On the one hand, this act of imagination can be liberating. Action is untethered from the constraints of reality: "In play a day can take half an hour, and a hundred miles can be covered in five steps." Thinking becomes acting; what the child wishes to happen, happens. On the other hand, playful imagination is purposefully restrictive: Play relies on the creation and expansion of constraints, rules, and boundaries. Through the creation of imaginary situations that enable freedom of action bound by rules, children in play can explore new fields of meaning that adopt increasing sophistication - a stick and later a postcard can transform into a horse, depending on the rules of the game and the developmental state of the child. Because of the rules derived from these imaginary situations, the freedom of meaning exploration is constrained, such as in the way that the child must resist the immediate impulse to treat an object as they see it

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or must abide by what she imagines constitutes a "sister" while role-playing as one. In play, the immediate impulse must be renounced and subordinated under the rules of the game. This constraint creates further opportunity for playful experimentation, for example the subversion of established social rules, or the pleasurable exploration of 'forbidden' emotions (e.g., 'schadenfreude', gloating, feelings of superiority): "For example, the child weeps in play as a patient, but revels as a player", Vygotsky writes.

It is with reference to this rule-following that Vygotsky's description of play can be dissected and alternative views presented. In this poster presentation, we explain our approach in which we frame play as dialogic, drawing on Wegerif's (2007, 2011) notion that learning involves an individual seeing things from two perspectives at once. Reiterating Bakhtin (1987), he argues that "relationships between things are very different from relationships between voices" (Wegerif, 2007, p. 43) and that learning is dependent on establishing and maintaining a dialogic relationship between the learner and the 'other.' This relationship between voices involves creating a 'space' between the self and other within which both "mutually construct and reconstruct each other" as they seek understanding (ibid). A dialogic approach is thus close to but distinct from a dialectic approach, particularly in its purported aims. In a dialectic approach (a la Vygotsky), effective cultural sign and tool use is the primary goal. The dialog is the pedagogical method. The aim of the dialog (under a dialectic model) is for the student to acquire, and for the teacher to transmit, a shared understanding of the socially constructed meaning of tools (Daniels, 2014, p. 20). In formal education, what is to be learned should be congruent with already-established culture norms (e.g., mathematics).

On the other hand, in a dialogic approach to learning, the role of the tool and sign is to provide support and expand dialogues between people with different viewpoints and understandings (Wegerif, 2011). Unlike dialectic learning, tool use and representations may take on multiple provisional meanings as one attempts to understand what the other is saying, these representations may or may not align with cultural norms. Dialog, in this case, creates the opportunity for development (i.e., the ZPD) that does not arise from the difference between the individual's understanding of the tool and the culturally evolved meaning of said tool, but rather from the different interpretations held and voiced by interacting individuals. The result of this kind of dialog is not the dialogic reduction of difference towards a particular aim, but the construction of new meaning that is not already present between the dialog participants (Daniels, 2014). This process of dialog interpretation may involve listening, trying to proceed in conversation, and addressing our own prejudices as we comprehend what the other says and contribute our own voice to the conversation (Vilhauer, 2010). Implications for this alternative approach are further detailed in the poster.

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To Wait or Not to Wait: Adding to the Debate on Immediate Versus Delayed Feedback

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Abstract. Prior work investigates the impact of feedback timing on math performance; however, *when* feedback is most effective remains unclear. We define immediate and delayed feedback and examine how timing affects student algebra performance. 1,629 students were randomly assigned to an immediate or delayed feedback condition, completed a two-hour intervention solving math problems in an online tutoring system, and received immediate or delayed feedback. We found overall learning gains, but no differences between the conditions.

Objectives and theoretical framework

Feedback is commonly used across educational contexts. However, there have been contradictory findings as to *when* it is most effective to provide students with feedback (Fyfe et al., 2021). Feedback timing has been examined in labs (e.g., Brackbill et al., 1963), classrooms (e.g., Sturges, 1978), and online settings (e.g., Kehrer et al., 2013), making it difficult to compare the effects of timing across different environments. Further, prior research has defined immediate and delayed feedback differently, creating a challenge to distill findings. *Immediate feedback* has been used in reference to feedback given post-attempt (Brackbill et al., 1963) as well as immediately after completing a problem set or test (Kulhavy & Anderson, 1972). *Delayed feedback* has been used in reference to feedback delivered at some point after immediate feedback, such as a few seconds post-item (Lintz & Brackbill, 1966), immediately post-assignment (Sturges, 1978), or minutes (Mason & Redmon, 1993) to months post-assignment (Sassenrath et al.1968). Further, research on the effects of feedback timing has shown mixed results: studies have found differing results when comparing the effects of immediate and delayed feedback (Kehrer et al., 2013). For example, Many Classes (Fyfe et al., 2021) compared the effects of immediate feedback, defined as immediately post-assignment, and delayed feedback, defined as one to five days post-assignment. Across 38 college classes and 2,081 participants, the authors did not find a significant effect of timing posttest assessments. We add to the ongoing debate by testing the effect of feedback timing in an online algebra intervention for middle-schoolers. In the current study, we employed two timings of feedback: immediate and delayed. We define *immediate* feedback as hints and correctness feedback provided immediately after a response to a problem and *delayed* feedback as correctness feedback provided immediately after completing an assignment. We pose the following questions:

1. Do students improve their mathematical understanding after completing four assignments?
2. Does immediate or delayed feedback on practice assignments impact students' learning gains?
3. Does students' prior knowledge moderate the effect of feedback timing?

Methods, data sources, and materials

The sample is from a randomized controlled trial run in a district in the Southeastern US during the 2020-2021 school year (Woodrow et al., in prep). We investigate the effects of immediate vs. delayed feedback within ASSISTments (Heffernan & Heffernan, 2014), an online tutoring system. Our sample includes 855 seventh graders (51% immediate; 49% delayed) who started pre- and end-of-semester assessments. Genders were 50% male and 50% female. In terms of race/ethnicity, 52% were White, 27% Asian, 13% Hispanic/Latino, 8% other.

Procedure

All study sessions were administered online in math classrooms during instruction periods. Students worked individually at their own pace on their own device. The analyses focused on the assessment data at 2 time points: start of the semester, and end-of-semester after four 30-minute intervention sessions. Students in both conditions solved the same math problems in ASSISTments. The problems were adapted from three open-source curricula. During the intervention sessions, students had 25 minutes to complete the problems, and five minutes to review their performance on each question. In the *immediate feedback* condition, the hints and correctness feedback were

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available *during* and *after* problem-solving. As students answered the questions, they received immediate correctness feedback after each answer attempt. If students answered the question correctly on the first attempt without using any hints, they received a green check as correctness feedback. If students entered an incorrect answer or used a hint, they received an X. Students received this correctness feedback after each answer attempt and had to enter the correct answer to advance to the next problem. In the *delayed feedback* condition, the hints and correctness feedback were available *only* in the session report *after* assignment completion. Students could not request hints and did not receive correctness feedback during the intervention sessions; they simply answered the problem then advanced to the next question. When students submitted their answer to a question, a blue dot appeared on the screen indicating that the system recorded their answer.

The *algebra knowledge pre-assessment* consisted of 10 items from a previously validated measure that tapped into conceptual understanding, procedural knowledge, and flexibility with a mirrored end-of-semester assessment (Star et al., 2015). Each item was scored as correct (1) or incorrect (0). The total score on the end-of-semester assessment was included as the outcome and the score on the pre-assessment was included as a covariate in analyses.

Results

RQ1. Across both conditions, students' end-of-semester assessment scores were, on average, 0.63 points (95% CI: [0.48,0.77]) higher than their pre-assessment scores, $t_{854}=8.5$, $p<.001$.

RQ2. When condition was the sole predictor, a regression model suggests a small benefit of immediate feedback on students' end-of-semester scores (0.248±0.260), $p<.10$. When including students' pre-assessment scores, fifth-grade state standardized achievement scores, English to Speakers of Other Languages status, Early Intervention Program status, and Individualized Education Program status, gender, and overall academic achievement (above or below grade level) as covariates, the effect of being assigned to immediate feedback was somewhat smaller (0.195±0.248; $t_{723}=1.5$, $p=.12$). Although we cannot confidently determine the sign of the average effect of feedback timing on students' end-of-semester assessment scores, the magnitude of the effect was small ($d<.17$).

RQ3. The interaction between condition and pretest scores was tested with the covariates, and the model shows that the Condition × Pretest interaction (0.062±0.088) was not statistically significant, $p=.169$.

Conclusions and significance

Aligning with the mixed findings in the literature, our results showed that effects of feedback timing on performance—if any—was small in magnitude. However, we did find that students improved from pre-assessment to end-of-semester assessment across conditions, suggesting that both feedback interventions might be beneficial.

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Using Organizational Change Theories to Examine Women-in-Computing Groups

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Abstract: The gender imbalance in computer science is getting worse, with computer science being the only Science, Technology, Engineering, and Mathematics (STEM) field in which women's representation has steadily declined throughout the past few decades. This study focuses on one attempt to redress the lack of women in computer science—Women-in-Computing (WiC) college clubs. Drawing on organizational change theories, we ask: How do students engage in WiC? Do WiC clubs engender changes? If so, how? We argue that WiC is an identity, a community, a safe space, and the beginning of a career-long practice of mentoring future women in computer science. Moreover, changes driven by such clubs have brought impacts to both the individual level students and the organizational level computer science departments. This study offers a new perspective on applying organizational change theories and contributes to the broader research community on diversity, equity, and inclusion in higher education.

Introduction

There are many more men than women in the field of computer science (CS) (e.g., Cohoon & Aspray, 2006; Margolis & Fisher, 2002). And the gender imbalance is getting even worse; computer science is the only STEM field in which women's representation has steadily declined throughout the past few decades (Cohoon & Aspray, 2006; Corbett & Hill, 2015). How can the problems that limit women's participation in computer science be redressed? There have been many efforts, but many may be difficult to replicate on a larger scale, as they relied on a great deal of investment of time and money from high-level administrators.

The current study focuses on one attempt to redress the lack of women in computer science that may provide some of the same benefits as these prior efforts but is relatively expensive and hence more likely to scale, namely, Women-in-Computing (WiC) groups. WiC groups, as one type of on-campus college student groups or clubs, have evolved and developed in the past few years across the U.S. Still, up to now little has been known about the values embedded in these groups and the practices they enact. Because college student groups could potentially benefit student development, leadership development, and organization development (Derby, 2006; Foubert & Grainger, 2006), which may in turn lead to more women participating in computer science, a deep dive into such groups' practice might provide crucial knowledge to understand both the current status of Women-in-CS groups and their future development.

Framework

In *How Colleges Change: Understanding, Leading, and Enacting Change*, Adrianna Kezar (2014) invited readers to think differently about organizational change and provided a multi-faceted framework for understanding change. Through research on how to successfully create change, Kezar (2014) reviewed elements of this change framework that were critical in understanding the change process, including but not limited to *agency of change*, *resistance and obstacles during change*, and *types and levels of change*. By connecting these various features back to the theories of change, Kezar (2014) provided a rationale for why they are important for facilitating change and moving toward action. Therefore, in the context of studying WiC's practices and its impacts, this framework can be extremely useful in articulating the process of change driven by WiC, by decomposing change process into these elements and features. This analytical framework allowed us to examine changes at both the individual level and the organizational level, as well as the group level—which is the club itself—in between.

Method

The participants in this study were members of the Women in Computing (WiC) club at a private university in the Midwest in the United States. Besides general WiC members, particular attention was paid to WiC junior board members and WiC executive board leaders, who hold leadership positions and are in charge of planning and executing WiC events. We chose this focus because WiC execs are not only active members of WiC but also leaders who make organizational level decisions to achieve WiC's goals and reflect WiC's values. The main source of data included participant observations with field notes and video recordings, as well as individual

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interview recordings. We began our qualitative analysis by identifying salient themes, and then focused coding was used to closely examine relationships between themes and identify patterns of relationships. Evidence that we considered in coding included both the actions and movements enacted by the students during the events and the conversations that WiC members had during the events and from the interviews.

Preliminary findings

Our preliminary findings suggest that WiC is an identity-based rather than a membership-based community. Evidence to support this claim comes, in part, from the gender identity and college major of those who attended meetings: Sometimes men attended the events, and there were attendees who self-identified as non-CS majors in almost all of the WiC events. Because WiC stands for Women in Computing, ostensibly these people seem not to fit the definition or purpose of WiC this definition. Then, why did they come to WiC events?

The former president of WiC provided an answer: *"You're in WiC if you are a WiC, like if you're computing, if you want to support. We keep saying it's an identity. There is no membership. You don't have to come to every event… It's an identity. It's a community…"*

The organizational change perspective allowed us to uncover various ways in which WiC is carried on by people in the club. WiC has been sustained through interactions between faculty and students, between upperclassmen and underclassmen, and between the senior executive board and the junior executive board.

Moreover, we gained insight into changes engendered by WiC and the mechanisms for those impacts. At the individual level, WiC organizes events to address imposter syndrome for individuals, and to increase women's sense of belonging in the computer science arena more broadly. At the organizational level, WiC also brings positive impacts to the computer science department, by having its members actively engaged in open dialogues about departmental issues and advocating for recruiting more female faculty members. These efforts ensure cultural and institutional change, which may then help sustaining changes in the long run.

Understanding change is more than assessing impacts; it is also about interpreting and articulating how changes occurred. Guided by our analytical framework, we identified both top-down and bottom-up leadership strategies employed by the WiC exec board, as well as how the exec board functions as a collective leadership.

Implications

Although organizational change theories have been used extensively to examine reform in higher education (e.g., Awbrey, 2005; Gumport, 2000; Kezar, 2011; Kezar, 2014), this perspective has rarely been used to examine changes initiated by college clubs. Therefore, this study is a new attempt to apply organizational change theories in the context of one particular college club and unpack change process by closely examining levels of change, agency of change, and resistance and obstacles. This cross-level approach is useful for describing change phenomenon and change impacts, and also for articulating change process and change mechanisms.

As diversity and inclusion initiatives become increasingly important in higher education, finding new approaches for understanding and facilitating change merits more attention. Because college clubs that are run by students act as a natural bridge between students in the clubs and higher-level institutional leaders who oversee the clubs, the cross-level perspective can be extremely valuable in providing actionable insights for group level changes that serve both individual level and organizational level.

Despite the new approach this study provides, questions remain regarding how representative this particular WiC is, whether findings from this WiC can be expanded or generalized to other Women-in-CS groups or even other types of college clubs for diversity and inclusion missions. Further research is required to fully understand how best to harness the power of college student clubs that allow for broader long-term impacts related to issues of underrepresentation of women in STEM and more general diversity and inclusion issues.

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Validating a Code-Free Computational Thinking Assessment for Elementary School Students: Preliminary Results

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Abstract: Computational thinking (CT) assessments are increasingly available, but it is still challenging to measure the impact of CT interventions. Assessments employing the same coding context as the intervention confer an advantage to treatment students, and possibly also to comparison group students with prior coding experience. Here we report initial findings of our effort to validate a CT assessment without a coding context and to account for prior coding experience in the validation process.

Introduction

The increasing number of computing-related careers has expanded the essential skills students need to develop throughout their school years. Such skills include computational thinking (CT), which Shute et al. (2017) defined as "the conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts" (p. 151). Due to its roots in computer science (CS), CT has been nurtured through engaging students in computer programming or coding-infused activities, such as scientific computational modeling where students build simulations of scientific phenomena in a coding environment. Therefore, many available CT assessments use coding languages as the context of questions (e.g., Román-González et al., 2017; Wiebe et al., 2019). This practice does not align completely with Shute et al.'s CT definition, which includes contexts beyond programming. In addition, using coding contexts in a CT assessment gives students with prior coding experience an advantage because they are more familiar with such representations compared to students with no experience. Hence, such an assessment might lead to biased interpretations and difficulty measuring the impact of CT activities. Relatedly, code-centric CT assessments might not be usable when conducting a study comparing computational modeling activity to a 'business as usual' condition in which students have not been exposed to coding, as the assessment would be overly aligned with the intervention. We encountered such a situation in the project from which this validation study stems. In response, we assembled a coding-free CT assessment for elementary school students to minimize pre-existing differences in students' prior coding experiences. The questions in this CT assessment measure five out of six CT facets proposed by Shute et al. (2017): decomposition, abstraction, algorithms, debugging, and generalization. This paper attempted to answer one research question: is this CT assessment valid and reliable?

Methods

Context and Participants

This study is part of a larger project focused on exploring the impact of learning mathematics through computer programming on fifth graders' CT skills. The study is still ongoing; the data we used in this paper were from the pilot study. A total of 127 fifth-grade students (age $M = 10.52$, $SD = 0.66$) participated in this pilot study and took the CT assessment. These students were from rural areas in a central US state and predominantly White (72%), 2% Black/African American, 1% Latinx, 6% mixed-race, and the remaining 19% did not provide their racial group information. Regarding gender, 46% of students identified as female, 48% male, and 6% opted not to answer the question. The number of students who reported never having any experience with coding (31%) was almost equal to the number of students who had some coding experience (at least a one-time experience learning how to code; 64%), and 5% of students did not report their prior coding experience.

The Code-Free CT Assessment

The pilot assessment was comprised of 16 questions. The questions were drawn mainly from three CT instruments for elementary school students: Bebras CT Challenges, the National Assessment of Educational Progress's (NAEP) mathematical problem-solving questions, and Math and Computational Thinking Through 3D Making (MPACT) assessment. Among the 16 questions, nine were from Bebras Challenges, five were from NAEP, and two were from MPACT. These questions were selected based on their concordance with Shute et al.'s (2017) CT facets. Each question measures multiple CT facets. Hence, we conceptualized that this assessment is unidimensional – measuring one construct, which is CT.

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Analysis and Validation Procedure

Rasch modeling was performed to gather evidence of the assessment's construct validity. Infit and outfit mean-square (MNSQ) values generated through Rasch modeling were used to evaluate whether each question could differentiate students with low CT scores from ones with higher CT scores. The MNSQ cutoff of 0.7 – 1.3 proposed by Wright and Linacre (1994) was used in this study. In addition, differential item functioning (DIF) analysis was run to identify any questions exhibiting bias based on students' prior coding experience. We used the cutoff of $p < .01$ for X^2_{13} to identify significant DIF as suggested by Choi et al. (2011). The questions either flagged as biased in the DIF analysis and/or having infit and outfit MNSQ values outside the acceptable range were removed. Reliabilities were computed using Rasch item and person reliabilities and Cronbach's alpha.

Initial Findings and Future Directions

We found that almost all questions had MNSQ values within the acceptable range and were not flagged as DIF prior experience, except Questions 13 and 16. Question 13 particularly had both MNSQ values outside the acceptable range and were flagged as DIF item, and Question 16 was flagged as a DIF item. We then removed these two questions and re-ran the analysis. The fourteen-question assessment (Table 1) had acceptable person and separation reliabilities as well as Cronbach's alpha values which were .64, .61, and .66, respectively. Furthermore, even though the findings do not yet have high interpretative power due to the limited sample size, we believe that the results are promising, especially toward establishing a more generalizable CT assessment. Hence, we plan to collect more data to strengthen the current findings and to have a more valid and reliable CT assessment for elementary school students.

Table 1

Psychometric properties of the final fourteen-questions CT assessment based on preliminary analyses

Task ID	Item Location	Outfit MNSQ	Infit MNSQ	DIF Prior Experience (p for X^2_{13})
Q_01	0.07	1.01	1.00	0.405
Q_02	1.11	1.12	1.10	0.808
Q_03	-1.21	0.90	0.98	0.893
Q_04	0.41	1.13	1.08	0.185
Q_05	-0.22	1.05	1.03	0.145
Q_06	0.88	0.88	0.90	0.993
Q_07	0.46	1.07	1.03	0.838
Q_08	-0.75	1.02	1.01	0.606
Q_09	0.49	0.95	0.94	0.150
Q_10	0.10	0.98	0.99	0.044
Q_11	0.50	0.99	1.00	0.655
Q_12	0.29	0.92	0.93	0.761
Q_14	-1.12	0.92	0.95	0.095
Q_15	-0.14	1.06	1.04	0.836

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Learning Natural Selection through Computational Models in a High School A.P. Biology Classroom

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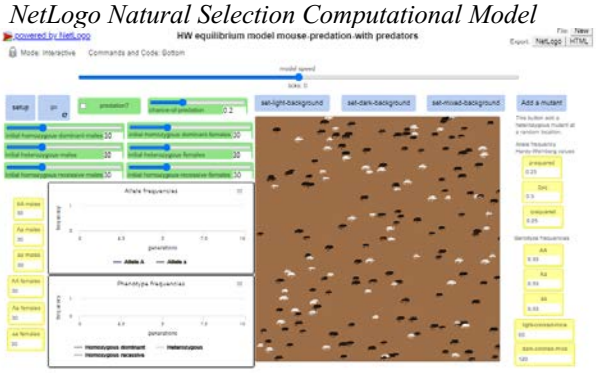
Abstract: Science education communities understand the importance of computational thinking but lack empirically tested learning materials. We report the implementation of a computationally driven natural selection unit in an A.P. high school biology classroom. Epistemic network analyses of student responses indicate that computational tools can facilitate learning of natural selection, and to varying degrees. We interpret these results to show that attention should be given to the fit between computational tools and natural selection concepts.

Introduction and Methods

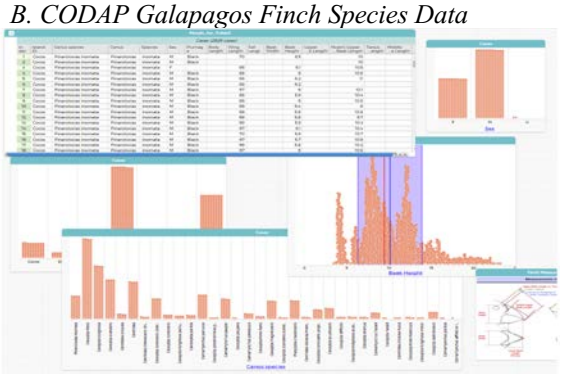
Computational tools and methods have restructured the nature of science. In response to this paradigm shift, and others, computational thinking (CT) has surfaced as a national and scholarly research interest. Due to CT's relative novelty, much of the research on CT has focused on the design of standards and curricular frameworks. Less attention has focused on empirically testing learning materials and exploring CT's ability to promote K-12 science learning (Grover & Pea, 2013). In this paper we report the implementation of a computationally driven unit to address these gaps. Moreover, we extend from previous work involving students' computational modeling of evolutionary processes (Dabholkar et al., 2020) to address the well-established and considerable difficulties students have in learning natural selection (Rosengren et al., 2012). Students in this study (N=35) interacted with four computational tools across an 8 week, 7-lesson unit on natural selection in an A.P. high school biology classroom within a large public school in the U.S. Midwest. We report two tools below in Figure 1: A computational model of natural selection (Dabholkar et al., 2020) developed in NetLogo (Wilensky, 1999) and an interactive data environment about Galapagos finches developed in the Common Online Data Analysis Platform (CODAP, 2014). The following research question guided our work: "How do computational tools facilitate learning of natural selection concepts?" Three researchers used a coding guide (Peel et al., 2019) to code unit questions and student responses. Interrater reliability was high across all codes (K_{avg} = 0.91). We analyzed student responses to two questions embedded in the unit that correspond to distinct computational tools and therefore distinct opportunities to investigate the influence of computational tools on student reasoning. We conducted epistemic network analyses (Shaffer, 2017) to understand (1) student use of natural selection in reasoning about speciation and (2) the effect of computational tools on student use of natural selection concepts.

Figure 1

A. NetLogo Natural Selection Computational Model



B. CODAP Galapagos Finch Species Data



Results

In Figure 2A we report the sum of natural selection concept codes for all students and both questions. In Figure 2B we disaggregate the natural selection concept codes by question and associated computational tool. Figures 2C and 2D show comparative epistemic network graphs of student demonstration of natural selection concepts with the NetLogo computational model (Figure 1A) and after the lesson with CODAP (Figure 1B).

Figure 2

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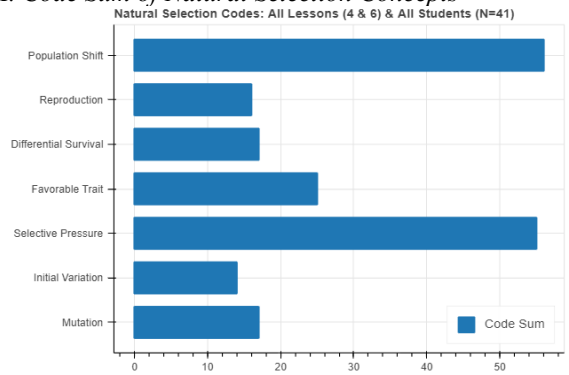
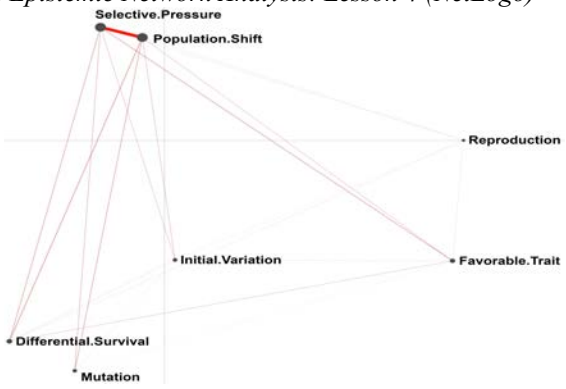
A. Code Sum of Natural Selection Concepts

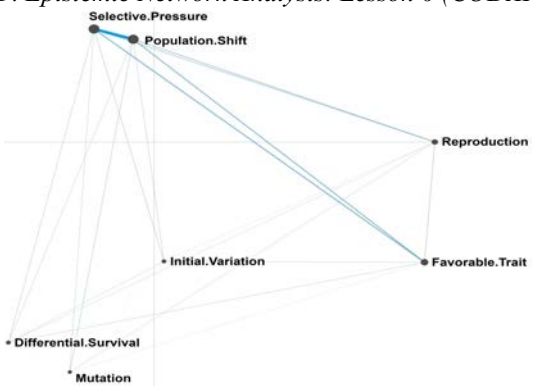


B. Natural Selection Concepts by Lesson (Tool)

C. Epistemic Network Analysis: Lesson 4 (NetLogo)



D. Epistemic Network Analysis: Lesson 6 (CODAP)



Discussion

Analyses indicate that computational tools can facilitate learning of natural selection, and to varying degrees. For example, in lesson 4 students used selective pressure and population shift concepts to explain natural selection in rock pocket mice, but fewer of the five remaining concepts (Figure 2B). Students then applied knowledge of natural selection to explain speciation of finches in the Galapagos and exhibited greater knowledge of favorable traits and reproduction (Figure 2B). We suspect this difference reflects the foregrounding of favorable traits and reproduction in the CODAP environment, which indicates that the explicitness of natural selection concepts in computational tools may lead to deeper learning. Comparative epistemic network analyses (Figure 2C and 2D) further support this interpretation and show that the NetLogo model elicited cooccurrences with differential survival, a key design principle of the model. On the other hand, student reasoning relied more on reproduction in the CODAP environment. Both tools surfaced initial variation and mutation concepts to lesser degrees, corroborating prior challenges found in teaching and learning evolution (Peel et al., 2019; Rosengren et al., 2012). Taken together, these results indicate that future work should investigate the fit between computational tools and natural selection concepts so that designs may better facilitate student learning.

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Exploring Identity Resources in Co-designing Chatbots

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Abstract: Co-design with students honors their lived experiences and invites participants to create novel solutions. We present insights from designing with youth ages 14-16 to create a collaborative chatbot in science. We explore the identity resources (material, relational, and ideational) embedded in the design activities, with implications for how designers and educators can provide access to resources and expand how youths participate in design practices.

Introduction

Co-design invite stakeholders such as students to reimagine learning environments, bring in lived experiences from other contexts, and creatively develop novel approaches (Bang & Vossoughi, 2016). Co-design centers young people's voices and challenges the power structures that underlie learning and participation. Central to recognizing youth's voices is an understanding of the different identity resources—material, relational, and ideational—that they draw from to relate to shared design practices (Nasir & Cooks, 2009; Roque, 2020). Material resources describe the physical artifacts and settings for the practice. Relational resources capture the social relationships that enable youth to strengthen their connections to the practice. Finally, ideational resources describe how youths position themselves and their values within the practice. Individuals use these identity resources to develop their positions within "figured worlds" of socially constructed norms and expectations (Holland et al., 1998). Figured worlds may overlap. For instance, the figured world of a design session might intersect with the figured world of interactions between co-designers and facilitators, and the larger figured world of designing. We explore (1) the features of identity resources that may foster participation in design practices, and (2) how these resources support the figured worlds of design and youths' lived experiences to overlap. Overlapping figured worlds allows individuals to adapt their positions and participation in design practices.

Methodology

The project took place in an environmental science curriculum for students in grades 8-11 in the southwestern U.S. Students learned about a local park's efforts to restrict overfishing, created models of the marine ecosystems, collected and analyzed data on the park's biodiversity, and made recommendations about conservation efforts to park scientists. The chatbot was part of a small-group modeling activity to provide conceptual and participation prompts to students. The research team conducted co-design meetings to align the chatbot's designs and talks with students' values. Participants included one male and four female students (hereon addressed as co-designers). The co-designers, who self-reported interests in science and design, were recruited from classes implementing the curriculum. The design team participated in four 60-minute online sessions over 2 months, where they engaged in activities facilitated by the researchers (a graduate and undergraduate student in Education).

Data sources included design artifacts (e.g., participants' chats, co-designed digital artifacts), field notes written by the facilitators during and immediately after each design session, and participants' verbal reflections before and after the design process. Examples of the reflection questions were "What are you hoping to gain from this experience" and "What are your takeaways from the design process?" The author and a research assistant analyzed data through the lens of identity resources (Nasir & Cooks, 2009), with a focus on how participants interacted with the physical materials, relationships, and self-positioning within design practices.

Findings

Below, we present the material, relational, and ideational resources that may bridge designs and participants' lived experiences, with elaboration on how individuals took up those resources. We further link the resources to the figured worlds that participants mentioned in the design process: A figured world of co-design in which participants and facilitators learned from one another, the figured worlds of home lives, schools, and local environments, and the larger worlds of design. All names are pseudonyms.

Connect material resources to participants' lived experiences

Material resources involve the physical space in which design meetings occurred and the activities and artifacts within that space. The activities intentionally involved artifacts familiar to the participants. The first activity asked participants to find an object in their home and describe how their desired chatbot may take up the object's features (texture, shape, characteristics, etc.). Alice (11th-grader, Asian American female) immediately grabbed a blue stuffed animal on her desk, and stated that the bot should be "round, soft, and cute". Meanwhile, Alex (11th-grader,

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Asian American male) showed the group his home assistant and mentioned "smart and responsive" as desirable chatbot characteristics. Involving familiar objects might have allowed participants to connect the figured world of design and agents and relationships in their home experiences. For example, in designing how the chatbot could provide hints to students in the modeling activities, Manila (10th-grader, Latinx female) stated: "You know, like my Google Home or Alexa, when you ask it questions it replies with information. Our bot can do the same: Oh you're stuck. You can start by thinking about fish, sand, planktons, whales, ..."

Furthermore, the activities spanned beyond the physical space of virtual meetings. Co-designers completed weekly cultural probes (e.g., "take a photo that connects your daily activities such as commuting to schools and the marine ecosystems"). Annie (10th-grader, Latinx female) reflected on how her conversations with friends had revolved around a recent oil spill close to school. This observation led to a discussion in the co-design group around how prompts focused on memorable events might enrich students' responses to the bot.

Promote dialogues

Relational resources involve opportunities for connection with other co-designers and facilitators. The facilitators were intentional about promoting dialogues among participants. Opportunities for connections with others, such as through design role-playing, might enable participants to empathize with the users they were designing for. Consider the overlap of figured worlds of designing, schools, and personal lives in the following vignette.

In a design session, co-designers joined an empathy mapping activity to imagine the profiles of future users with the chatbot, the challenges these fictional profiles may face, and the design opportunities that arose. Co-designers engaged in role-playing to create and act out learner-chatbot dialogues, based on the learner profiles they identified. *Distracted George* was a profile that co-designers came up with, as someone with average science knowledge and can be easily distracted. Co-designers came up with solutions to remind the fictional George that he was *going off-task* or to *alert* the teachers. When asked about the rationale for these solutions, Alex stated that "it's a classroom norm that kids react to". This comment illustrates how youth grounded designs in experiences as learners, often with teachers' monitoring. Later in the design session, following role-playing between the imagined bot and "George", co-designers identified a new strategy for the bots to *share experiences*. Manila suggested: "The bots can say: I will tell you my experience maybe it will help you remember what´s yours, and then tell a little story. This will make it more human and personal." Manila's comments illustrate a shift in her design lens to weave experiences and multiturn, relational conversations with users into the chatbot's dialogues. She positioned the chatbot as a guide for narrative construction, acting as a "human and personal" facilitator.

Foster participants' agency as ideational resources

Ideational resources refer to what is valued within a practice and how youths evaluate their success as designers. Prior to the design sessions, some participants like Manila and Annie had reservations that they were "not computer scientists" because they "haven't built technologies". They often turned to the facilitators to evaluate the design solutions with questions such as "does that sound right?" We saw this as an opportunity to remind students of practices that designers leveraged, such as user testing. Between the third and fourth design sessions, the co-design team administered a written survey to an external audience—38 eighth-graders who were also taking the marine science curriculum. The survey asked the eighth graders to choose between the co-designed dialogues (e.g., off-task nudge versus storytelling). Co-designers then went over the survey results together. This process allowed youth to position themselves as designers evaluating their work with a broader audience. Manila reflected, "I'm excited because there are only a few of us here, so it's nice to hear how others like what we design".

In this work, we outline the identity resources that allow young people to build from experiences at home, in school, and as designers. We highlight the utility of materials and artifacts that bridge across physical spaces, the role of dialogues among participants, and the focus on youth's agency to develop ideational resources.

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Machine Learning for Evaluating Critical Data Literacy in Open Online Learning Environments

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Abstract: The study highlights the application of machine learning in assessing critical data literacy in an open online learning network. The study uses Support Vector Machine algorithm to build a predictive model based on a labeled dataset with students' comments on data visualizations. Features that indicate reflection and curiosity can be used with machine learning algorithms to assess the level of critical data literacy in activities that are adaptive to data representation.

Introduction

The use of data visualizations in education is vastly growing and its application in online learning communities is becoming more and more prevalent. In response to this trend, the ability for students to critically reflect, reason and make sense of data is significant in today's learning and teaching processes (Ben-Zvi & Arcavi, 2001; Kjelvik & Schultheis, 2019). This implies that the development of critical data literacy is imperative in order to nurture competent problem solvers and well-informed digital citizens. Critical data literacy goes beyond the ability to use data, it entails the ability to reason and demonstrate higher order thinking and evaluate data in rich contexts (Hautea et al., 2017). As much as there has been a surge of open learning environments that use data visualizations for teaching and learning, there is still a gap in effective assessment of how students engage and demonstrate critical data literacy in these contexts. We therefore take advantage of machine learning to assess critical data literacy since it presents potential in conducting evaluations of complex environments (Zhai et al., 2020). In this study we base our investigation on an open learning network, New York Times Learning Network (Peralta et al., 2021), by extracting students' comments from the following four data visualization activities: Climate Threats (Network, T. L., 2020a), World Cities' Air Pollution (Network, T. L., 2021), U.S Wellbeing (Network, T. L., 2020b), and First Vaccinated (Network, T. L., 2020c). The main objective of this study is to highlight how machine learning can be used to assess the demonstration of critical data literacy in open learning environments. The main research question guiding this study is: How can machine learning be used to assess learners' critical data literacy in open online learning environments?

Method

The source dataset consisting of 1024 student responses from New York Times Learning Network data visualization activities was used for building a machine learning model. Since the analysis took the form of supervised learning, the dataset consisted of a human-labelled column called *More Information*. Kappa was found to be above 0.8 for this label, indicating good reliability. The label relates to the extent to which the student demonstrates curiosity about other data that the featured visualization did not show. This could be a future trend or when the student sought more contexts to interpret data trends. The column had binary labels of "1" and "0". Label "1" for the comments that indicated demonstration of data literacy and "0" for those that did not indicate a connection to critical data literacy. The study deployed a cross-validation train-test approach to split the dataset into two parts at 67% and 33% respectively.

The modelling process was done on LightSIDE, which is an open-source machine learning application for text classification (Mayfield & Rosé, 2013). The initial process involved feature extraction from the training dataset that included 687 observations. The feature configurations were primarily set to unigrams and included punctuations to account for the nature of the prediction exercise which is intended to classify text based on the demonstrated level of curiosity. In this phase a set of 3092 features from the training dataset were extracted as a feature table. The baseline model was built by the Support Vector Machines (SVM) algorithm it was tested on a dataset containing 337 observations. The competing model had the accuracy of 73.77 % and Kappa statistic of 0.27. In order to improve the model, the second feature extraction was performed and at this time, basic feature configuration was set to include "bigrams". The new constructed model had a marginal improvement with accuracy of 76.33% and Kappa of 0.31 ($p=.077$, $t=1.773$).

Findings

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The exploration of the confusion matrix (Mayfield & Rosé, 2013) was performed to identify features that can be used to predict critical data literacy in online learning platforms. The analysis and identification of features was done by considering two elements in LightSIDE, feature weight and frequency. The ideal predictive feature should have high frequency and weight. An analysis of instances containing the features was also performed in order to evaluate the contextual application and to validate the classification. The main identified features were "I_wonder" with feature weight of 0.30 and frequency of 168. This makes the feature a prominent predictor since this combination of words can be associated with curiosity in evaluating data visualizations. The second predictive feature is "graph" which has feature weight of 0.25 and frequency of 152. The feature is a feasible predictor since in analyzed instances, students referred to visualization in their descriptive responses which can be an indication of deep reasoning with data (Lee et al.,2021). The other identified feature is "countries" which had frequency of 24 and weight of 0.148. While tracking this feature in the instances, it was noted that students did comparative analysis between the U.S and other countries which demonstrates application of critical data literacy. Based on these results, we can conclude that, students can demonstrate deep reasoning by expressing curiosity in their descriptive responses and by making contextual references to examined data visualizations in the learning environment. However, despite these results, we have to acknowledge that there are still some gaps, both in the modeling task and in the quality of student responses in the platforms. In the testing set, there are 52 instances that did not indicate critical data literacy. There is an urgent need of developing innovative open learning resources that can support building capacities in critical data literacy.

Conclusion

The increased use of data visualizations in education drives the need for developing innovative solutions for assessing students' demonstration of critical data literacy. The results of this study indicate that machine learning provides promising approaches for evaluating critical data literacy in open learning environments. Features that indicate reflection and curiosity can be used with machine learning algorithms to assess the level of critical data literacy in activities that are adaptive to data representation. The study also calls for the need to develop open educational resources that can support building critical data literacy for students.

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International Society of the Learning Sciences

Game Design Experience for Teachers' Design Thinking in Participatory Design Culture

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Abstract: This case study explored how the experience of game design in the culture of participatory design contributed to teachers' design thinking. Three in-service middle school teachers were invited to be game design partners in an 8-hour workshop, aiming to enhance the reliability and validity of an architecture-based game. Data were collected from in-field observation, screen recording videos, and semi-structured interview debriefing. Three salient themes were extracted to explore teachers' game design experience in relation to their development of design thinking.

Introduction

Design thinking which refers to an analytic and creative process to solve problems is considered as a crucial skill that all students should possess (Razzouk & Shute, 2016). As a result, teachers, as the most important practitioners in K-12 classrooms, play vital roles in teaching design thinking to students in K-12 settings (Bressler & Annetta, 2021). Prior research suggested that the experience of game design is conducive to the development of teachers' design thinking (Bressler & Annetta, 2021). In these studies, teachers were given predefined game design scenario and placed in the position of independent game designers to design their own games.

However, the process of the design and development of a game is complex and difficult in the real world (Hauge et al., 2020). The success of the game design needs efforts and contributions made by various stakeholders (Khaled & Vasalou, 2014), which is called participatory design (PD). As a participatory designer, teachers will act as design partners in the game design process. However, few studies explore whether the experience of game design during the participatory process could contribute to teachers' design thinking. Therefore, it is warranted to investigate what benefits could bring to teachers when involving as game design partners in a situation of PD. Specifically, in the current study, we seek to have teachers contribute their creations to the educational game design process and at the same time learn knowledge and skills with respect to game design to advance their design thinking. The research question guides the entire study is: *How could the experience of game design during the participatory process contribute to teachers' design thinking?*

Methodology

We adopted a descriptive, holistic single case study approach (Yin, 2009) to examine the process and nature of learning by design within the context of participatory design in the case of computer game making. Three in-service math teachers at a suburban middle school in the southeast of United States were invited to be design partners for refining and designing a game called *E-Rebuild*, which is an architecture-based game for teaching conceptual understanding of mathematical concepts and problem solving for middle school students (Ke, 2019). Teachers participated in an 8-hour workshop, including program orientation, play-testing the prototype, as well as integrated brainstorming and interview. We collected data from in-field observation, screen recording videos, and semi-structured interview debriefing. All the collected qualitative data were analyzed by systematic coding followed by thematic analysis.

Findings

Three major themes found in the study pertain to participants' design thinking, including (a) cultivated problem solving skills through iterative troubleshooting, (b) better understanding of the principles of game design, and (c) improved divergent design thinking.

Cultivated problem solving skills through iterative troubleshooting

As observed, PD activities provided participants with iterative troubleshooting and hence cultivated their problem-solving skills. When involving as game design partners in the real-life context, teachers were given opportunities to identify "problems" of game design with respect to their knowledge, skills and expertise. For example, during the interview session, all the participants left comments stating that

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they "*have not done with the Q, E (keys)*". After analyzing this issue in terms of students' abilities, teachers confirmed that their students "*need more assistance in technical operation*". Subsequently, they had fruitful discussions of how to resolve it in the session of brainstorming. For example, Participant 1 suggested "*Hav(ing) a picture with Q, E functions*" as a supplement for "WSAD" keys. Participant 3 suggested associating keys to specific meaningful words, such as "*S equals back, like backwards; and W means forwards*." Even though participants did not have chance to evaluate the feasibility of the proposed solutions in a workshop, they were given opportunities to cultivate problem solving skills which included defining and representing the problem, formulating an expected result, and exploring a possible way of solving the problem.

Better understanding of the principles of game design

Qualitative interviewing indicated that PD activities could support participants' better understanding of the principles of game design. Such learning generally happened during the discussion between participants and members of game design team (e.g., researchers, game designers, and game developers). For instance, one of the design discussions was about "teaching versus experiencing". Participants tended to identify "*What is the idea of learning (unfamiliar game operation) through initiated playing (which caused) students' frustration for the first four or five hours*" instead of "*direct teaching*". Through discussion, participants were informed with the design intention from game designers' perspective that students would better master technical operations (i.e., input mappings) through their experience of interactions in the game.

Improved divergent design thinking

Involving teachers in PD provided opportunities to improve teachers' divergent design thinking, which was a vital stage for constructing individual design proposals. It was occurred when teachers tried to locate similar information in existing data (*E-Rebuild*) and connect it with their previous skills, knowledge, and experience. For instance, in the brainstorming, Participant 3 proposed a solution corresponding to the way to monitor game players' progress. She stated, "*Some thoughts like what a lot of mechanism all you know. Like kind of game success sound effects. I hear like 'Ching-Ching'. Just let you know (what has happened).*"

Discussion and Conclusion

The findings indicated that when participants were actively engaged in the PD process, they had many opportunities to foster their design thinking. Specifically, the experience of game design during the PD process cultivated teachers' problem-solving skills through iterative troubleshooting. Also, the findings show that PD could reinforce participants' design thinking by understanding the basic principles of game design through the discussions with team members. It is in line with the prior research that the PD provides teachers with opportunities of improving their understanding of game design (Bressler & Annetta, 2021). Furthermore, our findings are aligned with prior research that involving teachers in PD helps improve their abilities of divergent design thinking (Hu et al., 2018).

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International Society of the Learning Sciences

The Practices of Documenting in Research-Practice Partnership

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Abstract:
Documenting is critical for shaping and codifying processes in research-practice partnerships (RPPs). Prior work highlights a need for further theorizing of how documenting can support or undermine equitable partnership work. Drawing on practice theory, we examine how RPP documenting practices relate to participation and outcomes. Findings indicate a continuum spanning two affordance-constraint dyads: durable/static versus dynamic/ephemeral. This continuum illustrates how documenting surfaces and addresses tensions, which can inform decisions in RPPs regarding practices of documenting.

Introduction

As research-practice partnerships (RPPs) have emerged as an approach to educational improvement, so too have calls for close analysis of techniques, strategies, and enactment to examine how these partnerships operate. (Coburn & Penuel, 2016). To date, scholars such as Bang and Vossoughi (2016), Philip and colleagues (2018), and Vakil and colleagues (2017) have examined how partnerships come to be enacted through power dynamics. These papers also call on RPP researchers to examine how issues of power and equity come to be lived in partnership work. This poster draws inspiration from these scholars by attending closely to the enactment of partnerships and, more specifically, to the facilitation practices that come to constitute them. By attending to facilitation practices, we argue that insight can be generated into how partnership work comes to be carried out while creating opportunities to interrogate the practices of partnership work to improve them.

In our poster, we seek to surface, interrogate, and complexify *documenting* as a central facilitation practice for RPPs; here, documenting refers to the practice of inscribing actions, words, and relations into artifacts that represent and shape partnership work. While seemingly mundane and commonplace, the practice of documenting is fraught with contradictions that shape how people participate in partnerships. We illustrate how documenting simultaneously excludes and includes, produces durability and enables dynamism, and centralizes and peripheralizes perspectives and people. In this submission, we offer a brief theoretical framing, drawing on practice theory and actor-network theory to focus on practices generally and on documenting specifically. We then illustrate the practice of documenting using cases from two RPPs: one focused on curriculum development and another on participatory design. We argue that attending to the complexity of documenting is essential for talking about, studying, and enacting partnership work, particularly as it pertains to issues of power and equity.

Theoretical framework

Our focus on practices and the practice of documenting in particular is framed by practice theory and actor-network theory. Practice theory is centrally concerned with understanding how social life and organizations come to be produced through situated and recognizable actions (Feldman & Orlikowski, 2011). A core theoretical move in practice theory is to transcend dualisms; rather than viewing two phenomena as opposites (i.e., structure vs. agency), practice theorists view them as relational and mutually constitutive, where structure constrains and enables agency and agency (re)produces, modifies, and combats structure. We use this conceptualization of practice to highlight documenting as a situated and patterned action that is simultaneously inclusive, exclusive, durable, and dynamic (Latour, 1990; 2005).

Methods

We use qualitative case study methodology to examine the effects of internal documenting practices in two RPPs. The first case focused on implementing culturally relevant science curriculum included four university researchers and six high school chemistry/physics teachers. In the second case, educators and researchers co-designed an interactive web-based tool for pre-service teacher education. Partners included three university researchers, two secondary mathematics teachers, and one community educator. For both cases, videos, transcripts, meeting agendas, field notes, and researcher memos were analyzed using thematic coding and descriptive narrative strategies to represent how practices of documenting took place within each RPP and how they influenced facilitation, processes, and outcomes (Charmaz, 2006; Langley, 1999).

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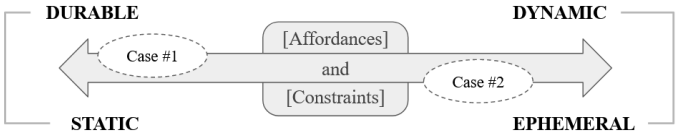
Findings

The first case illuminated practices of documenting that promoted durability of overall RPP processes. University researchers created meeting agendas, feedback surveys, and PDs enabling the creation of routines, known expectations, and decreased workload on partners. However, the lack of documenting partners' needs ultimately led to withdrawal. Partners experienced the static aspect of documenting practices in this RPP as alienating and noted that the concepts and decisions made durable in the process were misaligned with their working contexts. In the second case, participants experienced the commitment to dynamic, open-ended activity as an obstacle to design work due to the ephemeral character of documenting progress. In response, facilitators provided support through a design template intended to increase the durability of participant contributions while still affording opportunities to revise, rearrange, and recontextualize their ideas. The practices of documenting in these cases indicate a continuum that spans between two affordance-constraint dyads (See Figure 1).

Figure 1
Continuum of affordances and constraints in practices of documenting



On one side, the affordance of durable documentation comes with the constraint of being static; by inscribing ideas and choices in permanent forms, RPPs simultaneously enable future activity to refer to past work *and* limit participants' agency to revisit or change the premises of that activity. On the opposite side, the affordance of dynamic documenting entails the constraint of being ephemeral. By keeping the practices of documenting open to change and revision, RPPs both prioritize participants' voice and power in the working process *and* limit the ability of future activity to build on a stable foundation.

Implications

Our findings indicate that the opposing affordances of durability and dynamism are not only both valuable, but coexist to varying extents across different approaches to documenting. As a documenting practice approaches one affordance, however, the attendant constraint exerts a stronger effect, e.g. emphasizing durability entails increasingly static products and participation, while over-valuing dynamism can lead to problematic ephemerality (Latour, 1990). The impact of these constraints manifest as issues of participant agency, inclusion or exclusion, and the centering or marginalizing of participant voices (Vakil et al, 2016; Bang & Vossoughi, 2016). This indicates that while effective and equitable documenting might prioritize one of these affordances, partnership work benefits from cultivating deliberate balances between the two, treating them as a continuum as opposed to mutually exclusive properties. We suggest that facilitators consider which affordance (if either) better supports the context or aims of the activity at hand to inform their decisions about documenting work.

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Embodied Learning in Classrooms: Machine-learning-enhanced Computer Vision for Geometry Math Game

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Abstract: Embodied learning has been considered as an effective way of teaching and learning, having pedagogical potentials. Motion-tracking devices have been frequently used in research; however, it was difficult to apply them in classrooms. To bring embodied learning interventions into K-12 classroom settings, this research used machine learning enhanced computer vision techniques. Three hand gestures that are expected to be mathematically relevant were designed and implemented in a geometry math game through the techniques.

Introduction

As an alternative to Cartesian dualism, embodied learning is based on the belief that the mind is not the only source of knowledge, but rather that learning is taking place within an integrated form of mind and body through sensorimotor activity (Abrahamson & Bakker, 2016). Based on this perspective, embodied learning has been considered an alternative way of teaching and learning in education, garnering the attention of learning scientists and educational researchers working in STEM education (Lindgren et al., 2016; Núñez et al., 1999).

With the development of motion-tracking devices, studies in STEM education have been conducted incorporating embodied learning with digital technologies in various contexts. Lindgren et al. (2016) used a laser-based motion tracking system in a mixed-reality environment to prompt understanding of physics concepts, and Fischer et al. (2016) used digital dance mats arranged in a 3x3 layout to promote mental number-line representation. Focused on learning geometry, Smith et al. (2014) used Kinect for body-based angle tasks to enhance developing ideas about angles. With motion-tracking devices, these research projects have provided significant implications for technology-enhanced embodied interventions; however, it was difficult to bring these technologies into classroom settings.

To bring embodied interventions into K-12 classroom settings, this research used machine-learning-enhanced computer vision techniques in a geometry math game. With the help of machine learning techniques, body movements of students can be precisely tracked by webcam of a laptop or mobile device, without any external devices. Considering an important premise that mathematical understanding should be constructed by connections between mathematical concepts (Hiebert & Carpenter, 1992), I chose geometric concepts to be learned together, based on the mathematics standards in Common Core State Standards. To connect geometric concepts and embodied learning experiences, three hand gestures were designed and implemented in the geometry math game. This poster will lead to productive discussions regarding embodied interventions in STEM education and will provide meaningful ideas on how technologies could impact the way of teaching and learning.

A machine-learning-enhanced computer vision geometry math game

This research used machine-learning-enhanced computer vision techniques with a webcam, instead of using external devices. To detect body movements and hand gestures in real-time, MediaPipe was used. A game engine, Unity3D, was used to display webcam video, game contents, and detected body segments on the device screen. Game contents were gamified with giving rewards systems to increase students' motivation.

A math game focused on learning geometric concepts on two-dimensional shapes. With six two-dimensional shapes ranging from triangles to octagons, students are requested to identify vertices, sides, and angles on the two-dimensional shapes using hand gestures. Various game tasks guide students to embodied learning experiences, and students are requested to engage in certain types of body movements to achieve the goal of the game task. This game design was based on an assumption that students can enhance their understanding when they are engaged in mathematically relevant body movements. Three different hand gestures involve *outlining*, *clapping*, and *making angles*. These hand gestures were implemented in a game using the machine learning enhanced computer vision technique (Table 1).

Outlining is a hand gesture students need to do when they learn about sides of two-dimensional shapes. It refers to moving an index finger from the start to the end of a side on shapes. This hand gesture requires students to infer what sides look like and how many sides are on the shapes. For instance, in a game task for learning about triangles, students need to identify what sides are and move their index finger along the sides of a triangle. *Clapping* is a hand gesture used when students learn about vertices on two-dimensional shapes. As its name represents, clapping refers to two hands clapping. This gesture was implemented to provide experiences of identifying the location of vertices and counting their number. *Making angles* is two hand gestures that students

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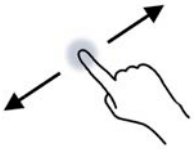
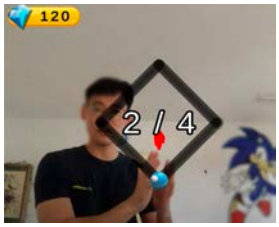
need to use for game tasks about angles on two-dimensional shapes. It refers to making a certain angle with two hands, holding the wrists or middle fingers connected, to make an A or V-like shape. These hand gestures request students to think about the concept of angles and can promote the mathematical meaning-making regarding angles. For instance, in a game task for learning angles on a triangle, students need to identify the center of angle, a vertex, and then represent the size of an angle using two hands.

Table 1

Types of gestures and their implementation in the math game

Type of gestures (Target geometry concept)	Gesture	Implementation in a math game
Outlining (sides)		
Clapping (vertices)		
Making angles (angles)		

Discussion and future work

With the continuous improvement of machine learning techniques and their pedagogical potentials, educational researchers now have more opportunities to facilitate embodied learning in classrooms. In this poster, a machine-learning-enhanced computer vision game was introduced as an effective way of enhancing embodied learning for geometry in classrooms. For future work, this project will investigate the impact of embodied learning on students' geometry understanding, self-efficacy, and engagement, in classroom settings.

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How adolescent learners in a STEM summer camp represent astronomy concepts through a drawing exercise

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Abstract: Learners in an informal, STEM-focused summer camp (n = 19) spent one week exploring hypothetical versions of Earth and known exoplanets in a customized version of the digital sandbox game, Minecraft. On the third day of camp, learners were asked to draw their own exoplanets and incorporate various scientific measurements used in the game (i.e. oxygen levels, temperature, etc..). A semiotics analysis was applied to the drawings to understand how learners use representations to explain scientific phenomena and convey specific contextual themes related to the content of the camp. Outcomes showed about 70% of learner drawings included multiple celestial objects, depicting planetary system relationships.

Introduction

Informal spaces offer opportunities for learners of diverse backgrounds to engage with and explore scientific phenomena. One way to capture how leaners consolidate and make sense of what they experience in a simulation is to ask them to create phenomenological drawings of the representations they interacted with throughout. The research presented in this paper explores how learners in a STEM-focused summer camp represent knowledge and understanding of basic astronomy principles and general scientific relationships through creative drawings of possible exoplanets. A majority of the time in the camp was spent exploring simulated hypothetical versions of Earth (i.e. Earth without a moon) and known exoplanets in the digital sandbox game, Minecraft, and activities such as drawing exoplanets were used to augment the digital experience. Our research explores how learners take concepts from simulated worlds in a digital game and represent them in a generative drawing activity.

Background Literature

Drawing serves as a means to consolidate learning of presented material through choices of how to represent concepts, which allows learners to reason and represent like a scientist trying to communicate ideas to a broad audience (Ainsworth et al., 2011). Drawing is seen as a generative exercise, which can result in deep learning for students (Fiorella & Mayer, 2016).

Visual representations are common in Astronomy textbooks, and learners often adopt features and sample existing conventions they see in textbooks in their own scientific drawings of phenomena (Galano et al., 2018). A semiotic framework created by Tang, Won, and Treagust (2019) took drawings from learners in high school Physics and Chemistry classes and deconstructed all relationships down into presentational, organizational, and orientational representations. To conduct our analysis, we adopted this framework to analyze how middle school learners take what they observe in a digital game setting, Minecraft, and translate those concepts into self-generated visual representations.

Methods

Our summer camp took place at non-profit community center in the Midwestern United States for underrepresented middle and early secondary learners (n = 19, 47% female, all participants identified as Black or African American, age range = 11 – 15 years, all participants eligible for free and reduced lunch). Remote consent was obtained from at least one guardian of each participant.

Participants attended a total of five camp sessions, with each session lasting 3 hours. Most of each camp session was spent exploring hypothetical versions of Earth and known exoplanets in the digital sandbox game, Minecraft. On the third day of each respective camp, participants were given a lesson on known exoplanets: how they are discovered, what we can infer about conditions on specific exoplanets, and whether experts think they might be hospitable to biological life. Simulations of three known exoplanets were then explored in Minecraft. Following exploration, participants were given blank worksheets and asked to draw their own exoplanet. Using the analytic framework from Tang et al., (2019) an undergraduate and graduate student looked at how the drawings were used to convey scientific information and represent relationships between objects. All aspects were discussed and mutually agreed upon.

Results

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Our analysis found most participants (68.4%) depicted multiple objects in their drawings (see *Table 1*). For those that did include multiple objects, we then looked at other categories within the broad frames of presentation, organization, and orientation. Included in Table 1 are the categories and relationships represented by many of the drawings. Considering categories of Distribution, Relative Scale, and Formality, we perceive that most participants drew a representation in earnest that closely resembled what they thought an existing exoplanet could look like and how objects around the planet might be oriented. One relationship we added under the category of Simplicity was "Layered", which we define as using a mix of colors to represent diverse composition of planetary features or atmosphere. This feature was present in 15 (78.9%) of the drawings, and even when participants only drew a single object they often differentiated regions of the planet to represent changes in temperature, oxygen, weather, oceans, or landforms.

Table 1

Semiotic analysis of student-generated drawings

Category	Relationship	Proportion (n = 19)	Definition
Association	Multiple	13 (68.4%)	2 or more objects in relation to each other
Distribution	Pattern	11 (57.9%)	Objects arranged in deliberate distribution
Relative Scale	Realistic	11 (57.9%)	Relative spatial and size accuracy
Abstraction	Macroscopic	19 (100%)	A view seen with the naked eye
Formality	Iconic	13 (68.4%)	Resemblance to real objects
	Layered	15 (78.9%)	Uses color to represent diverse composition
Text Context	Label	11 (57.9%)	Text for individual objects
	Caption	5 (26.3%)	Text for entire diagram

Discussion and Future Directions

Most drawings attempting to depict what could be a realistic situation, absent elements of fantasy or desire, was an encouraging result from an open-ended exercise that did not have any explicit assessment of learner knowledge. This form of self-related information processing has shown promising evidence for triggering interest in science and offering opportunities for learners to develop their interest in STEM (Renninger & Hidi, 2021). Even students who did generate planets that represented personal interests did include some labels or features consistent with themes explored in the informal camp experience.

Future analyses will consider fidelity to concepts conveyed throughout the camp and a more formal assessment of how drawings do convey knowledge and understanding of content presented through discussion and in Minecraft. Scoring drawings could then be correlated with other indicators of student interest in STEM.

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Pre-service Teachers' Growth in Epistemic Cognition through Learning Pedagogical Knowledge

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Abstract: This study examined pre-service teachers' growth in epistemic cognition by learning pedagogical knowledge. We evaluated whether pre-service teachers could describe a classroom practice's aim, processes, and ideals coherently by referring to the pedagogical knowledge they had learned in a course on learning theories. The results suggested that they did not necessarily recognize that aims, processes, and ideals should be coherent as components of the lesson.

Background and Research Purpose

Many studies in recent years have focused on how teachers promote adaptive epistemic cognition. Epistemic cognition is important for teachers to reflect on existing teaching practices and improve them (Lunn Brownlee et al., 2017). Barnes and Fives (2020) investigated in-service teachers' epistemic cognition as the teachers evaluated students' classroom assessments and revealed that the components of epistemic cognition, including *epistemic **A**ims and value, epistemic **I**deals, and **R**eliable processes* (Chinn et al., 2014), emerged in these teachers' assessment processes. However, the teachers rarely justified the reliable processes by citing a source to support their use. Accordingly, preparing teachers to ground their decisions in scientific theories as well as in their own experiences and observations would be a critical focus in pre-service teacher education (Hartmann et al., 2021).

In line with these studies, this study examines whether understanding scientific theories about teaching and learning could promote pre-service teachers' epistemic cognition. We particularly focused on pre-service teachers' cognitive engagement in epistemic performance, identified as an aspect of apt epistemic performance (Barzilai & Chinn, 2018). The purpose of our research was to reveal pre-service teachers' growth in epistemic performance through learning pedagogical knowledge when they have epistemic aims to interpret one recorded lesson presented by video. As a reliable process for this task, we evaluated whether pre-service teachers can describe the lesson's aim, processes, and ideals coherently by referring to the pedagogical knowledge they learned.

Method

Course Description, Participants and Video-based Evaluation

The course that was used in this study comprised a three-day summer intensive course on the design of classroom lessons for 21st century skills. Eighteen university students took the course as part of their program requirements. The course comprised three modules, in which students learned knowledge-centered approach, collaborative learning, and self-regulated learning. Their activities in each module were designed as collaborative multiple text integration using Jigsaw method.

The same video was used to measure pre-service teachers' situation-specific epistemic cognition at the beginning and end of the course, which helped us evaluate their growth after taking the course. The video was a summary of a science lesson on weather and pressure. It was about eleven minutes long. In the video, an experienced female teacher taught eighth-grade students. The students watched the video twice and were asked to describe on their worksheets (1) what they noticed as aims of the lesson, (2) what they noticed as reliable processes, and (3) what they noticed as ideals. The evaluation procedure took about forty minutes in total.

Data Analysis

We developed a coding scheme to capture descriptions of the lesson's aims, processes, and ideals based on pedagogical knowledge that students could have learned through the three modules of our course. In terms of the lesson's aim, we assessed whether the overall goal of the lesson was described. For the processes and ideals, the descriptions were evaluated from the viewpoint of each of the three modules: knowledge-centered approach, collaboration, and self-regulation (1 point for each valid description, 0.5 point for partially valid description).

Results

Almost all students could describe the lesson's aim at the pretest (valid: eight students, partially valid: nine students), and at the posttest (valid: thirteen students, partially valid: four students). We analyzed whether the

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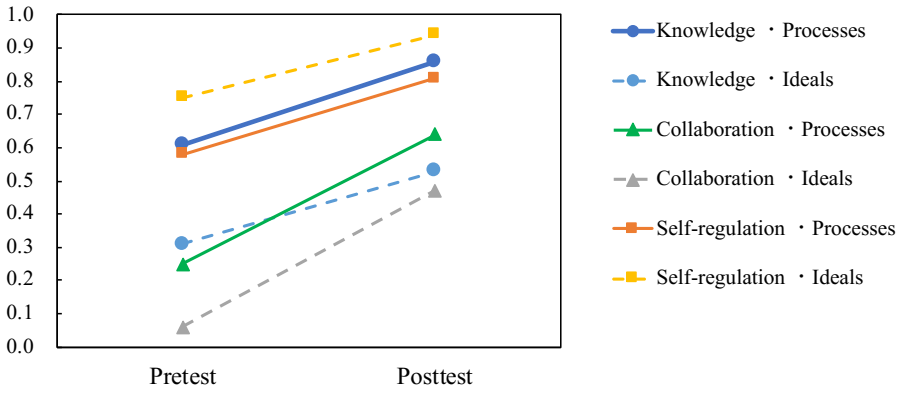
students could describe the lesson's processes and ideals coherently. Figure 1 shows the average scores for the processes and ideals. We conducted a three-factor within-subjects ANOVA for each scale on time (pretest/posttest), modules (knowledge-centered/collaboration/self-regulation), and components (processes/ideals). Significant main effects were identified for the time factor ($F(1,17)=38.08$, $p<.001$), and module factors ($F(2,34)=13.67$, $p<.001$). The total average score increased from pretest to posttest, and multiple comparisons showed significant differences in the module factor (self-regulation > knowledge > collaboration, $p=.05$). Furthermore, a simple interaction effect between modules and components was found ($F(2,34)=5.09$, $p<.05$), and multiple comparisons showed significant differences in the knowledge module (processes > ideals, $p<=05$), in the process component (knowledge, self-regulation > collaboration, $p=.05$), and in the ideal component (self-regulation > knowledge, collaboration, $p<.05$). In the knowledge module, the results showed that the pre-service teachers did not necessarily examine the presented lesson from the viewpoints of both processes and ideals.

Figure 1
Results of the pretest and posttest



Discussion

The findings indicate that pre-service teachers learned to explain the lesson using supportive learning theories during our course. Regarding the knowledge module, they did not necessarily grasp that aims, processes, and ideals should be cohesive as lesson components and tended to focus on processes rather than on ideals. Thus, it was found that our course should be redesigned to support pre-service teachers' epistemic growth in the awareness of coherence among this component. Additionally, the background of those outcomes should be examined by further analysis of the process data, such as the recordings of group discussions or worksheets during our course. Finally, epistemic aims that our students may have had when performing the evaluation task should also be considered. Redesigning the course to promote metacognitive aspects of apt epistemic performance would be beneficial for educating pre-service teachers to explain and question classroom practices in order to improve as teachers and learners.

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A Study of the Development of Evaluation Methods for Dialogical Reports in PBL Classes

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Abstract: This study developed methods of evaluating students' outcomes in remotely conducted project-based learning. "Dialogical reports" which used a hypothetical interview were introduced to encourage reflection on learning outcomes from others' perspectives. As a result of qualitatively analyzing the questions of dialogical reports, it was found that dialogical reports have the potential to encourage reflection on courses from the perspectives of others.

Background and Research Purpose

Higher education is adopting project-based learning (PBL), including inquiry-based learning. While the process of project-based learning gives rich experience to students, evaluating the process of what students have learned and the way they learned is difficult (Shirouzu, 2013).

In project-based learning, it is important that students inquire a lot of questions. Also, when engaging in problem-solving projects, it is important to see things from the perspectives of others. Ordinary report assignments, however, pose only one question, and are therefore not suitable for evaluating the process of project-based learning. It is necessary to promote the creation of interactive deliverables.

We propose "A dialogical report using a hypothetical interview" adopted as the final assignment for the classes in this study. The aim of this study was to verify whether such reports encourage learners to effectively review their learning from the perspective of others. To this end, we focus here upon the questions used in hypothetical interviews, analyzing the types of questions in the dialogical report.

Method and Analysis

The summer quarter classes of 2021 at Y Faculty of X University were conducted over 7 weeks. They were PBL classes related to learning and design, consisting of lectures, practical activities, and group work (Kolodner, 2002). The classes were inquiry-based, and involved paper prototyping, project activities, and review. About 90 students participated in the classes via Zoom. Six teaching assistants joined, facilitating students' discussions.

A dialogical report with hypothetical characters was used for the evaluation. Writing an account of one's own learning outcomes, via dialogue with the characters in a hypothetical interview, is called a dialogical report in this study. Such reports are backed by the multi-vocality concept proposed by Mikhail Bakhtin (1981), in which a variety of opinions from differing positions are presented.

Three important conditions underpin dialogical reports: 1) they are written in a question-and-answer format; 2) the target audience that is expected to read the article is clearly determined; 3) they contain hypothetical characters like interviewer, student, professors, and teaching assistants. The reports were required to be around 2,000 characters in Japanese. In this study, 82 reports were analyzed based on other assignment submissions.

Based on the questions and answers in the hypothetical interview, we analyzed whether they were from the perspective of others (Shirouzu, 2013). The questions in the report were classified as "Facts" or "Recognition". "Facts" refers to questions addressing the facts of course content, and "Recognition" refers to questions addressing the recognition of the author of the report.

Results

The average number of characters in the interview section of the analyzed reports was 2224.4 (SD = 335.2). In hypothetical interviews, the dialogue of one character is defined as a "unit," and one conversation is taken as one unit. This definition of a unit is based on the concept of multi-vocality of Shirouzu (2013).

The average number of units per report was 22.5 (SD = 8.7). In this study, these units were first categorized as "questions" or "answers." Also, units that did not fit into the "questions" or "answers" categories, such as filler words and sounds given during a conversation to show comprehension, were categorized as "other."

From a total of 82 reports, 1,848 units were extracted. The breakdown of the units is as follows: 677 questions, 697 answers, and 474 other units. Among the 677 units categorized as questions, tendencies in 522 questions posed by the interviewer were investigated. Among the 522 questions, 321 (61.5%) were posed by the interviewer to students, 117 (22.4%) were posed to professors, 56 (10.7%) were posed to TAs, and 28 (5.4%)

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were posed to other people outside of these conditions. Because approximately 40% of questions were posed by the interviewer to professors, TAs, and people outside of these conditions, the dialogical reports promote viewing from the other people other than oneself.

The questions were categorized along with the content of the answers. As a result, two categories were created, questions inquiring into "Facts" of classes and questions inquiring into the "Recognition" of the author. Table 1 shows the results of an analysis of the types of questions the interviewer posed to the characters.

Table 1 Proportions of questions posed by the interviewer to characters

Category	Subcategory	Students	Professors	TAs	The others	Total
Facts	Course overall	22(6.9%)	37(31.6%)	9(16.1%)	3(10.7%)	71(13.6%)
	Prototyping	7(2.2%)	9(7.7%)	2(3.6%)	2(7.1%)	20(3.8%)
	Projects	142(44.2%)	11(9.4%)	12(21.4%)	15(53.6%)	180(34.5%)
	Methods	6(1.9%)	21(17.9%)	4(7.1%)	0(0.0%)	31(6.9%)
Recognition	Knowledge acquisition	16(5.0%)	0(0.0%)	3(5.4%)	0(0.0%)	19(3.6%)
	PJ reflection	37(11.5%)	3(2.6%)	9(16.1%)	5(17.9%)	54(10.3%)
	Overall reflection	65(20.2%)	3(2.6%)	4(7.1%)	3(10.7%)	75(14.4%)
	Relativization	25(7.8%)	10(8.5%)	3(5.4%)	0(0.0%)	38(7.3%)
	Intentions	1(0.3%)	23(19.7%)	10(17.9%)	0(0.0%)	34(6.5%)
Total		321(100%)	117(100%)	56(100%)	28(100%)	522(100%)

Regarding the subcategory "Project" of the category "Facts," we will focus on questions from the interviewer to students. As a result, it is apparent that 142 questions (44.2% of questions posed to students), a high proportion, concerned the specific content of projects.

Also, regarding the subcategory "Intentions" of the category "Recognition," we will focus on questions from the interviewer to professors and TAs. As a result, it is apparent that a high proportion addressed the intentions of the course design. In the subcategory "Intentions" of the category "Recognition," there were 23 questions to professors (19.7% of questions to professors) and 10 questions to TAs (17.9% of questions to TAs). Thus, it seems that by creating a dialogical report, learners were able to consider the intentions of the course design by inferring the viewpoints of TAs and professors.

The following is a sample citation from a question regarding "Intentions". An interviewer asks a hypothetical TA if they kept anything in mind when giving support to students in projects. In response, the TA says that they did not give answers directly. It means that the learner created the dialogue based on her experiences.

> Interviewer: This is a question for the TA. Was there anything you kept in mind when giving advice to students?
> TA: Not giving the answer directly (…) Rather than simply telling students they were mistaken or providing the answer, I consciously asked questions designed to make students aware of their mistakes.

Discussion

We have focused on the possibility of the dialogical reports encouraging reflection on their learning. Creating the hypothetical interview can help reflection on their role and viewpoints in the project-based learning. The dialogical reports acted as a tool that allowed learners to review learning outcomes, while themselves assuming a monitoring role (Miyake 1986) and switching viewpoints with others.

However, this study leaves some issues unresolved. We will analyze data such as the discussion process to reveal a relationship between the reports and the learners' learning processes in the PBL.

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Scaffolding math learning and motivation by integrating casual play in computer-based practice for fifth graders

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Abstract: The difficulties experienced by many students in mathematics are characterized by anxiety and lack of motivation to learn. Intrinsic and even extrinsic integration of play, can influence students' attitudes and increase their motivation to learn. The purpose of this study was to examine the effect of external integration of play as a break between exercises in a computer-based tutorial on the topic of fractions. We hypothesized that compared to non-game-based learning, students' perseverance in solving math exercises would increase, which is reflected in performing more questions while investing sufficient time in solving the problems. Our pilot study compares the number practice questions solved between two groups of 5th graders: 30 students in the play condition, and 33 in the control condition. The results show that there is no significant difference in the number of questions answered in each condition, but that integrating play moderates the differences between motivated and less motivated students.

Background

The main challenge in designing digital games for promoting mathematics learning is to balance enjoyment of play and pedagogical support for understanding. A design with *intrinsic integration* of the mathematical content blends the mathematical challenge and the game challenge, whereas *extrinsic integration* combines a sequence of mathematical challenges or tasks with separate, game-based components (Habgood & Ainsworth, 2011). Intrinsic integration has been shown to enhance student learning when compared to an equivalent game with extrinsic integration (Habgood & Ainsworth, 2011), but later studies show that intrinsically integrated digital games do not have significant advantages for learning when compared with paper and pencil exercises, except for enjoyment of the learning process (Castellar, De Marez, & Van Looy, 2015). In addition, educational games that include intrinsic integration with standard mathematics content are much more difficult to develop, than interspersing mathematical tasks with games in extrinsic integration. Specifically, extrinsic integration of mathematics exercises with action games, using score points as incentives is a growing effort (e.g., Rahimi et al., 2021), but there is still little information of its effects on students' motivation to perform mathematical learning activities (Barzilai & Blau, 2014). This poster presents a study of the effects of an extrinsically integrated casual game wrapped together with a mathematics training platform, on student motivation and mathematics learning.

Design

We developed an integrated platform that combines a casual game between the stages of a mathematical training task. The mathematical training task (Figure 1, left) entails fraction comparison questions, that players solve to accumulate points. The casual game (Figure 1, right) is based on a common game - "Flappy Bird" in which the bull-shaped player must collect packages of hay to gain points and avoid obstacles. When the players lose their health points, they are redirected back to the training tasks, and after completing more than six training tasks successfully, the player is redirected to the casual game. The score in the casual game is added to the score of the training task thereby weaving the two activities together.

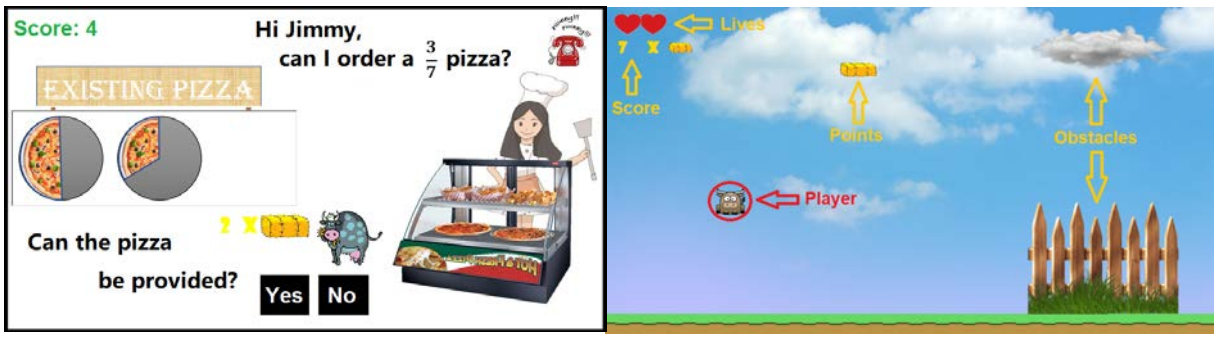

Figure 1 -The two parts of the extrinsically integrated learning platform, with the exercise task (left) and the "jumping bull" casual game (right). Note the "hay stack points", that players can accumulate in both parts of the game

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Method

The study was conducted with 63 students from two fifth grade classrooms from a state religious school with only boys. There were 35 students in classroom A and 28 students in classroom B. We randomly assigned 30 students to the play condition and 33 students to the control condition. The activity spanned 45 minutes and entailed 30 fraction comparison questions as shown in figure 1. We used persistence in completing exercises and the score of correct responses to fractions questions as dependent measures of the effect of the game on motivation and perseverance (Lucas et al., 2015). The time spent on solving questions was also examined and the data was based on log files. Our main hypothesis was that interspersing play during the fraction questions will raise students' motivation that will promote perseverance. However, we also hypothesize that the lure of gameplay will decrease the time students spend on solving, and may be detrimental to solution accuracy. Our research questions were:

1. Is there a difference in the total number of questions answered by the play group and the control group?
2. Is there a significant difference in the average time students devoted to solving questions and in their solution accuracy in each condition?
3. How much of the variance in students' math solution scores, is explained by their game score and time on task?

Results

Both the control group and the play group students answered an average of 27/30 of the questions, but classroom A students (from both groups) answered significantly less questions (26/30) than their counterparts in classroom B (29/30) ($p=0.05$). Also, students from classroom A scored lower on the mathematical exercises (37.5 points) than their peers in classroom B (42.7 points) although the difference was not significant ($p=0.11$). The difference in scores associated with the classroom, was much larger in the control condition (35.8 in A and 44.1 in B) than in the play condition (40.8 in A and 41.8 in B).

To study the 3rd research question, our analysis, revealed that question solution scores in the play condition were strongly correlated with their score on the casual game ($r=0.45$, $p=0.01$). The correlation of the math solution scores with the average time for answering each question was much smaller and non-significant ($r=0.25$, $p=0.19$). In the control condition, the correlation between average time per question and overall performance score on the math problems was significant ($r=0.395$, $p=0.02$).

Discussion and conclusions

Our study examined the effect integrating a casual game into a mathematical tutor on learners' mathematical problems solving. We found that motivation and consequent perseverance in problem solving of the students in classroom A was lower than those in classroom B as indicated in the average number of questions they solved in the tutor, and their average overall scores. However, we also show that the play condition mitigated some of the differences between the classrooms in terms of perseverance in answering the questions, and the overall scores - both were closer in the play condition than in the control condition. Moreover, the correlation between the game score and the tutorial score, indicates a possible motivational connection between the two. In the absence of play, less motivated students in the control condition spent less time on the questions, and their variance in performance was probably a result of their predispositions and grit (Lucas et al., 2015). Our use of the game between the stages of the educational task reflects extrinsic integration since it is detached from the educational content. Previous studies (Habgood & Ainsworth, 2011) have shown that such a combination is less effective than a combination of intrinsically integrated learning software. However, our study indicates that also extrinsic integration which is easier to develop, is beneficial for reducing motivational differences between students in mathematics.

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Online Pre-Service Teacher Learning Communities as a Tool for Teacher Education

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Abstract: The purpose of this descriptive case study was to better understand the characteristics of Teacher Professional Learning Communities(TPLCs) of pre-service teachers(PsTs). Data were derived from 2 TPLCs in which 15 PsTs volunteered to participate, within the context of a pre-school Science Education course they were enrolled in. We analyzed transcripts of videotaped TPLC meetings following the thematic analysis approach. Our findings provide insights about how this group of PsTs utilized opportunities for professional growth.

Theoretical framework

Teacher Professional Learning Communities (TPLCs) as a form of teacher professional development is widely recognized to serve school development associated with better student achievement (e.g., Vescio & Adams, 2015). TPLCs have led to a paradigm shift in teacher professional development (Vescio, Ross, & Adams, 2008), giving teachers a framework to act as students and schools as learning communities, for the teachers themselves (Clarke & Hollingsworth, 2002) in a collaborative, reflective, mutual and collective responsibility (McLaughlin & Talbert, 2006). Participating in TPLCs as early as during their university studies, may provide pre-service teachers (PsTs) the opportunity to be involved in the processes of monitoring and responding to students' learning, and cooperation and mutual support with other teachers. Despite the lack of professional experience, limited or no teaching experience (Kagle, 2014), the involvement of PsTs in TPLCs may provide opportunities for experiencing collaborative learning, reflective practice and the ability to link between teaching practice and learning outcomes. A number of studies have investigated the participation of PsTs in TPLCs. Bond (2013) suggested that through TPLC meetings PsTs started to think critically, to approach pedagogical problems from different perspectives, and to support each other. Kagle (2014) found that PsTs working in TPLCs built basic pedagogical skills, reflected on their practice and professionally addressed the educational challenges. Hoaglund, et al. (2014) reported that PsTs working in TPLCs showed an improvement in their perceptions of the various indicators studied.

The purpose of this study was to develop a better understanding of the characteristics of TPLC of PsTs in the context of their undergraduate studies.

Methods, data sources & analyses

This descriptive case study (Yin, 2017) took part during the Fall 2020 semester, in the context of an undergraduate course in Science Pre-school Education in Cyprus. PsTs in the course volunteered to participate in TPLCs organized as online synchronous sessions. Two TPLCs were created in which a total of 15 PsTs participated for a total of 7 1-hour meetings. All the participants were in the 3rd third year of their studies. They also had no previous experience of participating in TPLCs. All TPLC meetings were video-recorded and transcribed for analysis. Following the thematic analysis approach (Braun & Clarke, 2006; 2012), the two authors read the transcripts independently to identify characteristics of TPLCs of PsTs. During this process, we started with a list of relevant codes from the literature (e.g., Cox, 2004), which was revised and enriched during the process. All data were analyzed by both authors independently and differences were resolved through discussion.

Findings

Our findings suggest several TPLC characteristics related to the nature of running the TPLCs online with PsTs.

1. Student vs Professional Culture: PsTs recognized the need to work within a different culture when it comes to providing feedback to each other. They suggested that when received peer feedback, they mostly got positive comments, without any justifications of comments or any suggestions for improvement. They also acknowledged that solely positive feedback does not lead to any improvement. They suggested the need to work more "professionally", expressing their honest, “still-under-development” professional opinion, and providing more specific comments to each other, so that the feedback can be used to improve their work.

2. TPLC time was used for reflection on the course experiences. PsTs were comfortable sharing and criticizing issues related to the topics discussed in the course, the way their course meetings were structured, and the tasks they had to complete as part of their course obligations. They also talked about their concerns about the

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online form of lectures. This reflection also seemed to help participants use pedagogical ideas that they had discussed during course lecture time, to talk about and evaluate their learning experience in the course.

3. Engagement in small groups. TPLCs participants reported satisfied working in group activities during TPLC meetings regardless of the members of their subgroups. They talked positively about this collaboration and its result.

4. Recognition of the work accomplished in the TPLC meetings. The participants highlighted the importance of the way they worked in the TPLC and the outcomes of their participation. They recognized the effect of the TPLC meetings on the tasks that they had to fulfill, but also on the way they dealt with understanding ideas discussed during the course meetings.

5. Sharing individual/community challenges and outcomes with peers. PLCs participants discussed their responsibilities and the tasks they had to complete as part of their course requirements; they also talked about the feedback they received for particular tasks from the instructor and their peers. They were comfortable sharing the instructor's and their peers' comments. They also referred to personal or group issues from the lecture that they did not understand.

6. Sharing individual/community outcomes with peers. During TPLC meetings, participants felt comfortable sharing both individual and community outcomes from their participation in the course. They referred to outcomes that arose either from the way they work or from the activities they completed in a specific lecture.

7. Identifying ways of collectively responding to individual or community challenges. TPLCs participants recognized the need for a collective response to both individual and collective challenges. In several cases they identified different ways to do so. They referred to actions that they need to take in order to improve the outcomes of their various course assignments, and they talked about ways to resolve their concerns about the ways the course was taught.

Discussion

Most PsTs peer group work is related to working on group assignments or studying together for an exam. However, if TPLC is an instrument of professionalization in the teaching profession (e.g., Vescio & Adams, 2015; Warwas & Helm, 2018; McLaughlin & Talbert, 2006), it is important that PsTs become familiar with it as early as during their teacher education. In combination with university courses on practical issues and phases of internship, participation of PsTs in TPLCs offers the opportunity to anticipate the job, and to practice and to reflect on practical experience. The findings we presented provide insights into the process of professionalization of PsTs. Despite their limited professional experience, PsTs can easily participate in TPLC as early as their teacher studies.

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Eye Movement Tracking During an Embodied Collective Activity in Science Teacher Training

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Abstract: Middle-school science teachers who trained in the field of embodied pedagogy for teaching and learning physics, experienced an embodied collective activity for learning the concept of angular velocity. We tracked the teachers' eye movements during the collective activity in order to characterize their gaze behavior. The findings show that the subjects looked ahead during the activity, in contrast to their verbal report but in line with studies showing that eye movements can precede body movements.

Background

Neuro-pedagogy is an interdisciplinary field that integrates perspectives of the learning sciences and neuroscience. One of the main areas of this field is the study of teaching and learning strategies. Observing the brain can enable an understanding of the effects of different teaching environments and pedagogics. This is a central objective of the research presented in this poster. The pedagogical aspect of our research is based on embodied pedagogy for teaching and learning physics (Zohar et al., 2017). The neurobiological aspect of our research is based on eye-gaze tracking to discover interesting patterns from the field of vision (Duchowski, 2002). A unique feature of this study is the use of eye-tracking for investigating collaborative learning of complex concepts in *full-body movement,* which to the best of our knowledge has not been studied before.

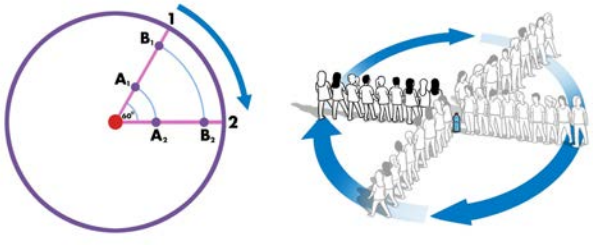
The concept of angular velocity and the embodied collective activity pertaining to it

Embodied pedagogy for teaching and learning physics (Zohar et al.,2017) coheres with the embodiment paradigm that affected educational research (Abrahamson et al., 2020). The assumption underlying this pedagogy is that actual physical experience can be used as a unique resource for learning complex concepts (e.g. angular velocity in physics) by associating them with daily bodily activities.

Angular velocity is defined as the angular displacement of a body over time in a circular path. In Figure 1, we see an example depicting the concept of angular velocity and the embodied collective activity ("collective circular exercise"), which pertains to learning this concept according to our approach. The angular velocity of points A and B moving from their respective point 1 to point 2 is the same because the segments connecting each of the points to the center of the circle advance at the same time at the same angle (see Figure 1a, the angle is 60°). In the collective circular exercise, the learners are asked to walk together around a bottle (see Figure 1b). Using trial and error, they negotiate, verbally and using gestures, a collective method to circle the bottle together. They move to keep the row intact with those farther away from the bottle who walk faster.

Figure 1

Illustration of angular velocity (a), The collective circular exercise: enacting angular velocity by walking around a fixed-point (b).



(a) (b)

Methods and Analysis

Thirty middle-school science teachers experienced the collective circular exercise described above, moving in 6 groups. The teachers were unfamiliar with the concept of angular velocity. This study examined the 12 teachers who stood at the edges of the moving lines (see Figure 1b). We collected data from video recordings and eye movements. We used Pupil Labs eye trackers, which were connected to a cell phone attached to the subject's clothing. This eye tracker device has two cameras for each eye and a head world camera (see Figure 2a).

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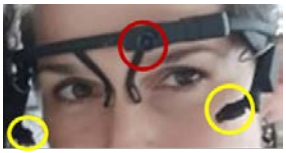
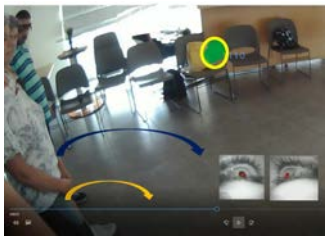
Figure 2
Pupil Labs eye tracker device with one head world camera (circled in red) and two eye cameras (circled in yellow) (a). Snapshot from the Pupil Labs software while performing the collective circular exercise (b). The green dot circled in yellow is the gaze point.



(a)



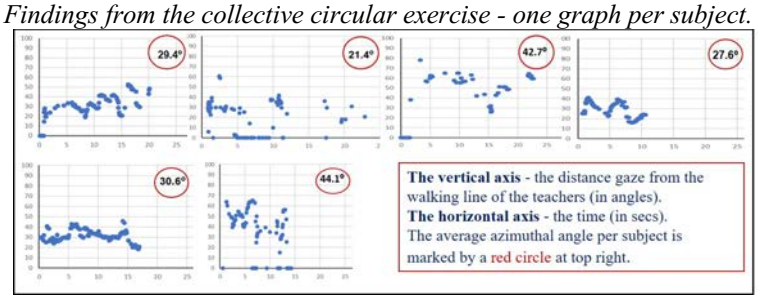
(b)

The collective circular exercise lasted approx. 30 seconds and data from 6 of the 12 subjects was reliable enough for analysis based on the Pupil Labs software. Video tracking analysis used the Pupil Labs software to track the subjects' gaze points during the walking activity. Figure 2b shows a snapshot of the activity as viewed by the subject standing near the bottle at a certain time. The green dot circled in yellow is this subject's gaze point. The output from this subject's two eye cameras is shown in small square images in the bottom right of the figure. The blue and yellow curved arrows indicate the directions of the teachers' movement. Calculations using the software's output provided a measure of the distance gaze from the teachers' walking line in each snapshot in which the gaze could be seen. The distance gaze from the walking line is represented by an azimuthal angle, which is a horizontal angle where the vertex is the subject's head.

Findings and Discussion

Looking-ahead during the embodied collective activity - The graphs in Figure 3 show the distance gaze of every subject from the walking line relative to time during the collective circular exercise. The four graphs at the top of Figure 3 pertain to the subjects who stood near the bottle, and the two graphs at the bottom of Figure 3 pertain to the subjects who stood at the end of the walking line. Dots on the horizontal axis represent a situation where the subject was looking at the walking line, so the measured azimuthal angle is zero. In calculating the average time the subjects looked at the walking line, we found that this was the case in only about 16% of the duration. This finding contradicts the subjects' verbal report, stating that they were constantly looking at the other teachers in the line. However, this coheres with studies showing that eye movements can precede body movements We used a binomial test to examine whether the subjects indeed looked at the walking line for 50% of the activity time, and for each subject, the statistical test showed rejection at a level of $p < 0.05$.

Figure 3
Findings from the collective circular exercise - one graph per subject.



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International Society of the Learning Sciences

Leveraging student-written chapter summaries to assess understanding and motivation in an introductory statistics course

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Abstract: Instructors often assign students to write summaries of what they have learned. Beyond being a helpful learning exercise, written summaries can reveal latent models of what students do and don't understand about the instructional content. Drawing on data from an introductory statistics course, the current study assessed the relationship between written summaries and student understanding and motivation in the course. Findings revealed significant associations which can inform support for struggling learners.

Introduction

Summary writing is an effective method for students to synthesize knowledge, identify misconceptions, and build a mental model of the learning content (Radmacher & Latosi-Sawin, 1995). While a range of research has demonstrated the benefits of summary-writing as a learning exercise, less research has assessed what the content of summaries reveals about student understanding, and how this information can be leveraged by instructors. A handful of studies have utilized advanced natural-language processing algorithms to analyze the syntactic and semantic quality of summaries (Strobl et al., 2019). However, these tools are primarily designed to help students improve their writing skills, not directly to assess understanding. Additionally, to our knowledge, prior research has not studied what a student's written summary reveals about their motivation in the course. Frequent and unintrusive indicators of student motivation can be crucial in preventing learner burnout and dropout, particularly in STEM courses where the 'leaky pipeline' is especially prevalent (Burke, Mattis & Elgar, 2007). The current study analyzed data from an introductory statistics course to examine the relationship between written summaries and student learning and motivation. These preliminary findings lay the groundwork for interventions that can identify and support struggling learners.

Methods

Data in the current study was sourced from 166 students who participated in an introductory statistics course taught in the winter of 2021 at a large public university in Los Angeles. The primary instructional tool was an online textbook developed by the course instructors (see Stigler et al., 2020, for more details). The textbook contained twelve chapters, each of which covered a different statistics concept, such as distributions and modeling variation. Prior to beginning each chapter, students self-reported their motivation by answering three questions that probed their expectancy and value for the course. These questions were abbreviated from the expectancy-value-cost scale developed by Kosovich et al., (2015). At the end of each chapter, students wrote a summary of what they learned and took a practice quiz.

For the purposes of this study, the chapter variables we focused on were the self-reported motivation scores, written summaries, and the end of chapter quiz scores. Metrics from this data were calculated for each student and for each chapter. We also incorporate the students' final exam grade in the analyses. However, due to the COVID-19 pandemic, students were not required to take the final exam, so the sample for these analyses was significantly decreased. Two primary metrics were generated from students' written chapter summaries: summary length and semantic content overlap. Semantic overlap was calculated using the cosine similarity between the term-frequency, inverse-document-frequency (tf-idf) of the chapter text and the students' chapter summary. Table 1 presents examples of student-written summaries from the data with high and low tf-idf similarity values.

Results

The results showed that the length of a chapter summary was positively correlated with chapter quiz score ($r(1818) = .17$, $p < .001$), expectancy ($r(1649) = .10$, $p < .001$) and value ($r(1646) = .08$, $p = .001$). The semantic content similarity between the chapter summary and the chapter content was also associated with quiz score ($r(1818) = .16$, $p < .001$), expectancy ($r(1649) = .17$, $p < .001$) and value ($r(1646) = .10$, $p < .001$). Additionally, average semantic similarity between summary response and chapter content throughout the course was

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predictive of performance on the final exam (R^2= .16, $F(1, 41) = 7.51$, $p < .01$). However, this association did not hold when controlling for summary length.

Table 1

Examples of students' written chapter summaries with high and low tf-idf cosine similarity values

	Chapter summaries of Chapter 10: Confidence Intervals and Their Uses	tf-idf similarity
Student 1	*"The reason we invoked sampling distributions is to model variation in our estimate (in this case the mean) across samples. Sampling distributions help us deal with sampling variation—how much samples from the same population (or Data Generating Process) might vary. We used the sampling distribution to estimate the margin of error—how far off the population mean could be from our estimate…*	0.57
Student 2	*"In this chapter we learned about estimating errors. We also learned about confidence intervals. We further learned about how to use the bootstrapping method to conduct CIs."*	0.03

Discussion

Our findings revealed that summary length and the semantic similarity between summary and chapter content was positively and significantly correlated with both chapter quiz score and student motivation. The link between summaries and quiz scores reveals that written summaries can be an indicator of student knowledge and how well they learned the material. However, due to the correlational nature of these findings, it is difficult to ascertain the direction of causality. For example, it could be that writing a comprehensive summary that drew on diverse content allowed students to learn the material better and perform better on the chapter quiz, a finding well established in the literature. On the other hand, a student who already had a good grasp of the content would write a better summary and perform better on the quiz. We also found that average semantic similarity of summaries was predictive of final exam scores. However, the association did not hold when controlling for summary length. This suggests that more sophisticated metrics of semantic analysis for summaries are necessary to better differentiate student understanding. One future direction is to use latent semantic analysis or keyword and entity extraction in order to pinpoint the exact concepts that students may or may not understand. Interestingly, our results also revealed a positive correlation between summary metrics and student motivation at the beginning of the chapter. One potential explanation for this finding is that motivated students write higher quality summaries. On the other hand, the act of writing a comprehensive summary could increase student motivation in the course. Again, the direct interpretation is elusive and future research should explore the chain of causality, but the significant correlation suggests that summary metrics may serve as a frequent and unobtrusive method to probe motivation in a course.

Conclusion

Although course instructors will often ask students to write summaries of what they have learned, these are most often assigned as a useful learning exercise. However, the findings presented demonstrate that instructors can also derive important insights from this data. Notably, it can indicate how much students retained and their current state of motivation in the course. Instructors can apply this information to tailor instruction or to provide support for students who may be struggling with course content or who are feeling unmotivated. Future studies should explore methods that allow instructors to pinpoint exact misunderstandings from summary data and explore techniques to help instructors digest and act upon this data.

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International Society of the Learning Sciences

Student Profiling on Behavioral Patterns in an Online Mathematics Game: Clustering Using K-Means

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Abstract: This preliminary study examined whether distinct student profiles ($N = 760$) emerged based on their behavioral patterns in an online algebraic learning game. We applied k-means clustering analysis to clickstream data collected in the game and then examined how students' behavioral patterns varied across the clusters using data visualization. The results identified four groups of students based on their in-game behaviors, showing that there was a large variation in their behavioral patterns for engaging with the game.

Introduction

With the rapid development of game technology, there has been an increasing interest in the use of online educational games in mathematics learning. Previous studies have reported that well-designed online games are effective in improving students' mathematical knowledge, skills, and engagement (Chang et al., 2016). However, due to the greater flexibility and interactivity of online educational games compared to other types of educational technology tools, their effects largely depend on many factors, in particular, student behavioral patterns in games (Martin et al., 2015). Thus, it is important to understand how individual students behave differently in the game and how their different behavioral types relate to learning outcomes in order to provide more personalized learning environments (Vandewaetere et al., 2011).

Our team has developed an online mathematics learning game to help middle-school students' algebraic learning. Our previous work has shown that the game is effective in enhancing students' algebraic understanding, but the efficacy varies depending on students' behavioral patterns in the game (Authors, in review). In this study, we aim to replicate the findings of our previous work with a larger dataset that includes a more diverse sample in terms of instructional level and race/ethnicity. Our study addresses the following research questions: 1. How many different clusters emerge based on students' behavioral patterns in the game? 2. How do the students' behavioral patterns vary across the clusters?

Method

The game was developed based on perceptual learning theories to help students' algebraic learning. The goal of the game is to transform the expression into the mathematically equivalent, but perceptually different, target goal using various gesture actions. The game allows students to dynamically manipulate and transform numbers and mathematical symbols on the screen so that they can identify algebraic structures easily and think flexibly. Our sample consisted of 760 (55% male, 45% female) 7th-grade students from ten middle schools located in the Southern U.S. The students played the game individually for nine 30-minutes intervention sessions. For cluster analysis, we included four variables of in-game behaviors that correlated to learning outcomes identified in our earlier work (Authors, in review). These variables were the total number of problems completed, the average number of resets, the proportion of reattempts (i.e., revisiting the completed problem again), and the average pause time (i.e., the amount of time spent before making the first action).

Results

The elbow method was used to determine the optimal number of clusters, suggesting four clusters. The k-means cluster algorithm, selected for its scalability and guaranteed convergence, divided the entire sample into four clusters of students based on their behavioral patterns: Cluster 1 ($n = 188$, 24.7%), Cluster 2 ($n = 186$, 24.5%), Cluster 3 ($n = 76$, 10%), and Cluster 4 ($n = 310$, 40.8%). Figure 2 shows the box plots of four variables of student behavioral patterns by cluster.

The clusters were labeled based on the most dominant characteristics appearing in each cluster: Slow Progressors (Cluster 1) included students who completed the least number of problems, with the lowest proportion of reattempts and average number of resets. Fast Progressors (Cluster 2) included students who completed the largest number of problems but had a low average number of resets, proportion of reattempts, and average pause time. These students sped through the game, completing as many problems as possible, rather than taking time to think about their first step. Slow-Steady Progressors (Cluster 3) included students who had the highest proportion

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of reattempts and average number of resets. This cluster carefully progresses through the problems, resetting and retrying along the way. Intermediate Progressors (Cluster 4) included students who showed middle values for all variables.

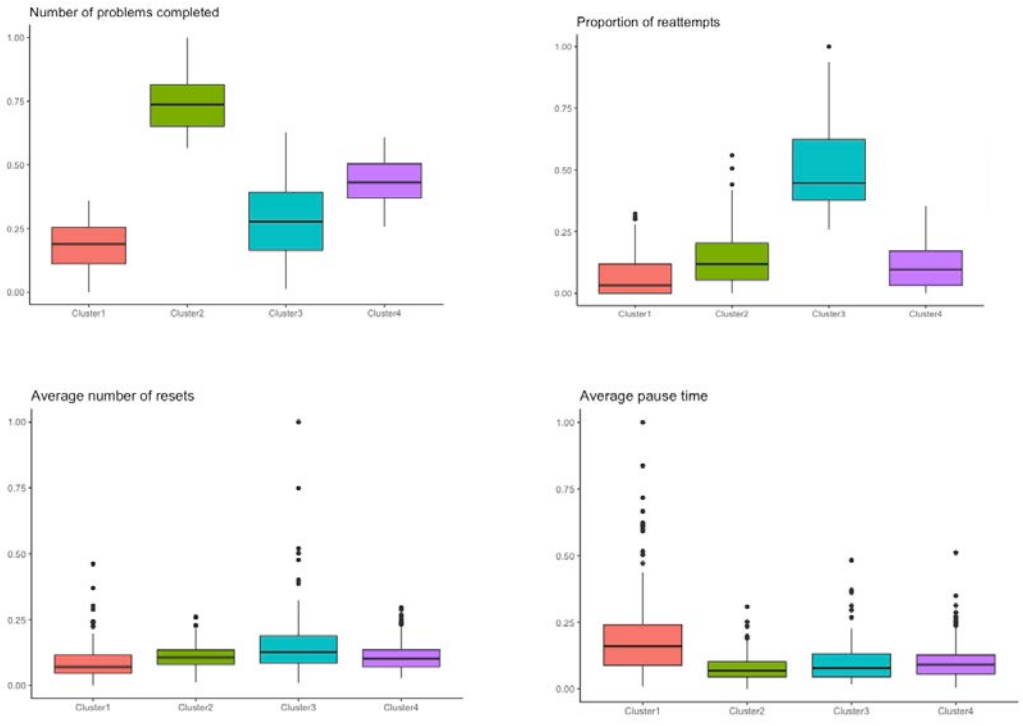

Figure 2

Cluster results depicting the distribution of variables of behavioral patterns for four clusters (Note: Red: Cluster 1- Slow Progressors. Green: Cluster 2- Fast Progressors. Turquoise: Cluster 3- Slow-Steady Progressors. Purple: Cluster 4- Intermediate Progressors)

Discussion

This preliminary study examined whether distinct student profiles emerged based on behavioral patterns in an online algebraic learning game. The results of the k-means cluster analysis identified four distinct groups of students based on in-game behaviors, showing that there was a large variation in their behavioral patterns for engaging with the game. The student profiles identified from the cluster analysis can serve as a basis for building an adaptive learning environment (Vandewaetere et al., 2011). Further research should be done to investigate how these different behavioral patterns correlate to mathematics performance.

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International Society of the Learning Sciences

What We Ought to Know: How Digital Museums Can Facilitate Reflection and Discourse of The Nigerian Civil War

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Abstract: The Nigerian Civil War is a key event often unspoken of in public or taught in schools, despite its aftermath still being felt decades later in Nigerian society. In this paper, we make a case for how a digital museum offers room to reflect, discuss and remember this important part of the country's history. We use design-based research to develop a digital museum to improve access to this history through a diversity of voices.

Introduction

The Nigerian Civil War (NCW), also referred to as the Biafran War, took place from 1967-1970 when Nigerians from the Eastern part of the country made a secession attempt. The number of lives lost are estimated to be between 500,000 to 3 million people (Anthony, 2014). As important and definitive as this event is in Nigerian history and current life, this war has received little productive discourse or reflection in schools and public spaces.

Recent technological advancements in culture and history preservation such as digital museums have provided an opportunity to curate cultures and histories, some of which are controversial, in a low-pressure environment while engaging directly with the public and those impacted by it.

Objectives

With this study, we seek to understand how Nigerians currently learn about the civil war, the role technology can play in this learning process and the importance of spaces of memory in the preservation of history, through the design of a digital museum. As virtual museum spaces are often a replica of physical museum structures inspired by architectural designs, we aim to design a space that is informed primarily by the needs of visitors and those affected by the war, and allow those needs drive the interaction with the exhibition. We also seek to generate more conversations and research on providing more accessible learning materials for learners using virtual reality tools.

Background

There are multiple accounts of the NCW across academia, literature, and media (Dalley, 2013; Omaka, 2014). The digital museum is drawing from these multiple accounts, as well as interviews with a diverse group of Nigerians, to paint a bigger picture in one space where they can be analyzed and studied side-by-side to construct a better understanding of the war and facilitate critical exploration of its different parts.

Virtual museums, offer ideal spaces for cognitive actions of critical thinking, and reflection on some of the more devastating effects of war—like destruction and death—can take place safely with the support, guidance, and scaffolding available for the learning. They also provide an environment for a community of learners to develop where meaning can be constructed and mediated.

Methodology

The paper presents the first iteration of a design-based research project. This first step of this iteration involved carrying out a needs analysis to identify the current issues in the learning about the NCW within Nigeria. This was achieved through interviews with nine Nigerians (between the ages of 18 and 65). The interviews followed a semi-structured protocol designed to elicit personal understanding and experience of the war and individual narratives about the war. These interviews were thematically coded, and the emergent codes allowed us to build a framework to guide our design for a virtual museum focused on the NCW. The framework to understand the learning needs was patterned in the following order: 1) Identifying the current understanding and gaps, 2) uncovering hidden stories and alternative narratives, and 3) highlighting the goals of the study with evidenced-based research, all these with the overall outcome of a richer and more nuanced understanding of the war.

Before describing the design, we first present a summary of the interview responses and analysis.

Interview Results and Analysis

The responses showed a wide range of understanding of the war and how it should be addressed. Some responses evidenced a parallel in thoughts and opinions, while others showed a divergence in opinions and may provide a

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clue as to why even today, this topic remains divisive. We discuss a few of the responses below to highlight particularly important themes:

- *Knowledge of the war.* Most of the participants showed a comparable understanding of basic information around the war and revealed parents and books are the recurring primary sources of information.
- *Silencing of war narratives.* Silencing of historical trauma and personal narratives has been identified as being a prominent outcome in areas with a history of conflict (Liem, 2007). Participants discussed why they thought the war wasn't being discussed enough as a country and explained the existence of the culture of silencing people they believe has been adopted with regards to the war.
- *Monuments and memorials.* Participants expressed the importance of informal spaces, monuments, and memorials about the war. Many comments referred to them as symbols of remembrance, to honour victims and a part of national memory.
- *Future of history Education.* Participants also suggested digital materials and informal spaces such as a digital museum as an ideal platform to present a history of the war, as its controversial nature could make it unsuitable for the formal structure of a classroom, a concern identified by Lindquist (2010).

Design of the Digital Museum

The museum design is guided by the themes that emerged from the interview analysis and the framework of understanding the learning needs referred to in the methodology. Below we describe our first iteration of the design, which can be viewed at www.nigeriancivilwarmuseum.com

Poor knowledge of the war and its impact on the availability of learning resources and spaces was frequently alluded to during the study. To bridge this knowledge gap, the museum is curating learning resources and instructional materials for students and for teachers to incorporate into their lesson plans for use within and outside the classroom. As respondents identified, this digital representation places a low demand on the educational resources available.

The discussion forum in the museum facilitates constructive interaction and fulfils the vital and enriching social aspect of learning. Here, visitors can engage in detailed analysis and productive conversations drawing from the various resources located in different parts of the digital museum space. These interactions also promote varied opinions in the dissection of the history and give strength to minority accounts that often get drowned out. The exchanges are characteristic of a community of learners and the kind of activities that improve the scholarship of the community.

Conclusion

The history of a nation to her people is of great importance, and the education of same is vital. This study proposes a non-traditional approach to achieving this and implementing it within and beyond the classroom and school structure. This digital support of history pedagogy seeks to concretize learning, improve understanding, and provide a more inclusive approach to education using the history of the Nigerian Civil War as an example. Future design iterations will review a more robust curriculum, include more minority voices, engage public and private stakeholders, and aim for integration into the traditional school structure. Through these future iterations we hope to truly impact people's understanding of the Nigerian Civil War and unsilence the important stories and lessons its history can teach the world.

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Designing for Connected Arts Learning through Culturally Sustaining Practices

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Abstract: Community-based arts organizations curate and build experiences rooted in local culture through culturally sustaining practices. Through analysis of interviews with leaders at community-based arts organizations, we found that each took a different route to supporting culturally sustaining arts practices, which enacted relational elements of connected learning environments. We describe three models of culturally sustaining arts approaches (i.e., heritage and history, intergenerational, and youth culture) and suggest that each supports relational elements of connected learning.

Introduction

Connected learning is learning that transpires at the intersection of interests, supportive relationships and academic, civic, and career opportunities (Ito et al., 2020). Community-based arts organizations put connected learning into practice by building learning experiences rooted in local community cultures and culturally sustaining practices (Paris & Alim, 2017). To address key problems of practice facing community-based arts organizations, including communicating the legitimacy of arts education and issues concerning equity (Peppler et al., 2021), we argue that arts organizations can take different routes to supporting culturally sustaining arts practices that enact relational elements of connected learning environments (i.e., shared purpose, shared practices, sponsorship of youth interests, and making connections across settings) to support a framework for 21st century arts learning that includes a broader range of opportunities and outcomes of arts education. To detail the relationship between connected learning and culturally sustaining practices, we compare data from three arts organizations that prioritize culturally-inscribed arts practices for youth. Through analysis of interviews, here we show how three arts organizations take up culturally sustaining practices in different contexts with particular arts practices and organizational priorities, to arrive at cultural sustenance as a learning goal. We consider this work to be a theoretical innovation for describing the different ways in which culturally sustaining arts practices might constitute connected arts learning ecologies with practical implications for the design of arts learning experiences.

Methods

We drew on culturally sustaining pedagogies (Paris & Alim, 2017) and connected learning for our theoretical frame. Taken from a larger dataset, we analyzed interviews with five leaders at three arts organizations, including: 1) The executive director at a multidisciplinary arts organization in Brooklyn, New York; 2) The founding artistic director and executive director at a performing arts organization in Boston, Massachusetts; and 3) The executive and deputy directors at a media arts organization in Salt Lake City, Utah. Organizations were chosen based on practices in alignment with connected learning principles such as making connections to opportunity (for a longer discussion, see Peppler et al., 2021). In our sampling we also aimed for diversity in geographic location and types of arts experiences emphasized (e.g., dance vs. media arts). We took a deductive approach to analysis, using the three domains of connected learning (interests, relationships, opportunities), as well as resonant connected learning themes around shared practices, shared purpose, making connections across settings, and sponsorship of youth interests. As we engaged with the data, we attended to culturally sustaining practices as an emerging theme that enacted elements of connected learning.

Findings: Culturally Sustaining Arts Toward Enactment of Connected Learning

We found that arts organizations took different routes to enacting culturally sustaining arts practices that emphasized relational elements of connected learning environments (i.e., shared purpose, shared practices, sponsorship of youth interests, and making connections across settings). Table 1 presents an overview of models that describe different ways in which organizations supported a culturally sustaining arts approach within their programming. We acknowledge that organizations could take more than one route toward integrating culturally sustaining arts, though we found that one model of culturally sustaining arts prevailed at each organization. In Table 1 we describe each of these models of culturally sustaining arts and use examples to highlight the ways in which arts organizations might leverage relationships with teaching artists to support elements of connected learning environments.

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Table 1
Enacting of culturally sustaining arts across arts organizations and programs

Culturally Sustaining Arts Model	Description of Approach to Culturally Sustaining Arts	Examples of Relational Alignment with Connected Learning Design Principles
Heritage, and History Sustaining Arts	Often found in Black-serving organizations through intentional use of African languages and arts programming grounded in traditional practices, connecting Black neighborhoods where youth live with African heritage *Example: West African drums, conga, capoeira*	Role of the teaching artist is to facilitate interactions that call youth to interrogate history and culture toward a *shared purpose* in better understanding themselves, their communities, and unique histories. "We start from what it means to be a person of African descent, not in relation to whiteness, but in relation to how that impacts how I move through the world" - *Executive Director, Arts Org 1*
Inter-generational Sustaining Arts	Takes a familial, intergenerational approach, understanding how to leverage family relationships to support youth cultures, histories, and art forms *Example: Student and alum arts instructors; parent participation*	Role of the teaching artist is to bring in families as part of the co-organization of arts learning toward *making connections across settings* for learning in youths' lives such as between home and out-of-school contexts. "There's respect, protocol for eldership … this idea of rites of passage ... it's woven into the fabric of what we do and we have found it has been very beneficial for the young people, as well as their parents who learn from their engagement with us." - *Executive Director, Arts Org 2*
Youth Culture Sustaining Arts	Takes a service perspective, working to understand how to best grow and support student voice within the local community context; centers youth culture, often through their interest-driven learning in media arts and technology *Example: Media arts and youth storytelling; Performances to community audiences*	Role of the teaching artist is to *sponsor youth interests* in the arts by celebrating and explicitly connecting them to opportunities, as well as engage in *shared practices* to support interest-driven forms of collaborative artistic production. "They're contributing to the civic discourse in their communities and they're talking about the stuff that's really important to them. The artistic piece is the vehicle for that voice and digital media in particular is really critical" - *Executive Director, Arts Org 3*

Conclusion

Our findings highlighted different models for how arts organizations took up culturally sustaining practices in different contexts (i.e., heritage and history, intergenerational, and youth culture) as well as how through the role of the teaching artist, each culturally sustaining approach supported elements of connected learning. These findings show that arts organizations are actively leveraging culture in its dynamic forms as they work toward curating connected arts learning experiences. Each organization emphasized the role of arts media and traditions to not only engage students through interest-driven learning and boost connected learning environments, but also to connect them to history, family, and their developing voice. Importantly, this work reminds the field to consider the community and cultural roots of youth interests. Practical implications include how arts-based learning and programmatic design might be tailored around connected learning design principles to support culturally sustaining outcomes such as connections to history or youth culture. The theoretical implications of this work include extending how connected learning conceives of culturally sustaining practices through the arts.

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International Society of the Learning Sciences

What if the computer crashes? Findings from an exploratory factor analysis on stressors in online exams

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Abstract: The pandemic has forced higher education to shift from onsite to online environments. This novel situation may increase students' exam stress and induce new stressors. In the present study, we identified stressors in online exams by conducting an exploratory factor analysis of a novel questionnaire. The analysis revealed five factors that categorize students' experience of stress. Preliminary descriptive results suggest that possible system failures and social pressures cause the highest stress for students.

Introduction and related work

Writing an online exam from home was uncommon until a few years ago but has become common practice for many students due to the Corona pandemic. However, to date, only little is known about the students' subjective experience in such new settings and about the stressors they might face in online exams (Harley et al., 2021). For instance, writing an online exam from home involves that students are asked to provide their own technical infrastructure (e.g., hardware, software, internet access). Thus, technical issues presumably arise due to a slower internet connection, poorer hardware quality or outdated or incompatible software. Besides technical problems, also social and emotional aspects of online exam settings might be challenging and stressful for students. Since a higher stress level negatively impacts one's performance (Hafeez et al., 2018) the identification of potential stressors in those novel exam settings is highly relevant. Thus, our goal for this study was to identify and investigate stressors in online exams via exploratory factor analysis. Our results may provide insights for the development of futures online exams.

Method

As part of a larger project at our university, we investigated the subjective experiences of students during online exams. The sample of this study consisted of 93 psychology bachelor students (73 females, 19 males, 1 diverse; M_{age} = 26.81, SD_{age} = 5.14). After finishing their individual exams at the end of the spring semester in 2021, participants were invited (via email) to participate in an online survey (conducted via EFS Survey (2021)) including a total of six scales concerning their subjective experiences in online exams (stressors, emotions, appropriateness of exam formats etc.). Participation in the study took an average time of 16 minutes. The stressors questionnaire consisted of 26 items (e.g., Stress_14; "*The exam software no longer works*") which were created following the scales used in a study by Caltabiano et al. (2021). The participants reported their level of stress (i.e., "*For each of the following statements, please indicate how stressful the situation is for you during an online exam.")* on a scale from 1 – "not stressful at all" to 5 – "extremely stressful". To examine the questionnaire, we conducted an exploratory factor analysis.

Findings

Since a multivariate normality test indicated a non-normal distribution, we conducted the factor analysis with axis factoring instead of maximum likelihood. Moreover, we decided to use an oblimin rotation, which is better suited for an exploratory factor analysis, as we had no indicators for possible correlations between the factors (Osborne, 2015). The exploratory factor analysis yielded five factors, with 18 items indicating sufficient loadings to a factor (> .3) and low complexity (factor loadings are presented in Table 1). The following five factors were derived and named based on the items' common subjects (see Table 1): (1) The factor '*system failures'* consists of items that apply to possible external failures of the exam software or the technical infrastructure. (2) The factor '*social pressure'* includes items regarding stressors that stem from either monitoring through a proctor or social comparison. (3) The factor '*self-inflicted noises'* includes items relating to self-produced noises. (4) The factor '*time indication'* consists of items that convey to stressors inflicted by time indication. Finally, (5) the factor '*external disturbances'* consists of items that assesses stressors inflicted by external factors. We refrained from attributing a total of eight items to the factors, since either the factor loadings were too low, the item was too complex, or the item did not semantically match to the other applied items (even though the factor loadings would

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have been high enough). In a next step, we descriptively investigated the level of stress induced by the respective factors as perceived by the participants. The results suggested that the factor *system failures* caused the highest level of stress (M = 4.67, SD = 0.59), followed by *social pressure* (M = 3.67, SD = 0.75), *external disturbances* (M = 3.35, SD = 0.91), *time indications* (M = 2.47, SD = 1.00), and lastly *self-inflicted noises* (M = 1.63, SD = 0.82). In conclusion, students seem to be afraid that the technical infrastructure, (i.e., soft- or hardware) may cause problems, which presumably might affect their performance in an exam. Moreover, *social pressure* including monitoring during online exams was perceived as second largest stressor by students. Monitoring may also include the presence of a proctor (e.g., through webcam) which – apart from ethical considerations – might also result in additional perceived stress. As a next step we plan to increase our sample and expand it to more universities to subsequently validate the questionnaire with a confirmatory factors analysis. Nevertheless, this study helped us in further developing the questionnaire for future survey of subjective experiences in online exams and may also provide insights for related research.

Table 1

Exploratory Factor Analysis of Stressors in Online Exams.

Items	Factor					Label
	1	2	3	4	5	
Stress_15	**0.917**	-0.023	0.065	-0.022	-0.095	System failures
Stress_16	**0.841**	-0.007	-0.014	-0.015	0.113	
Stress_14	**0.821**	0.034	-0.045	-0.053	0.019	
Stress_13	**0.596**	0.046	0.008	0.043	0.188	
Stress_5	-0.011	**0.705**	0.028	-0.109	0.127	Social pressure
Stress_6	-0.055	**0.613**	0.091	-0.074	0.102	
Stress_23	0.218	**0.578**	-0.068	0.028	-0.058	
Stress_25	0.034	**0.506**	-0.089	0.126	0.047	
Stress_22	0.068	**0.452**	-0.123	0.160	0.146	
Stress_21	0.106	**0.320**	0.152	0.024	0.069	
Stress_8	0.022	-0.081	**0.919**	0.029	-0.001	Self-inflicted noises
Stress_7	-0.037	0.065	**0.908**	0.012	0.020	
Stress_9	0.172	0.074	**0.466**	-0.196	0.019	
Stress_3	-0.055	-0.026	0.031	**0.890**	0.048	Time indications
Stress_1	0.007	0.040	0.009	**0.751**	0.003	
Stress_10	-0.021	0.248	0.112	-0.093	**0.712**	External disturbances
Stress_12	0.098	-0.164	0.055	0.231	**0.614**	
Stress_2	0.090	-0.049	-0.007	0.219	**0.517**	

Note. For each item the largest factor loadings are bold. Due to limited space, items which did not indicate a sufficient factor loading (> .3) were not included in this table.

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Co-developing Immersive Learning Experiences in Interdisciplinary Projects in Upper Secondary Education

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Research topic and aim

Through dialogic design practices, we explore how we can create innovative learning designs with immersive technologies. Existing research has demonstrated the benefits of such technologies in education (see Markowitz et al, 2018), but there is a need to generate more knowledge about how immersive technologies can be integrated with collaborative learning activities (Enyedy & Yoon, 2021). Our aim is to create digitally mediated learning experiences targeting the special interdisciplinary curricular topic of "health and wellbeing". Researchers are working together with teachers from language arts, social science, and sports science to employ Augmented Reality (AR) and Virtual Reality (VR) technologies to create embodied learning experiences that both align with and disrupt existing classroom practices. We do not develop technical immersive solutions, but rely on pre-existing tools. Our focus is on understanding the potentials and pitfalls of introducing immersive experiences, pursuing a dialogic and participatory "bricolage" approach to design practices where participants make creative re-use of available technologies (Richter & Allert, 2017).

The project is ongoing (2020-2023) and in this poster, we account for the project framing, collaborative design work, and concept development. It is important to reflect on the lessons learned during these initial and middle phases of design-based projects, as these processes are often obscured and given less attention in the learning sciences community (Svihla & Reeve, 2016; McKenney & Reeves, 2018). Our study is guided by the research question: *How does teacher-driven innovation develop in the context of the design of immersive pedagogies*?

Across the narrative description of the design work presented below, we identify three ideas as particularly innovative and relevant for the learning sciences community: (1) the unique organization of a design-based project that is initiated and deeply driven by teachers themselves; (2) the "health and wellbeing" concept as a driver of design work; and (3) our approach to immersive technologies as dialogic and collaboratively oriented.

Theory and methodology

In designing and researching immersive technologies in learning, we draw on sociocultural and dialogic approaches emphasizing a more comprehensive understanding of the learner as well as a focus on how learning is inextricably bound up with motivation, identity and features of learning ecologies that learners dwell in (Silseth & Arnseth, 2011). Classrooms are complex learning ecologies and the effects of innovations can be unpredictable. Through developing and testing prototypes, we study how teachers and learners adjust innovative ideas to the classroom context. Prototypes represent solutions to concrete problems and they enable us to test innovative ideas in practice. They also enable and support collaboration through externalizing knowledge into objects that we together can act on. In order to research how design ideas emerge and become materialized into more elaborate designs, we document the process by video-filming activities. We draw on design-based research where the strategy is to engage in mutual development of ideas and practices together with teachers and students (Sandoval & Bell, 2004). Our collaborative relationship with the school came about because the teachers wanted to explore how AR and VR could make learning more engaging and abstract concepts more tangible and meaningful to students.

In the past decade, an increased emphasis has been put on the contributions and status of stakeholders in design-based methodologies, such as social design experiments (Guittérez & Jurow, 2016), research-practice partnerships (Coburn & Penuel, 2016), and recent interpretations of DBR (Bang, et al. 2016). However, we often find that university researchers lead the innovation process. It is therefore important to underline that the problems and issues emerged in and through teachers practical experiences.

Narrative description of the trajectory of design work

Rather than engaging in design and re-design iterations, where these processes are clearly distinguishable, we pursued a dialogic design practice mediated by conceptual artefacts such as sketches, prototypes, or technological resources. In our first meeting, we introduced examples of VR and AR applications to teachers and challenged them to specify and articulate their understandings of the new interdisciplinary topic of "health and wellbeing". Through dialogue issues related to students understanding of the body and how it works came up, as did issues related to

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digital images of the self and how people use filters to play with their appearances and identities. Issues related to how we can design for embodied experiences of gender and identity also came up as ideas to explore.

Before the next workshop, we summarized these ideas into a conceptual artefact and introduced a more systematic suggestion for an interdisciplinary topic. Based on teachers' initial ideas, we suggested focusing on the topic of "The body across physical and digital spaces". We did not suggest any clear learning goals or learning activities at this point, because we wanted these specifications to come from the teachers themselves. The teachers found this topic interesting and we decided to continue specifying and operationalizing the topic into more concrete pedagogies.

In the third meeting, the researchers visited the school. Here, the purpose was to test different types of immersive technologies. The teachers tested VR headsets and tried out different types of games and software. At this stage, it was important that the teachers involved actually got first-hand experience with AR and VR resources. This was also done to engage the teachers and enable them to search for and explore applications that could be relevant for them in their daily work and what they wanted to accomplish in their classroom and work on the interdisciplinary topic "health and wellbeing". The teachers were interested and fascinated, particularly with VR games and design programs such as 'tiltbrush', as well as voicing concerns with implementing VR/AR as part of a more comprehensive learning activity and making experiences available to all members of a classroom community. Through dialogic design practices, the concerns and opportunities of immersive technologies dynamically emerged instead of being inferred or presupposed.

In the fourth workshop, which took place at the University, we tried to more explicitly develop and articulate prototypes for learning designs. We split into two groups and teachers, researchers and designers together tried to come up with ideas for learning activities. We did not want to put limits on the teachers' creativity, so they were urged to come up with as many ideas for learning activities as possible. Our aim was to enable teachers to reflect upon learning goals and pedagogical methods and strategies. This became an interesting session where the teachers contributed with insights about both opportunities and challenges when designing for immersive learning environments. Through dialogic design, the contextual framing for understanding the opportunities and constraints of immersive technologies for learning were gradually introduced and made more complex for participants.

In the fifth meeting, we continued to work on the development of the prototype. Between the last two meetings, teachers had also had the chance to discuss and test VR and AR solutions amongst themselves. As a result of our dialogic design practices, it became clear that it would be premature to develop and test a comprehensive learning design with students. Among other things, this was because the learning situation would be too complex and there would be a high risk for not being able to go through a common activity for all students at the same time. Therefore, we agreed to include a set of VR/AR experiences for students as learning stations in the classroom, split students into groups, and have them test the technologies, as well as reflect on what they experienced and how these immersive technologies can be used meaningfully in future classroom activities.

Through our co-design pedagogical concepts are emerging, namely one task focusing on identity and ethnicity through immersive video and construction of avatars, one task focusing on body representations and a more open task focusing playing with the possibilities for social interaction using RecRoom. The next step in our joint design work will be to further involve students in the dialogic development of innovative immersive learning designs through in-class pilot testing.

Conclusion

We found that it was important that teachers themselves initiated and have ownership of the project. Even though it has been challenging to organize the project and for the teachers to find time to innovate during a pandemic year with many constraints, they still have a stake and interest in the project. This is crucial for further innovation. In our design work, we have been careful to not simply develop a design independently and bring it to the school. We have been concerned with organizing the design work dialogically, and our suggestions have been sensitive to teachers' voices in the emerging design work. At the same time, during the development, we have analyzed and reflected on what kind of support teachers need to create pedagogical innovation. The teachers' everyday experiences of immersive technologies and of "health and wellbeing" concepts were transformed into new pedagogies through dialogic design processes with us. We have experienced that it is challenging to align immersive technologies with collaborative activities, because the number of devices needed would not be feasible and because aligning attention across multiple devices is difficult. Still, it is important to emphasize that immersive experiences makes up only a fraction of the overall activities. Small group discussion and design work and whole-class reflection are planned to occur before, during, and after the immersive experiences.

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Development and Formative Evaluation of a Learning Game for Overcoming Typical Difficulties in Historical Thinking

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Abstract: Research has been conducted on teaching materials for historical thinking using historical sources. However, historical thinking encounters challenges in the use of historical sources, and short-term interventions have limited effectiveness. This study developed a learning game by combining the ideas of a studying-errors guideline and game-based learning to overcome typical difficulties in historical thinking using historical sources. The formative evaluation showed that the learning game affected challenging historical thinking using historical sources.

Introduction

Historical thinking is an important part of education in many countries. Although there are multiple definitions of historical thinking (Wineburg, 1991; Van Boxtel & Van Drie, 2018), historical thinking using historical sources (UHS) is emphasized in all. History is unique in how it manipulates and interprets historical sources for reasoning about the past. Here, historical thinking UHS refers to understanding or interpreting the past with historical sources.

Several methods for fostering historical thinking UHS have been developed, but short-term interventions have limited effects (Fox & Maggioni, 2018). There are two reasons for this. First, Wineburg's (1991) novice-expert research shows that beginner students have difficulty with sourcing (the act of looking first to the source of the document before reading the body of the text), corroboration (comparing documents with one another), and contextualization (situating a document in a concrete temporal and spatial context) when interpreting the past using historical sources. Generous and step-by-step support is needed to overcome these typical difficulties. Second, controlling the complex historical discussions necessary for developing historical thinking is difficult. It is essential to have an ideal historical discussion that promotes historical thinking UHS and includes individual feedback.

This study develops a learning game that provides an ideal and individualized learning experience to overcome typical difficulties in historical thinking UHS and supports formative evaluation.

Development

This study focused on two teaching methods to address the challenges in fostering historical thinking UHS. The first is the studying-errors guideline, a method that involves a mixture of correct and incorrect examples—both of which students learn from. This approach is more effective than learning from correct examples alone (Renkl, 2018). The second approach is game-based learning, which can provide step-by-step, individualized learning experiences and individualized feedback that is adapted to individual players.

A learning game called *Rekiseeker* (Figure 1) was developed by combining these methods to foster historical thinking UHS. This game's objective is to present a valid historical account using historical sources. The concrete goal of the game is to locate errors in the historical account of the opposing characters who interpret the past without sourcing, corroboration, or contextualization and to demonstrate valid historical accounts. When a player makes an incorrect choice, scaffolding and feedback are provided by an allied character. These features then enable an ideal historical discussion to overcome typical difficulties in learning historical thinking UHS among all players. One play of the learning game takes about 15 minutes. The game's theme centers on labor issues during the Industrial Revolution, which is covered early in the Japanese history curriculum in high school. The historical thinking UHS learned in this game is intended to support learning in later units (e.g., the Lincoln unit).

Formative Evaluation

A formative assessment was developed to measure whether the historical thinking UHS acquired in the learning game, especially sourcing, contextualization, and corroboration, would transfer to other history unit tasks. Data were collected in an 80-minute session with six Japanese high school students (three pairs) after classes on October 26, 2021. Each student read historical sources related to the transfer task, and each pair discussed during the transfer task. Then, each student played the learning game, and each pair discussed during the same transfer task, and each student responded to the post-questionnaire. In the transfer task, the question "What kind

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of person was Lincoln?" was approached using three historical sources that provided contradictory versions of Lincoln's image. Historical thinking UHS is needed to resolve this. The post-questionnaire determined whether the learning game impacted students' post-discussions in the transfer task and, if so, what kind of awareness it promoted in free-text format.

After collecting data, we investigated whether student statements related to sourcing, corroboration, and contextualization increased in the post-discussions in the transfer task relative to the pre-discussions and whether sourcing, corroboration, and contextualization were mentioned in the post-questionnaire. The effects were discussed along with the results.

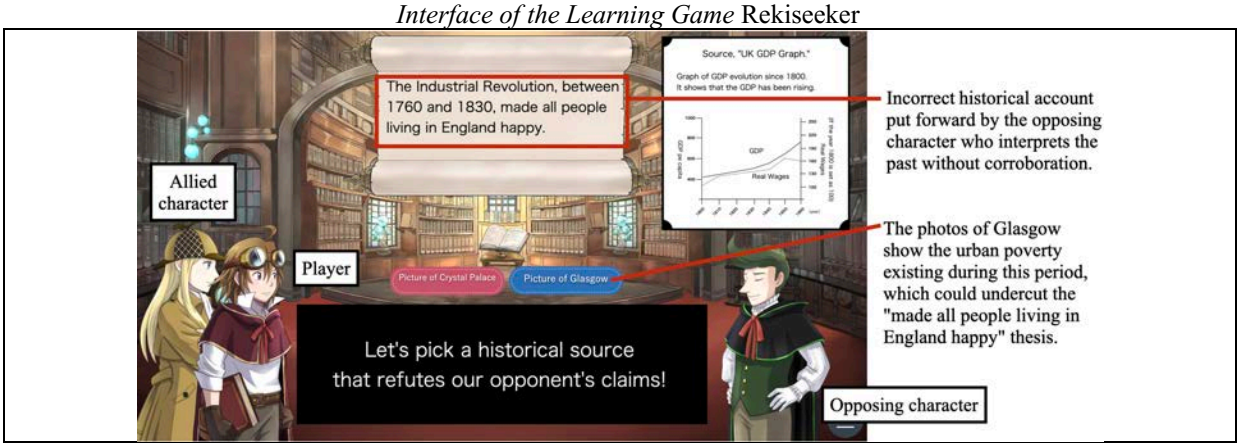
Results and Discussion

While sourcing was not performed by all pairs in the pre-discussion task, references to it were found in two of three pairs' post-discussions. Although no student explicitly mentioned it as an effect of the learning game, analysis of the conversations in the transfer tasks suggested that the learning game affected the students. With regard to corroboration, all pairs compared the historical sources with one another in the pre-discussion task, and there were no changes in the post-discussion task. However, considering that one student in Pair 1 and one in Pair 2 mentioned the impact of contextualization in the post-questionnaire, both pairs seem to have compared historical sources with one another in the post-discussion task. Therefore, this learning game supplemented the historical thinking UHS that had been lacking in each pair. All pairs situated the historical sources in a concrete temporal and spatial context during the pre-discussion task, and two of three pairs were aware of and referred to new historical contexts in the post-discussion task. In the post-questionnaire, four people (one each in Pairs 1 and 2 and two in Pair 3) wrote about the impact of contextualization. This indicates that this learning game helped develop greater awareness of the historical context in the students.

These results show that the learning game successfully combines the ideas of a studying-errors guideline and game-based learning to overcome typical difficulties in historical thinking UHS. Future issues include conducting more elaborate experiments and verifying whether such a learning game format is also effective in developing thinking skills in other subjects.

Figure 1

Interface of the Learning Game Rekiseeker



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Self-Regulated Learning with Task-Centered Microlearning

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Abstract: The need for self-regulated learning (SRL) skills was intensified during COVID-19, with schools shifting to online-learning. Using microlearning (short videos with self-evaluation) may promote SRL while an organizing-task may help assemble learning-units into a wider concept. We propose a task-centered microlearning framework for promoting SRL and other 21st century skills. Our pilot with middle school students revealed practicing aspects of SRL such as controlling the learning-environment, self-reflecting, and overcoming obstacles by using peers' support.

Introduction

As educators, we need our instructional methods to consider skills and competencies that are required for our students' career mobility as grownups. These skills, often referred to as 21st-century skills, include Self-Regulated Learning (SRL), critical thinking, collaboration, and more (Ananiadou & Claro, 2009). The need for SRL was intensified during COVID-19 worldwide spread, which drove school systems to online-learning and required students to learn by themselves.

Microlearning is a set of small chunks (5-10 min of length) of digital media learning units (microunits) that target small learning objectives and are usually delivered online. Microunits include short videos accommodated by short tasks for self-evaluation (Hug, 2007). Using the video operating keys and the embedded tasks, the student controls his learning environment and monitors his progress, both are pillars of self-regulated learning (Zimmerman, 2002). Furthermore, microlearning may reduce some of the cognitive load involved as the units are structured in learner-paced segments (Mayer, 2002).

Microlearning by itself may not be sufficient when there is a need to acquire complex concepts since a single microunit covers only a fragment of a curriculum concept and the student needs to relate between sets of microunits and put them into the appropriate larger context. An organizing-task may help the student cognitively assemble different learning units and engage him in the learning activity by providing meaning and motivation (Ahlfeldt et al., 2005; Krajcik & Blumenfeld, 2006). In addition, timely teacher interventions and facilitation (Goodyear & Dudley, 2015) are crucial to monitor the student's progress. We developed and piloted a task-centered microlearning framework with 18 microunits centered around a team's task of creating a digital escape room. We intend to further assess how this framework promotes self-regulated learning & 21st-century skills in general.

Research Goal and Questions

Our research intends to evaluate the promotion of SRL skills and additional 21st-century skills with the proposed task-centered microlearning framework. The research questions are: (1) Which SRL skills are promoted through Task-Centered Microlearning? And how? (2) Which other 21st-century skills are promoted through Task-Centered Microlearning?

Method

Participants

Our research includes four science teachers and 23 8th grade students from one middle school. The participants signed a consent form approved by the institutional ethics committee.

Materials

The program lasted four weeks. During the first week, the teacher explained the program's collective task (building a digital escape room), introduced three digital tools for the digital game creation, and exposed the microlearning platform. During the following three weeks, the students individually learned environmental concepts by watching 18 microunits and completing the unit's microtasks. In parallel, the students, working in teams, developed a digital escape room. The final week is devoted to the projects' presentation and a reflection process. See figure 1 below.

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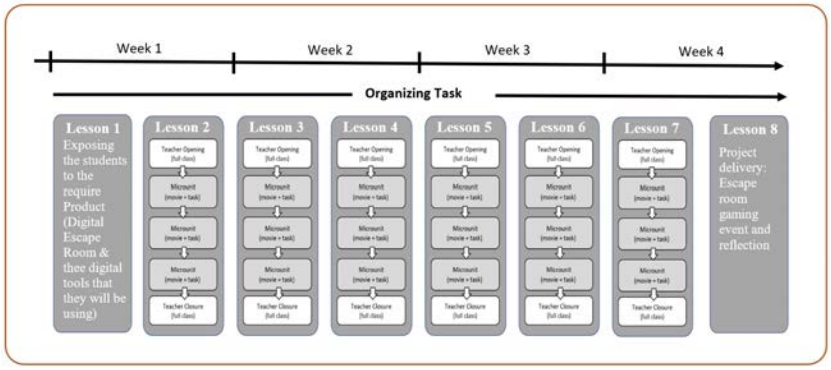
Figure 1*The task-centered microlearning progra*m



Research Tools

We used mixed methods, including quantitative and qualitative data research tools. We used the adjusted MSLQ questionnaire (Pintrich & Others, 1991) to measure students applying aspects of SRL related to controlling their learning environment and managing time/goals. We used open-ended questionnaire to collect aspects of SRL that the students were applying while facing obstacles during the program., In addition, we collected qualitative data regarding applying aspects of SRL and other 21st-century skills by interviewing the teachers.

Preliminary Findings and Discussion

As part of this pilot study, twenty-three 8th grade students used the framework for learning about the human impact on earth resources. We found, following the preliminary analysis of the data, that the students were practicing one or more aspects of SRL, such as controlling and replaying the videos to ensure self-learning ("I replayed the video over and over again until I understood all of it"), self-balancing between learning and off-learning, and overcoming obstacles by using their colleagues', teacher's, or parent's help.

The teachers reported that the students were actively engaged through self-controlling their microlearning environment, demonstrated ownership of the learning outcomes, and applied critical thinking.

Next, we plan to use a Learning Management System (LMS) based environment, to automatically-collect data related to the students' control of the microlearning environment, including usage of the video control buttons, partial watching, rate of completion unit's tasks, etc.

We also plan to explore the promotion of additional SRL aspects with this task-centered microlearning framework, such as evaluating personal progress and motivation to learn. Since the proposed framework fits remote and face-to-face learning, this research may contribute to a worldwide need for effective tools and methodologies for online and blended learning. It may also extend the knowledge about Microlearning applicability in K-12 education.

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International Society of the Learning Sciences

Intertwining Research and Practice in Higher Education: Presenting LPI's Learning Sciences Master Program

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Abstract: The LPI and Université de Paris have developed the AIRE Master program to train future change-makers and researchers in response to the transformation happening in our world. This innovative program offers high-level training through a learning-by-doing-based curriculum and social implications. It aims to embark on a rich discussion between various stakeholders on how research and hands-on practices can be combined in such a way to transform our higher education system.

Introduction

Today's world is changing rapidly, becoming more interconnected, technologically complex, and economically competitive (Sawyer, 2014). Meanwhile, we are facing global and social challenges that require us to take immediate action. Yet, the traditional pedagogies have failed to train our society to overcome such challenges. To succeed in confronting these challenges, we need to co-construct and share new ways of teaching, learning, doing research, and mobilizing collective intelligence. In other words, we need a "learning transition" that enables us to learn how to learn and support the learning of individuals everywhere and anytime. In response to this challenge, LPI (Learning Planet Institute) and Université de Paris have developed a master's program to train future change-makers and researchers concerned with the way we teach, learn, and conduct research as well as work, create, and collaborate. The program, namely AIRE (Interdisciplinary Approaches in Research and Education), offers high-level training in learning sciences and intertwines research and practice, the collaboration of multiple stakeholders, and an interdisciplinary approach to transforming our way of teaching and learning.

General Overview of The Program

The program aims at enabling students to comprehend the concept of teaching and learning harmonized with needs and changes, design and implement effective learning environments, and bridge research and practice to address problems through an evidence-based approach. One of the significant objectives of the program is to develop the ability of students to face and deal with a diverse range of analyses. As (Doise, 1986) proposed, human actions, such as learning, can be explained through the conceptual framework of the four-level of analysis: intra-individual processes (level 1), inter-individual but intra-situational dynamics (level 2), effects of social position in a situational interaction (level 3), and intervention of general beliefs (level 4). In this perspective, the program enables students to understand and experience themselves at these different levels through being exposed to various disciplines and being involved in diverse types of (a) community, (b) ecosystem, and (c) internships. In line with (Renn & Arnold, 2003) and based on Bronfenbrenner's Ecological Systems Theory (1986), the program strives to let students comprehend that any learner is in the "center of concentric rings of environments", ranging from immediate (microsystem) to most distal (macrosystem) contexts.

Curriculum

The curriculum aims at providing students with a global understanding of the transformation happening in education, and it encourages them to design relevant and challenging entrepreneurial projects. Based on the figure of social-scientist-entrepreneur, the interdisciplinary teaching units aim to transmit the fundamental knowledge of sub-disciplines related to learning sciences and develop associated skills. The courses are offered in a block mode to increase engagement and accelerate learning (Zepeda & Stewart, 2006). It starts with an intense four-week bootcamp where students discover the basics of learning sciences and develop initial reflections about learning. Following this, a variety of courses (e.g., instructional design, learning theories, game design, critical thinking, data science, etc.) and activities are offered to enrich students' learning paths through theory and know-how, practical knowledge, seminars and masterclasses, research methodologies and statistics, and project management foci. Moreover, as part of the curriculum, students do three internships in research labs, NGOs (Non-governmental Organizations), or companies to gain hands-on experience working on learning-related issues.

Pedagogy

The pedagogical modalities of the program are developed to enable students to acquire knowledge and crucial

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skills and apply them to everyday life. It is based on the concept of "learning-by-doing" to enable students to gain knowledge and skills through working in real-life contexts. For instance, internships and various courses (e.g., learning by doing curriculum and learning by doing research) provide students with opportunities to acquire practical knowledge and transversal skills through experiencing firsthand. Moreover, it offers project-based learning by bringing bachelor's, master's, and doctorate students in the LPI ecosystem together to address challenging interdisciplinary problems. For example, the 'creative week' is organized every year for master's and doctorate students from diverse backgrounds to work collectively on an interdisciplinary project and present it to the LPI community. Also, the program values peer-to-peer learning as it develops a spirit of collaboration amongst learners and lets them enhance their in-depth knowledge by learning from each other. Lastly, it attaches great importance to mentorship as it provides continuous improvement throughout the process.

Social Implication

The program not only aims at enriching students' knowledge and skills but also equipping them intellectually to be able to reflect upon their own actions and how these actions affect their immediate social and physical environment. In an attempt to compose a learning environment and curriculum that support students in functioning in social reconstruction, the program put emphasis on three significant elements: (a) diversity, (b) national/international networks, and (c) sustainable development goals (SDGs). Regarding diversity, it welcomes each year a cohort of passionate students from diverse backgrounds and nationalities. For example, 14 students from 12 different countries (e.g., China, France, Russia, India, USA, UK, etc.) across the globe were admitted to the program for the 2021-2022 academic year, and their majors range from business to psychology, art and design, education, social sciences, and engineering. Students' desired career paths in the program vary as they strive to hone relevant skills and knowledge in the area of their greatest interest. Graduates the program may choose, for example, a career in educational research within or outside academia, work in a company (e.g., e-learning manager, instructional designer, etc.), in NGOs, as creators of educational materials or educational consultants, and so on. Almost 35% of our alumni in an academic year apply for a Ph.D. in the field of learning sciences. Furthermore, the program attaches great importance to sharing best practices, experiences, and knowledge with large and enthusiastic international and national networks, learning from each other to achieve goals that cannot be achieved alone. For instance, students get immersed into the LPI ecosystem where they work collectively with other stakeholders such as scientists, researchers, students, and individuals who are willing to bring about a change. Lastly, the program cultivates a sense of belonging to humanity and responsibility to take action to address changing societal needs, thus fostering mutual understanding and orchestrating SDG-oriented activities towards sustainability.

Conclusion

We need a "learning transition" that transforms the way we teach, learn, and do research to keep pace with the fast-changing world. In light of this, the AIRE Learning Sciences Master program aims to intertwine research and practice, the collaboration of multiple stakeholders, and an interdisciplinary approach through innovative curriculum, adaptive pedagogy, and social implication to train future change-makers and researchers.

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Demonstrating Core Components of a Game-Based Fraction Supplemental Curriculum

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Abstract: Simulated learning environments, such as serious games, have the potential to significantly advance engagement and conceptual understanding for all students. The need to bolster engagement and conceptual understanding is pronounced for students with learning disabilities and difficulties. Dream2B includes a web-based video game designed with the Universal Design for Learning framework to maximize access, advancement, and power for fourth through sixth grade students in supplemental mathematics instructional settings. A demonstration of the game-based curriculum's design and development are shared.

Keywords: Rational Numbers, Special Education, Technology, Equity

Traditional K-12 STEM education does not fully address the unique issues of access to and advancement of STEM knowledge for students with LD (DeWitt, 2020). Game-based mathematics interventions may be a powerful way to improve students' engagement and learning outcomes, especially in difficult to teach content areas such as fractions. Summaries of gaming research have identified the potential of games to enhance STEM content accessibility, increase problem-solving, promote self-regulation, and allow students to explore mathematics in ways that were previously inconceivable for students with disabilities (Ke & Abras, 2013). Developed using the Universal Design for Learning (UDL) framework, Dream2B maximizes accessibility and engagement by providing fraction conceptual understanding challenges rooted in authentic STEM careers. Tutorials, action adaptive prompting, and authentic formative and summative assessments are included within the user interface. Game-based problem-solving and after-game play discussion activities promote connections and strategically link to National Council of Teachers of Mathematics (NCTM) standards. Below, we unpack Dream2B's core components. In session, we will demonstrate each component and explain how to use the program within Tier 2 intervention settings.

Demonstrating Dream 2B Core Components

Dream 2B is a narrative-based mathematics game where students play the role of "Bunny" who helps various STEM/ICT career specialists complete tasks by demonstrating their conceptual understanding of fractions. In a dream, Bunny is introduced to different career specialists who are each encountering an issue at work and are seeking Bunny's help to fix it. Therefore, Bunny's role in the dream (or game) is to solve these challenges. Each challenge requires Bunny to engage in problem tasks that involve creating and quantifying fractions. There are six worlds in the game, with the first five worlds corresponding to the different STEM/ICT careers: wind technician, solar engineer, fire inspector, photogrammetrist, and programmer. Each of the first five worlds corresponds to a specific career; world six is a combination of tasks from all careers. We take an innovative approach to tiered instructional design by integrating the following core components into Dream2B based on Hunt et al's (2020) curriculum: (a) Game Tasks along a Fraction Learning Trajectory, (b) Universal Design for Learning, (c) Action Adaptive Self-Regulation Prompts, and (d) After Game Concept/Skill Connections.

Fraction learning trajectory. Dream2B's challenges and tools are based on a documented learning trajectory of fractions for students with LD (Author). Learning trajectories are not the same as a task analysis, the amassing of skills, or longitudinal cognitive patterns, such as processing or working memory. Instead, learning trajectories consist of a learning goal, developmental stages of thinking, and activities (i.e., problem tasks, representations) designed to explicitly promote each stage of thinking (Author, year). The stages of thinking are grounded in students' conceptual development toward the goal, with each stage growing more sophisticated than its predecessor. Author's program documented six developmental stages of fractional reasoning within and among an inclusive group of students in authentic school settings that aligned with research in math education. Students' engagement in the progression of trajectory stages yields a concept of fractions as coordinated units of measure.

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Students build the concept by engaging in the actions of partitioning, iterating, and splitting as they solve fraction problems. In session, we will demonstrate each core component.

Universal design for learning. Universal Design for Learning (UDL) is a proactive design framework for meeting the needs of neurodiverse individuals (CAST, 2018). The framework is organized around nine guidelines and 31 checkpoints, organized vertically to provide: (1) multiple means of engagement, (2) multiple means of representation, and (3) multiple means of action and expression. Version 2.0 of the framework (see Figure 1) added horizontal alignment to identify how students could access, build, and internalize learning materials as they strive toward the goal of becoming expert learners who are purposeful, motivated, resourceful, knowledgeable, strategic, and goal directed (CAST, 2018). King-Sears (2020) pointed out UDL-based interventions must include a flexible, purposeful design in order to engage a maximum number of learners.

Action adaptive prompting. A growing line of research on student-centered math interventions reveals further design elements promoting robust STEM abilities. The most prominent - promoting noticing and reflection upon students' thinking while solving problems - are underutilized in instruction for students with LD. However, without the appropriate support, students often face difficulties self-regulating their learning. Thus, students' reliance on ineffective regulatory processes and communication of reasoning often continues because self-regulation is left unsupported in the midst of learning. The first step in addressing these issues is ensuring students have the opportunity to utilize and regulate their own problem-solving strategies while developing rich concepts for fractions. Dream2B provides students this opportunity through the use of problem-solving challenges and Action Adaptive prompting. Action Adaptive prompts are narrated, real-time responses from a game agent to students as they engage in gameplay actions. The agent provides feedback to help the player (a) set problem solving goals, (b) notice or monitor their game-based actions, and (c) reflect upon the results of their actions, which often feeds back into their goal setting within and across challenges. The prompts were designed as a part of Author's (year) learning trajectory, which maps common strategies students with disabilities used to solve fraction tasks for each conceptual stage.

After game concept/skill connections. In Dream2B, we re-conceptualized Author's (2020) curriculum to integrate students' gameplay with opportunities for students to engage in mathematical explanation and justification through game replays, worked examples, number strings, and language routines. *Game replays* involve students re-creating a strategy for a problem they solved in the game and explaining and justifying their solutions. *Worked examples* engage students in explaining and justifying a problem that has already been solved (McGinn et al., 2015). In Dream2B, the worked examples relate to a concept students are working toward within gameplay or a related skill that connects to a concept built up in gameplay. *Number Strings* engage students in mentally solving a "string" of related equations. The repetitiveness encourages students to notice a particular mathematical concept or make use of a particular strategy. When paired with conversation about how students solved a problem, specifically discussions that highlight efficient strategies and how the strategies work, number strings can support abstraction of mathematical concepts (McGinn et al., 2015). In Dream2B, the number strings relate to a skill that connects to a concept built up in gameplay. Tiered number choices allow for differentiation.

Each worked example or number string is paired with a mathematical *language routine* (Zwiers et al., 2017), which is a structured format for amplifying, assessing, and developing students' language related to a given concept. They provide productive opportunities for students to revise and refine not only the way they organize and communicate their own ideas, but also to ask questions to clarify their understanding of others' ideas. Together, worked examples, number strings, and math language routines can promote students' understanding of concepts, skills, and reasoning through explanation and justification. In session, we will demo a sample curriculum lesson, complete with gameplay.

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International Society of the Learning Sciences

Machine Learning and Student Reasoning Patterns in NGSS Assessments

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Abstract: SPIN-NGSS (Student Reasoning Patterns in NGSS Assessments), an NSF funded project, responds to the national need to document various student reasoning patterns in three-dimensional (3D) science assessments and tied machine learning techniques to automated diagnosis and feedback to support science learning. This presentation describes a framework of student reasoning patterns illustrated by example student responses, the development and evaluation of machine learning methods, and an exploratory study on how students reacts to the automated system.

Introduction

The SPIN-NGSS project addresses critical challenges faced in research and practice in the implementation of NGSS or NGSS-like standards in many states. Capitalizing on existing assessment data and machine learning techniques, the SPIN-NGSS conducted a proof-of-concept study to develop an automated diagnosis and feedback tool to support student science learning. SPIN-NGSS responds to the national need to document various student reasoning patterns in response to 3D science assessments and support students' 3D learning through real-time, automated diagnostics. This presentation describes the assessment material and data resources, a framework of student reasoning patterns illustrated by example student responses, the development and evaluation of machine learning methods, and a discussion on potential uses of these AI models in science classrooms.

Sense-making as Building off Student Reasoning

Learning as sense-making of the world has been emphasized in the Next Generation Science Standards (NGSS Lead States, 2013) and various National Research Council reports (NRC, 2008; 2012). Sense-making should build on student reasoning about science. There has been abundant research on analyzing how scientists reason (e.g., Kind & Osborne, 2017). There is less research, however, on categorizing student reasoning patterns, partly because the previous assessments do not necessarily elicit how students reason about science during their problem solving or sense-making. With ongoing NGSS-aligned assessment development efforts, it is possible to conduct a systematic analysis of student reasoning patterns. These NGSS-aligned assessments should provide evidence about how students reason and inform characteristics in their reasoning.

Assessment and data resources

SPIN-NGSS investigates student data in constructed response items collected from a scenario-based ecosystems assessment task developed in an IES funded project (Liu et al., 2021). The ecosystems task requires students to use their understanding of the crosscutting concept of systems and system models, and knowledge of relationships among organisms in ecosystems to come up with an argument through engaging in the practice of model-based argumentation. The constructed response item followed a simulated activity of the corn rootworms invasion on the corn field and how adding a predator (harvestmen) into the farm ecosystem impacted other system components including rootworms and corn yield. The constructed response item asked students to use data generated from the simulation and construct an explanation for why adding harvestmen into the system did not resolve the rootworm invasion issue. A total of 864 student responses were used to develop and validate a student reasoning pattern framework.

Student reasoning patterns

Student reasoning patterns are typical ways of student thinking when making sense of a natural phenomenon. They are essential stepping stones to use and interpret student data to inform evidence-based instruction. Leveraging existing NGSS assessment data, SPIN-NGSS developed a framework that described four typical patterns, three of which were associated with 3D science learning. The first pattern represents unidimensional reasoning, focusing on Science and Engineering Practices (SEP) only. In other words, student responses only include data patterns or data points, but no mention of scientific principles. The second pattern also represents unidimensional reasoning, but only focuses on Crosscutting Concepts and Disciplinary Core Ideas. For example, student responses only mention system mechanisms like "rootworms eat corns" or "harvestmen get rid of

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rootworms" without reference to data or data patterns. Note that we combined crosscutting concepts and the third pattern represents integrated reasoning with a mix of practice and system mechanisms, a so called multi-dimensional response. Text relevant to the practice dimension will be highlighted in blue, and text relevant to system mechanisms in orange. The fourth category (unidentifiable pattern) is for student responses that are too vague or irrelevant to identify their reasoning pattern. Among the 864 student responses, the distribution of the above four categories were the following: 36.34% for unidimensional SEP, 16.32% for unidimensional DCI/CCC, 26.62% for multidimensional, and 20.72% for unidentifiable pattern. Note that we combined DCI and CCC due to much overlaps between the specific CCC of systems and system models with the specific DCI of interactions in the ecosystems, which would make it extremely difficult to disentangle them.

AI Model Development and Evaluation

Automated scoring tools are in high demand by K-12 educators to provide timely feedback to students. The complex 3D learning makes it challenging for teachers to provide timely feedback. With high quality assessment data, it is possible to train the machine to learn about how students reason about science and identify what is still missing in their reasoning regarding the three dimensions of science. The machine generated diagnosis can be used to define differentiated feedback to support individual student needs. However, to develop reliable machine learning based AI innovations, it is important that we have appropriate assessment data and reliable human codes to train the machine.

To achieve reliable human codes, iterative training and revisions took place to reach high human interrater reliability (ranging from 0.67 to 0.83 of Cohen Alpha value). Then we deployed two phases of AI model building. Phase 1 model building focused on predicting the reasoning pattern label and phase 2 model building aimed to predict spans of text corresponding to NGSS dimensions. In phase 1 AI modeling, we compared two models. The first model was a Support Vector Classifier (SVC) with features extracted from the words in student responses. The second model was a fine-tuned BERT transformer model, which took the Google model trained on massive amounts of English texts and adapted it to the language in our student data. We used 10-fold cross validation to evaluate the prediction in terms of accuracy and macro f-score. The transformer model outperformed the SVC model, achieving over 78% accuracy in label prediction (compared to 73% for the SVC). Phase 2 AI modeling aimed to automatically highlight relevant textual evidence corresponding to NGSS dimensions in student responses. We treated this as a sequence labeling task and used a fine-tuned BERT with Conditional Random Fields to annotate three types of evidence: SEP related evidence, DCI/CCC related evidence, and PROMPT evidence when students copied texts in the assessment prompt into their responses. The highlighted texts could be useful information for teachers to interpret student assessment data associated with the three dimensions in science learning. Phase 2 modeling achieved over 80% accuracy at the word level compared with human annotations.

Discussion and Future Work

There are critical challenges in the implementation of NGSS or NGSS-like standards in many states. Providing a score only is insufficient to support learning and teaching and, teachers need support to understand student reasoning. The SPIN-NGSS AI innovations have the potentials to help teachers hone the knowledge of attending to student thinking by identifying student reasoning patterns. We just completed the data collection of 45 students to explore how students used the automated diagnosis information to revise their explanations and will report the results in the presentation. Our future work includes collaborating with teachers to optimize the AI tool use by incorporating their knowledge about individual students' needs, learning contexts, and other background information essential to their learning pathways.

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What do teachers learn about assessment via Co-Design of Game Dashboard

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Abstract: Increased use of educational technologies, such as games and simulations, requires classroom teachers develop new assessment literacies and practices related to understanding data affordances of playful learning environments. In this paper, we discuss how a co-design process that involves teachers to develop dashboards for an educational game can serve as a constructionist model of teacher professional development and report two ways the co-design process shifted teachers' understanding of assessment.

Introduction

Increased use of rich, interactive technologies such as games requires teachers to make sense of student performance from the volumes of data generated. These technologies are often equipped with teacher dashboards that display a variety of data, from low-level descriptive statistics (e.g. how many students in this class have finished Quiz 1) to machine learning driven predictions (e.g. who is likely to fail this class?). The increase of use of games in classrooms thus requires new practices around use of data and assessment. However, little is known about what teachers' assessment practices look like in game-based learning. For example, Nousiainen and colleagues (2018) report that teachers who are using games in classrooms should be able to envision evidence for learning using the collection of process-related data to plan how the game-based activity produces this evidence.

A question arises as to how professional development can support teacher adoption of innovative assessment practices. Co-design has been widely adopted in educational research as a form of design-based research (Penuel et al., 2007) where researchers, students, and teachers are all equal stakeholders who are co-constructing how educational innovations work in a particular place (Datnow et al., 1998). While still nascent, co-design also has been recognized as a form of professional development, especially to introduce innovative practices (Voogt et al., 2015). Teachers' learning from participating in a co-design process can be understood via the lens of constructionism (Papert & Harel, 1991). That is, teachers are actively constructing artifacts in collaboration with the design team, where the design team provides prompts, probes, interactive tools, and prototypes. Through this process, we expect teachers to adopt new insights and practices towards game-based assessment.

Method & Analysis

The research team implemented a 12-month co-design process with 8 practicing teachers (called *design fellows*) to develop analytics models and data visualizations for an online game, *Shadowspect.* The research team facilitated (1) 10 co-design workshops where the design fellows and research team participated in generative to identify and define learning analytics that the teachers value and need to act on, (2) individual think-aloud sessions with various iterations of the prototypes, (3) whole group and individual reflection of the co-design process.

Two researchers conducted thematic analysis (Braun & Clarke, 2014) by reviewing the pre- and post-interviews. The guiding question was, "*How were teachers thinking about the connection between assessment and student learning, and how did the co-design process play a role in shaping their understanding?"* Working independently, descriptive codes were generated; they were then reviewed together to either combine codes, generate new themes, or to reassess whether a new code might need to be applied to the original data.

Preliminary Findings

In general, teachers came into the co-design process with similar assumptions about assessment. The teachers reported utilizing assessment tools that showed what students could do in-the-moment through brief questions that reviewed material at the start or end of class. The digital tools teachers reportedly used did not encourage diving into the data. After participating in the co-design process, teachers demonstrated their thinking about assessment shifted in two key ways: (1) from skill/knowledge demonstration to process oriented and (2) from algorithms as "truth" in a black box to algorithms as products of human work that can be critiqued.

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Themes	Pre-process perception and examples	Post-process perception and examples
Demonstration to Process	Teachers were primarily concerned with whether students demonstrated evidence for what they know by answering questions correctly, completely, and efficiently during assessment.	Teachers were encouraged to seek alternative representations of student thinking and process. Teacher 3 remarked a shift towards looking to see "if the process is sound and there's just a minor mistake that's affecting them from getting an end result." Teacher 2 further explained that "showing mathematical thinking is not just showing step by step processing, that's like procedural thinking."
Algorithms: Black Box to Human Product	Teachers did not consider algorithms as something that can be critiqued. Teacher 1 saw the algorithms associated with learning platforms as being able to calculate a "truth": "I trust a calculator, so I trust this program too."	Teacher 1 pivoted in their exit interview to describe algorithms as a product of "choosing what it is that fits into the measurement." Teacher 4 elaborated how describing algorithms as choices breaks them out of obscurity, "unboxing of what's kind of happening." They go on to describe that, "there usually isn't a great support system around it unless it's other teachers," demonstrating how important it is that designers are able to explain the inner workings of the algorithm. Teacher 5 summarizes this ultimate connection between algorithm and designer as ultimately being important for use: "I'm very willing to take a lot of these algorithms on faith as long as I have a kind of higher-level faith in the people who have made the product."

Discussions and Implications

This study provides an opportunity to investigate how a co-design process can help teachers to learn emerging practices for assessment and critically reflect on conventional assumptions for assessment and common tools. Creating opportunities for teachers to play with their own understanding of students alongside dashboard prototypes supported the change in perspectives.

While this analysis focuses on the bookends of the co-design experience, further investigation into this data will allow the research team to construct an understanding of which activities led to the greatest shift in teacher thinking as well as further theorizing how to design a co-design process to support teachers' learning. Furthermore, this work of co-design as a constructionist activity can be expanded into other domains to identify its value beyond that of student assessment and data collection.

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International Society of the Learning Sciences

Beyond the Design of Assessment Tasks: Expanding the Assessment Toolkit to Support Teachers' Formative Assessment Practices in Elementary Science Classrooms

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Abstract: Teachers experience challenges in effectively using formative assessment practices in their classrooms. In the US, only 28% of elementary teachers report using formative assessment. This study highlights the need to design resources to meet teacher needs and support teachers in making sense of assessment information to inform three-dimensional learning and teaching. By surveying and interviewing five elementary school teachers, we identified specific barriers in using assessment information and 10 key needs from resources designed to support their formative assessment practice in science.

Introduction

Formative assessment practices are important in advancing student learning but difficult to implement (Hattie & Timperley, 2007; Heritage, Kim, Vendlinski & Herman, 2009). Formative assessment applies to the function assessments serve in providing evidence that can be used to support and inform instructional adaptations (Black et al., 2003). To engage in the practice of formative assessment, teachers must use evidence from student responses to determine where students "are in their learning, where they need to go and how best to get there" (Assessment Reform Group, 2002; pp. 1-2). Historically, science education has been inadequate in elementary classrooms (Trygstad, Smith, Banilower, & Nelson, 2013). Elementary schools tend to restrict science instructional time in favor of English language arts (ELA) and math. Given lack of emphasis on science instruction, elementary grade teachers' experience with implementing instruction and formative assessment that is in line with the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) is limited. Only 28% of elementary school teachers reported using formative assessments to monitor student learning in science (Smith, 2020). To better understand how to support teachers' formative assessment practices, this study explores the following research question: *What do elementary teachers need from resources designed to assist them in making sense of student responses on 3D science assessments?*

Theoretical framing

The formative assessment framework proposed by Wiliam and Thompson (2007) conceptualizes five key strategies for successful formative assessment: (1) clarifying and sharing learning intentions and criteria for success; (2) engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding; (3) providing feedback that moves learners forward; (4) activating students as instructional resources for one another; and (5) activating students as the owners of their own learning. We use this framework to categorize what teachers need from resources designed to aid their formative assessment practice.

Methods

This study is part of a larger project that aims to design and use 3D assessment tasks to help build elementary teachers' capacity to instruct and formatively assess in science. These tasks are developed to measure the 3D performance expectations (PEs) of the NGSS. The five teachers who participated in this study are collaborators in the larger project and were invited to provide feedback on rubric design. These teachers have at least 5 years of experience teaching at upper elementary grades (3–5) and used an NGSS-aligned curriculum.

Data and analysis

Our data consisted of (1) a survey about making sense of assessment information by using resources such as rubrics, (2) a focus group on what teachers find important and useful, and the barriers they face in using resources designed to make sense of assessment information, and (3) individual interviews with teachers to gather feedback on an initial rubric design. We examined the data for emerging themes that would help in identifying key resources

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for teachers. We first enacted an open coding approach followed by focus coding to develop themes from our data (Maxwell, 2013), then created conceptual categories in which claims were grounded in data (Emerson, Fretz, & Shaw, 2011).

Findings and discussion

In math and ELA, teachers report frequently using rubrics for two key purposes: (a) to grade student work and (b) monitor student progress over time and on multi-day projects. In science, teachers do not tend to use resources such as rubrics, citing the lower prioritization of science, which led to lower instructional time and fewer assessment opportunities in science. Teachers reported that students have not had adequate opportunities to learn and are wary of using rubrics which will rate a majority of the students on the low end of the scale. In addition, given the lack of in-depth experience with 3D learning targets, it is often not clear to teachers how to make sense of information about students' 3D learning that is contained in resources such as rubrics.

We identified 10 key needs of teachers that should be addressed by resources that accompany assessment tasks. We have categorized them under the key strategies for successful formative assessment practice and highlighted how we will address these needs through resources designed within our larger project.

Of the resources suggested, we gathered feedback from teachers on the initial design of an analytical rubric through individual interviews. The multi-component feature in the rubric provides a fine-grained picture of what students know and can do and allows teachers to focus on a targeted aspect of 3D learning. One major feature in our rubric design is that we have separated evaluating the student response based on criteria from determining proficiency level. By delineating these two, teachers can focus more on whether a student response has met a given criterion and not focus on what it means with respect to proficiency. After evaluating a response on all the criteria, the level of proficiency can be determined by tying the criteria back to the proficiency being measured. Teachers noted that applying the criteria to student responses was straightforward and quick. Teachers reported that they were able to concentrate on whether a criterion was met without making a simultaneous determination about students' proficiency level. This facilitated consistent use of the criteria to make claims about student proficiency. Most teachers said this allowed them to be more objective and consistent in applying the criteria and determining student proficiency. While grading was not the focus of the rubric, all teachers mentioned that it would be straightforward to use this design for grading, if need be.

Significance of the work

This work provides insight into the needs of teachers in resources accompanying an assessment and the use of information from the assessment to make 3D claims about what students know and can do. High-quality assessment resources that address teacher needs can positively impact teachers' use of these resources to make sense of student learning. As a result, teachers will have better insight into what students know and can do, and can make instructional decisions to support 3D learning for all students. Absent accompanying resources that address their needs, teachers are unlikely to use the assessment effectively to guide practice.

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International Society of the Learning Sciences

What do diagrams reveal? A comparative analysis of impact of different external representations on conceptual understanding

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Abstract: Learning is both guided by and constrained by the features of the external representation (ER) used for developing conceptual understanding. This work uses a case-study design to study three groups of 5 pre-college biology students (n=15) who used three different ERs- *concept-map*, *symbolic model* and *molecular model*, to perform tasks related to the structure of the DNA (Deoxyribonucleic acid) molecule. A descriptive synthesis analysis of students' diagrams revealed ER-specific changes in their conceptual knowledge.

Introduction

As science education researchers and practitioners, we use different external representations (ERs) to influence the processes and outcomes of learning. These representations carry some aspect of the represented concept and there are some aspects which are specific to the representation itself (Palmer, 1978). This is one of the reasons why different ERs provide different extent of support to the process of learning (Scaife & Rogers, 1996). And, hence, we have literature reporting different ERs, like concept maps (Novak & Gowin, 1984), diagrams (Kindfield, 1994), models (Malacinski & Zell, 1996; Srivastava, 2016), animations (Falvo, 2008) and others, to have wide-ranging impact on students' learning. The present study makes a move in this direction and tries to elicit the influence of specific features of three different ERs-*concept-map*, *symbolic model* & *molecular model*, on learners' ability to both visually and verbally manifest their conceptual understanding about one specific biological concept. Since concepts in Genetics are known to be difficult, especially the ones concerning structural and dynamic aspects of biomolecules (Lewis & Kattmann, 2004; Tang & Teng, 2005), this study focuses on the structure of one of the most complex biomolecules that holds our genetic information- the Deoxyribonucleic acid (DNA).

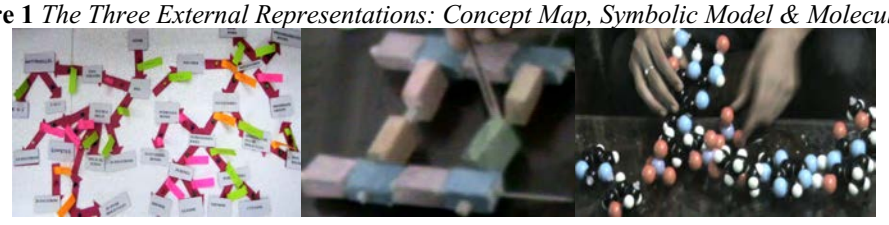
Theoretical Framework

This study relies on the power of student-drawn diagrams as windows into students' extant conceptual understanding and to capture conceptual shifts that an intervention generates. This reliance is theoretically grounded in multiple strands of literature that use student-generated diagrams to measure thought processes & way of reasoning (Schönborn & Anderson, 2009; Schwonke, Berthold and Renkl, 2009). The overall workflow of the study follows the principles of 'descriptive syntheses' proposed by Schönborn & Anderson (2009), where student-generated data (here, pre- and post-intervention diagrams) is studied to reveal and describe students' understanding and the differences that emerge from the groups.

Methods

Fifteen pre-college and college biology students participated in the study and all of them provided their written consent for the same. The study followed a case-study design, where interactive sessions were closely followed through video recordings and notes. Three groups of five students each (3*5) were asked to work with one of the three ERs (see Fig. 1), sandwiched between two diagram-making sessions, where individual students were asked to draw a diagram of the 3-D structure of the DNA molecule.

Figure 1 *The Three External Representations: Concept Map, Symbolic Model & Molecular Model*



The concept map group was asked to construct a concept map (see sample in Fig. 1, left picture) using given type-written concept cards (n=36) related to the DNA structure and to specify linking phrases using pin-up labels. The symbolic model group was asked to dissect the given symbolic model (see Fig. 1, center) made from knitting needles and colored styrofoam blocks, to identify 5 DNA structural elements: nucleotide, nucleoside,

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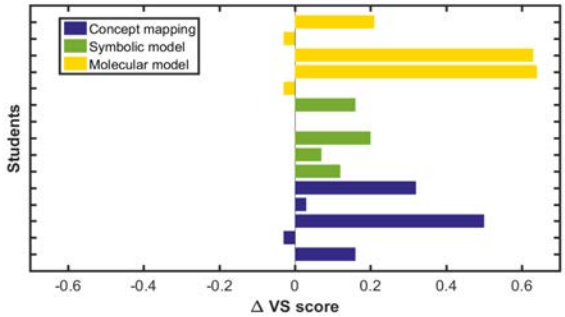
nitrogenous base, phosphate group and deoxyribose sugar molecule. The molecular model group was asked to dissect the given molecular 3-D model (see Fig. 1, right), made from colored balls, to identify similar DNA structural elements as in the symbolic model dissection task.

Analysis & Findings

The pre- and the post-task diagrams of each student was analyzed to compute a quantitative measure of diagrammatic competence- the verbal-spatial (VS) scores. VS-scores were calculated per diagram by dividing the number of concepts represented verbally (through labels) and spatially (marked using arrows) divided by the total number of concepts represented in the diagram. We illustrate the change in students' VS scores (plotted on X-axis in Fig. 2) in their diagrams for the three groups (Fig. 2). Overall, we found that the interventions led to enhanced verbal-spatial performance in 73% of students in the post-test diagrams. However, the effect of molecular models was more pronounced than concept-maps and symbolic models. We also found several representation-specific errors and corrections which were correspondingly absent or present in the post-task diagram. For instance, all participants of the concept-map group either incorrectly mapped or did not use the 'planar molecule' concept card, likely because they did not realize that DNA base pairs are 'planar' or flat structures. In another instance, all the symbolic modelers got the four nitrogenous bases correct, while all the molecular modelers got it wrong. This can be attributed to the difference in the visual affordances of the models.

Figure 2 *Improvement in Verbal(V)-Spatial(S) Scores for all the three groups*



Low VS scores signify the missing link between students' understanding about specific concepts and their spatial locations, and along with the ER-specific errors, can act as cues to help instructors identify difficult concepts and improve the pedagogical process.

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Robots in Science: How middle school science teachers design integrated robotics units for their science classes

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Abstract: Robotics activities can provide students with opportunities to engage in computational thinking (CT) as well as support disciplinary learning goals. The goal of the Robots in Science project is to create, implement, and refine a PD program for middle school science teachers to design and implement robotics and CT-integrated science lessons. Two case studies illustrate how teachers used robotics activities to provide opportunities for science learning.

Introduction and framework

Robots are becoming increasingly familiar in K-12 schools, and with good reason. Robotics activities provide students with opportunities to engage in critical thinking, computational thinking (CT) practices, problem solving, and collaboration (Sullivan & Heffernan, 2016). Integrating robotics design activities into disciplinary courses is an exciting way to increase students' exposure to technology and engineering while supporting disciplinary learning goals and students' use of CT practices within the STEM disciplines. In physical science, integrating robotics activities has been shown to support students' learning of force and motion, energy, and electricity (Souza & Duarte, 2015; Williams et al., 2007).

However, teachers may shy away from using robotics in their disciplinary classes if they do not feel confident in using the technology or prepared to make it 'relevant' to their discipline (Khanlari, 2016). There is little research on how best to design integrated interventions and to facilitate this process with teachers. In response, the Robots in Science (RiS) project provides professional development (PD) for middle school teachers to gain confidence with robotic technology while exploring physical science disciplinary connections and creating new instructional materials. By supporting middle school teachers to design integrated robotics lessons, our project facilitates the creation of integrated instruction that enables students to build, program, and use robotic models to explore, describe, and investigate scientific phenomena. Also, working with these models provide opportunities for students to engage in CT practices (Dong et al., 2019). Our work addresses the following research question: *How do teachers design integrated robotics units to enhance students' science learning?*

Methods

Data presented in this poster is drawn from the second cohort of educators in a multi-year project. The goal of the RiS project is to create, implement, and refine a PD program for middle school science teachers to design and implement robotics and CT-integrated science lessons. Thus far, the project has served 16 teachers and approximately 370 students in two states. We present preliminary analysis in the form of two case studies (Yin, 2018) from this larger data set. These two cases are intended to be comparative – in one case, the teacher replaced a previous lesson focusing on the same content but saw an opportunity for lesson enhancement based upon the affordances of the robotics kit; in the second case, two teachers worked together to develop a new lesson based on a newer state standard. Each case highlights the potential of a robotics integration approach.

Due to the COVID-19 pandemic, Year 2 PD was presented virtually. The goals of the 3-day PD were: (1) Help teachers get comfortable with the Hummingbird robotics kit and programming in MakeCode, (2) Learn about CT, and how engaging in CT practices could enhance students' understanding/experience with science concepts and the robotics kit, and (3) Discuss how robots could support students' engagement in modeling and experimentation during science class. Following the 3-day PD session, teachers also participated in approximately 3-4 hours of school-year PD focusing on sensor use and approaches for designing integrated units.

Data sources include teachers' implementation logs and follow-up interviews, artifacts (teacher unit plans, student work from integrated lessons), and classroom video. For this poster we analyzed two teacher-created lessons, focusing on the design and intended enactment of each lesson. The first two authors wrote memos about each lesson (Saldana, 2011) and discussed them with the research team. Memos were guided by questions drawn from Roehrig et al.'s (2021) analysis of integrated curriculum materials: what is the performance expectation/central goal?; what are the main concepts to learn in each lesson?; was the science content relevant and necessary for making robotics design decisions?; did the robotics contextualize science learning or vice versa?

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Findings and discussion

Case 1: Using robots to study energy transfer

A technology integration specialist, collaborating with two 6th grade science teachers, designed an integrated robotics and CT activity to help students understand the relationship between potential and kinetic energy. This integrated unit replaced a previous lesson where students built a rollercoaster out of foam tubing and observed marbles moving through the rollercoaster but were not able to collect speed data. In contrast, the integrated robotics unit enabled students to build and program cars outfitted with distance sensors, and use the cars to engage in pull/release experiments which allowed them to calculate and graph speed and displacement, and examine their data to contemplate the question, "how does the distance you pulled the car back affect the kinetic energy?"

Case 2: Using robots to study waves

Two 6th grade science teachers developed a unit to help students investigate how light waves travel through materials. The teachers first presented relevant vocabulary (transmission, reflection, refraction, absorption) and CT definitions. Then students collected data about whether LED light could be detected through different materials (e.g., sponges, felt, water, clear blocks), by programming a rotation motor to spin when light was detected via the light sensor. A 'trial sheet' was created by the teachers for students to use while collecting data (see Figure 1). The unit supported some student engagement with CT as well as investigation of absorption and transmission of light waves.

Figure 1

Student data collection sheet from the waves unit

TRIAL SHEET

Now that you've tested the light to see if the sensor could pick it up, you need to determine what the material did to the light wave. In the following chart, use the code you made to see if the light on the hummingbird **refracts**, **transmits**, **reflects** or **absorbs** through the various materials. In the third column explain **WHY** you chose what you did.

Material options: Mirror, Water (in glass jar), colored felt (write the color you used), plastic blocks, foil, sponge, 2 materials from sensor check

Material	Did the light sensor sense the light? Yes or no	Transmission? Reflection? Refraction? Absorption?	WHY

In case, 1 the robotics activities provided opportunities for students to investigate the transfer of energy. In case 2, robotics activities provided an opportunity for students to investigate and describe a property of light waves. Future research will explore how PD supports can help teachers further integrate CT into their lessons, specifically to support students' exploration of science concepts. For example, teachers in Case 2 could be supported to develop an experimental approach that allows students to systematically vary where they place the light, sensor, and materials while collecting data, detect patterns in their data, and identify properties of materials that transmit, absorb, reflect, and refract light.

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Examining the development of perspective-taking through social annotations in collaborative text study

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Abstract: Reading literature has been found to be positively related to perspective-taking. We studied perspective-taking through the use of social annotations of texts and asked how perspective-taking develops during collaborative text study, and which elements of social annotation support perspective-taking development? Specifically, we studied an undergraduate education philosophy course in order to gain insights about perspective-taking in online spaces, using a social annotation tool.

Literacy and perspective-taking

Studies have shown that reading literature is positively related to perspective-taking (PT) (Ivey & Johnston, 2013) and that reading literary fiction, more specifically, led to higher levels of perspective-taking as opposed to other types of genres (Kidd & Castano, 2013). A literary text also provides resources for reading a text through new voices. By doing so, the person who reads engages in perspective-taking as she reads and uses their social imagination of the other as part of a conversation with one's "self" (Lysaker et al., 2011). Thus, reading literature leads to increased perspective-taking among students who constructed meaning in their lives (Ivey & Johnston, 2013). A strong engagement with the text can be viewed as going beyond just "putting yourself in another person's shoes" but rather "be" that other person.

One of the ways to teach students how to read through the perspective of the character is through *dialogic pedagogy*. In such settings, the teacher demonstrates authentic responses to text such as empathetic response and perspective-taking. This is then an invitation for the students to make similar connections in their reading process. Through this kind of modeling, the teacher is actively presenting his relationship to the text as seen in facial expression or intonation and thus demonstrating how one reads. This process includes creating a connection between the text and personal life experiences, expressing different feelings toward the characters, and taking their perspectives while reading (Lysaker et al., 2011).

The benefits of reading may extend to other abilities such as understanding and sympathizing with others' emotions or motivations. Kozak & Recchia (2019) refer to this set of abilities as *social understanding* and propose different classroom activities to promote them. For example, asking students to retell the story, or parts of a story, from the perspective of a different character, writing a letter to one of the characters, writing reading responses, or turning a novel into a play requiring the students to interpret the perspectives of the characters in this process.

In this study, we chose to use social annotations as a prompt to do close-reading of the text as students ask questions, make comments, or create a connection between the text and additional sources. Our goal was to use social digital annotation to facilitate interaction with the text both individually and collaboratively.

Social digital annotations

Annotations are usually informal and unstructured comments written in the margins of a text as one reads the text. They may include a question regarding the text, a correction, explanation, interpretation, and more (Johnsrud et al., 2017; Nielsen, 1984). A *comment* is one kind of text that is reactive, short, and asynchronous (Kalir & Garcia, 2021). Annotations can also be used to present an agreement or disagreement with the author, mark important information, or answer a question (Marshall, 1998). In addition, annotations can include drawings or links to additional texts (Marshall, 1997). In this regard, annotations can be viewed as the reader's way of talking to or with the text. A *text* according to Kalir & Garcia (2021), has an author and is defined by its content as it communicates a message through different modes or styles.

Kalir & Garcia (2021) demonstrate how previous interdisciplinary research has shown that annotation, whether written by hand or in a digital format, assists learners in thinking, reading, and writing, and can also motivate their learning, both in the K-12 and higher education classrooms. Therefore, such online annotation platforms increase student learning. However, annotation can help the learning process when it is supported by other activities. Today, annotations can be digital as part of online annotation systems which also enable users to share their annotations, making this process collaborative.

By working collaboratively in online networked environments, students are required to generate and share their own understandings. Such participation creates a dynamic knowledge-building process through social interaction, an important characteristic of computer-supported collaborative learning (Järvelä et al., 2004). Textual

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computer-mediated communication can also establish productive argumentation as learners reread and revise their comments, both before and after they post them, allowing them to reflect on their work (Asterhan & Schwarz, 2016). Such reflectiveness can also promote critical thinking and perspective-taking (Tay et al., 2018).

As a computer-mediated communication tool, the option of social annotations allows learners to collectively read and annotate different material online. Social digital annotations in educational assignments have been referred to by scholars as a type of learning arrangement called *anchored discussion*. This occurs when students "talk" with one another about a shared text through digital annotation. Other studies have shown that annotations enable a rich conversation requiring students to actively read the text and use the social annotations to elaborate their thoughts as well as learn from other perspectives through additional interpretations of the text (Kalir & Garcia, 2021). *Higher-level discussions* are characterized by mutual negotiations including theory-based postings and postings of new points or questions. Therefore, as students engage in high-level discussions, they are likely to show high levels of PT and this study aims to provide an online space that supports such learning outcomes (Järvelä & Häkkinen, 2002).

Methods

We used *Perusall*, a platform designed to allow students to share annotations and sometimes respond to each other's comments while creating shared understanding. This social annotation tool allowed students to reflect upon their own reading process as well as their peers', making this a collaborative knowledge-creation experience. By analyzing changes in PT levels that occurred as a result of collaborative discussions in the form of social annotations, we used qualitative methods to study PT on an individual and collective level. Although this study is still underway, it contributes to the literature on PT in humanities classes and teaches us how social annotations can be used to foster PT.

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Simulating students: An AI chatbot for teacher training

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Abstract: This article describes the development of a chatbot designed to simulate students in a 3D virtual environment for the purpose of pre-service teacher training. Using a generative pre-trained transformer-based deep neural network model, researchers created an artificially intelligent chatbot using language resource data from authentic classroom dialogues. Results indicate that the chatbot needs to be fine-tuned with additional programming. This program is intended to be used in future research on teacher-training in virtual simulations.

Introduction

Virtual 3D environments provide a convenient and immersive space for pre-service teacher training to take place. In these virtual spaces pre-service teachers can practice classroom discourse and classroom management without the pragmatic difficulties of undergoing such training in actual classroom environments with real students (Dieker et al., 2014). Presently, most 3D virtual teacher-training environments rely heavily on puppeteered student avatars to avoid the complexity of natural language processing associated with machine generated discourse (e.g., Cohen et al., 2020). Puppeteered avatars detract from the authenticity of the dialogue and can also be resource intensive because an individual must be employed to play the role of the students. Therefore, this study saw the development of a chatbot which can be used to program student virtual agents to simulate authentic science, technology, engineering, and mathematics (STEM) classroom environments for training purposes.

The contributions of the study are twofold. Firstly, the development of a custom designed chatbot by fine-tuning a pre-trained deep neural network model on classroom conversation data. And secondly, the generation of real-life dialogic responses for domain specific queries using a the chatbot.

Method

The foundation of the chatbot is a generative pre-trained (GPT-2) transformer-based deep neural network model which was developed by OpenAI (Radford et al., 2019). Pre-training of GPT-2 model was done on a large volume of web data from Reddit making it capable of generative quality text (Fig. 1). For the purpose of the study, the "medium" 355M parameter model (1.5 GB on disk) of GPT-2 was selected, to ensure a good balance between scalability for fine-tuning with large amounts of data and creativity during text generation. The model takes a sequence of tokens as an input and choses a sequence of output tokens, based on probabilities determined by the inner neural network.

In order for the chatbot to produce dialogue that simulates the diversity and richness of teacher-student interactions in STEM classrooms, data were collected from video recordings of real lessons and manually transcribed. The videos were obtained from online open-access sources such as (https://rme.org.uk/) and (https://ambitiousscienceteaching.org/). Thus far, about 13.5 hours of classroom dialogue have been transcribed, and 9.5 hours have been provided to the chatbot for training. The remaining 4 hours of data were withheld for testing the chatbot.

After the transcription of the dialogue data, it was annotated with tags by two researchers, which guides the chatbot for a more logical and consistent output during response generation. The tags were formatted in a specific order "<Person>_<Domain>" to maintain singularity as well as preserve scalability for future integration with newer datasets. Once the data format was ready, the chatbot parameters were set for fine-tuning the model. For our study the model was fine-tuned for 500 steps, saving the checkpoints every 100 steps. We also set the temperature parameter to 0.6 to keep a balance between the coherence and randomness of the generated responses. The chatbot is deployed in virtual machine in Google Cloud with 128 GB memory and Nvidia Tesla V100 GPU.

Preliminary testing of the chatbot was done by providing it with authentic queries from the transcribed data withheld for testing purposes. Chatbot responses were assessed subjectively using a linguistics-based metric.

Figure 1
Workflow of the designed chatbot

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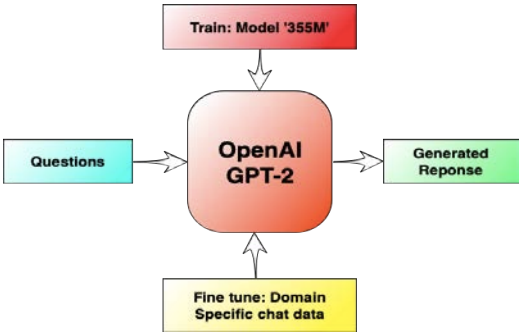

Results

The chatbot was inconsistent in its ability to produce appropriate responses. The following example demonstrates the chatbot could return relevant, and appropriately concise answers with the testing data.

> *Query: Well that's a very good question. Obviously, how many points do I really need to make a line?*
> *Chatbot answer: Two.*

However, the same question met with an inconsistent answer when it was paraphrased. Asking "*What number of points is needed to create a line?*", the chatbot answered *"Three."*

Another noted difficulty in the preliminary analysis is that a lack contextual information forced chatbot responses to be interpreted in isolation. For instance, in the following example the data were taken from a classroom activity in which the teacher was demonstrating the properties of pressure by blowing up a balloon.

> *Query: Ok, so what happened? What are your observations?*
> *Actual student response: You applied pressure and it got bigger.*
> *Chatbot answer: Um, that it's hard.*

Although pragmatically and grammatically, the chatbot answer was not necessarily infelicitous, and indeed might be observed from a student in an actual classroom, the lack of contextual information regarding the balloon makes the chatbot a difficult partner in an ongoing dialogue.

Discussion and conclusion

Programming a chatbot to accurately portray the verbal behavior of student avatars is an iterative process central to the creation of a classroom simulation which does not rely on puppeteered avatars. One likely reason for the chatbot's answers being inconsistent despite queries aimed at producing identical answers is that the temperature parameter, here set to 0.6, may be too low for the chatbot to interpret queries that stray too far from the original text in the data. Setting this parameter very low will produce only responses found in the dataset and setting it very high may produce incoherent responses. Furthermore, programming the chatbot to incorporate ongoing dialogue into its resources might allow it to show more consistency in its responses by following dialogic threads.

The authors intend to employ the chatbot with virtual agents using *Open Simulator*, which will be used in studies addressing the efficacy of using virtual simulations for pre-service teacher training.

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International Society of the Learning Sciences

What *Songo* board game can teach us about culture and literacies

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Abstract: Contending that gameplay is a constellation of literacy practices could imply that video/digital games are the only spaces where players engage in literacy practices. Literacies in game environments have mainly been evidenced by video/digital game research. Literature on board game literacies is still scarce. This paper investigates literacy practices in the gameplay of the board game *Songo* and demonstrates that culture shapes literacies.

Introduction

The New London Group multiliteracies theory has reframed and advanced our understanding of literacy in various contexts. Multiliteracies theory explains that there are multiple ways of communicating and brings to light cultural and linguistic (Perry, 2012; Sang, 2017). Game research has used multiliteracies as a theory and framework to investigate, explain, and demonstrate the literacy practices players engage in during gameplay (Ellison & Solomon, 2018). Yet, this research leaves out board games, and specifically African board games such as *Songo*. This study engages the literature from a multiliteracies perspective to start uncovering literacy practices in *Songo* (Figure 1) and shows the cultural situatedness of these literacies.

Literature shows board games as learning spaces. Board games enhance deep learning (Azizan et al., 2018) and facilitate learning of various science, technology, engineering, and mathematics (STEM) content (Bayeck, 2020). Computational thinking (Berland & Duncan, 2016); collaboration, scaffolding, and mathematical thinking are other practices board gameplayers engage in (Tsarava, Moeller & Ninaus, 2018). *Songo,* a board game played in Cameroon. It is a competitive strategic game with two rows played by two people, with 70 /seeds^2, equally divided between players and consecutively drop in clockwise direction in the 14holes that make up the game (Bayeck, 2019).

Figure 1. *Songo* board game

Theoretical perspectives and Methods

Multiliteracies serves as a framework to examine literacies in *Songo* board gameplay. Using video recordings of gameplay, this microethnography employs interaction analysis as discussed by Erickson (2006) to investigate the different modes of communication employed by players during gameplay. Therefore, this analysis will include language and other forms of expression (e.g., body movements, or gestures) occurring during gameplay in Yaoundé, Cameroon. Participants were adult players.

Study Context

On the cultural spectrum, Cameroon identifies more with collectivist cultures (Legare &Nielsen, 2015). Cameroon has two official languages, French and English, as a result of the colonial past. However, these official languages interact with local languages. Different languages such as pidgin-English or Camerounism, peculiar to Cameroon have emerged from this interaction (Nkwain, 2014). Camerounism draws on local languages and distance itself from standard French (Biloa, 2012). The communal approach to life and ways of doing facilitates interactions among the multiple ethnic groups that make up the country (Bayeck, 2019). The city of Yaoundé, where the study was conducted, is multiethnic, located in the French speaking part of the country, and has the Ewondo ethnic group as first dwellers. Interestingly, the literacy practices discussed below echo the complex cultural make up of Yaoundé, and Cameroon

Findings

Findings from this study indicate that meaning making is shaped and informed by the cultural context. The following paragraphs highlight the interplay of language use and collaboration with the cultural context.

Language Use. The language used during *Songo* gameplay in Yaoundé, Cameroon was informed by the cultural context. As shown in the excerpt below, in a game opposing Caulet and Abi, language was a combination of local and former colonizers' language, that is, French.

Excerpt 1.

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Caulet : tu auras les pourrissons (plays the second hole on his right)
[You will have pourrissons]
Abi : qui pourrissons ?
[*Who pourrissons?]*
Caulet: tu auras les pourrissons (plays the third hole on his right)
[you will have the pourrissons]

The exchange between both players exemplifies the use of a language that is peculiar to Cameroon. Words like "pourrissons" is the combination of the French verb "pourrir *[to rot*] and the suffix "ssons" which is a form for French verbs conjugated in the first plural person of the present tense. "Pourrissons" is used here as a noun to mean seeds with no strategic importance because they cannot lead to victory. Similarly, "bricole and bricoler *[tinkering*]" is a camerounism that means not doing well or succeeding in the activity one is engaged in.

Culturally-informed collaboration: The cultural practices explain audience participation and collaboration with players during the game. The excerpt below illustrates interaction between players and the audience in a game opposing Nti to Ngibi. Nti, in difficulty, benefits from his collaboration with Pierro an audience member.

Excerpt 3
Pierro: [to Nti] ta case a combien?
[How many seeds do you have in your hole]
Nti: (counts seeds in the third hole on his right)
Pierro: c'est combien?
[How many seeds?]
Ngibi: [to Nti] il faut qu'on te montre
[They need to show you]
Pierro: 23 (gazing the board game)
[23 seeds]
Nti: (plays the fourth hole on his right)
Pierro : [to Nti] eh, pourquoi tu as mis 24 ? Heureusement que lui aussi il est comme ça
[Eh, why did you make it 24? Fortunately, he is not that good]
Nti: [to Pierro] j'ai normalement 16 (showing seeds in his hands)
[I currently have 16 seeds]
Pierro: non va comme ça Nti (points to a hole on the right of Nti)
[No play like this Nti]

Conclusion

Findings in this study show that literacy practices in board gameplay are culturally situated. The field of New Literacies Studies has contributed to our understanding of the cultural situatedness of literacy. However, it only focuses on communities' peculiar use of reading and writing skills (Mills, 2010). This study contributes to research on board games by focusing on literacies. It highlights the influence of culture on literacy practices in games. Game researchers are yet to extensively explored the role of culture in shaping literacies in gameplay. These findings will inform game studies and advance our understanding of meaning making in various cultural contexts.

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Design of an Argumentation-based Learning Activity: Connecting Veterinary Students to Real-world Problems

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Abstract: The study investigated the design of an argumentation-based activity that focused on animal welfare and advocacy in a first-year veterinary class. The objective was to understand students' learning experience and to provide evidence-based insights for future improvement. The reflections of eighty students were analyzed using semantic network analysis. We found that allowing for topic selection, providing background resources, and scaffolded evaluation of biases and evidence may be important design considerations.

Introduction

Argumentation skills are of great significance for students and scientists as it is commonly used in daily thinking in science learning and research. The use of argumentation has been associated with positive learning outcomes such as critical thinking, logical reasoning, and problem-solving skills (e.g., Boğar, 2019). However, it is challenging to engage students in argumentation (Noroozi et al., 2020). Learning occurs through interacting with artifacts. More specifically, the construction of knowledge occurs when learners construct mental models by generating, experimenting, and modifying artifacts - particularly when such artifacts have real-world impact (Papert & Harel, 1991). Thus in the course design investigated in this study, students were introduced to authentic situations and construction of authentic artifacts for the purpose of observation and constructing valid argumentation. The objective of this study was to understand students' learning experience in a learning activity combining argumentation and real-world work to provide evidence-based insights for future improvement.

Method

This study used semantic network analysis methods. Data for this study were students' reflections about their learning experience in an argumentation-based learning activity. Students from a first-year veterinary class were asked to compose a letter to their legislator advocating for or against the issue of equine slaughter. A 30-minute online teaching module was provided for students to provide background information that could support formulation of an advocacy position. After writing the letter to the legislator, students were then asked to reflect on the benefits, struggles, activity design, and suggestions. For the eighty students completing the reflection activity, MAXQDA Analytics Pro software was used to code the data. A codebook was developed, with 42 codes and 548 code segments. We then calculated the Pearson's r among all codes and imported the correlation matrices into the UCINET software to create semantic network maps using Girvan-Newman cluster analysis (Girvan & Newman, 2002).

Findings

A semantic network analysis map is presented in figure 1. We identified 3 clusters from codes at the $p < .05$ level at the robust confidence of Q = 0.43. Some students struggled with *information selection* to build a sturdy logical foundation of their argument (black cluster in figure 1). The data shows that there were students struggling with *understanding laws* and a *lack of background knowledge* in regard to the topic chosen by the instructor. The primary suggestions center around the *topic* and *options for participation* which correlated with the strengths of the *overall evaluation* and *research/reiterate* aspects of the assignment. Several students expressed that they benefited from the practice of researching, organizing, and writing the arguments based on facts and data using real-world problems they may or may not be familiar with. The data suggested that instructors can consider providing multiple topics for students to choose the one they are most interested in. Also, some students were struggling with the *word/paragraph limit* when writing the letter to their legislator. *Expanding the page limit* can be an option for those students who feel comfortable communicating with more words.

A strength of *good instruction* of the assignment was identified (red cluster in figure 1), which interconnected with design strength of *well structured*. However, a design weakness in the video module has surfaced due to a lack of supplement instructional resources. Some students found rewinding instructional videos back and forth to be troublesome. It is suggested that instructors *provide outside reading beside the module* to help students gain more contextual knowledge. However, some students found the given materials already hard to cope with due to *time* issues.

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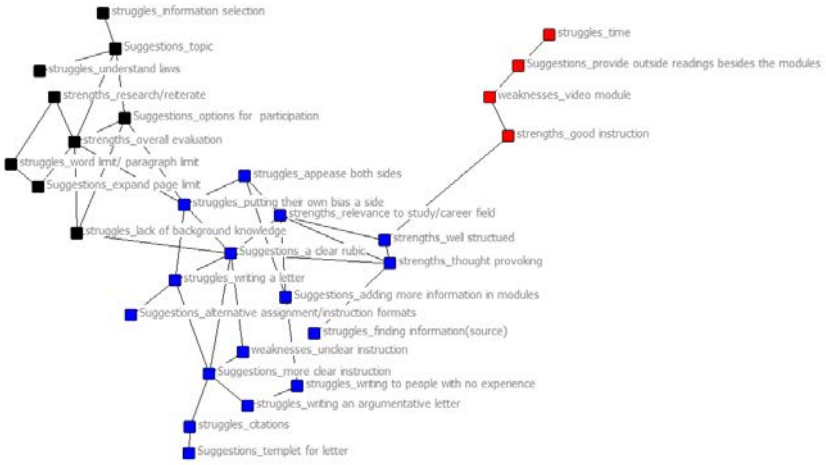
Some students found it difficult to *put their own bias aside* (blue cluster in figure 1), which was correlated with another struggle about the desire to *appease both sides*. They also struggled with *writing to people with no experience*. One design suggestion to help with these struggles is to provide more information in the video module so they could make a more informed decision and explain it well. The suggestion of making the instruction more clear was linked to the weakness of *unclear instruction* and multiple struggles including *writing a letter*, *citations*, and *writing an argumentative letter*. Considering that students may not be familiar with the letter format, we need to further clarify expectations and requirements in the instruction. For instance, a reference guideline and format explanations need to be added in the instruction in the future class.

Figure 1

Semantic network map of student reflections on the activity



Conclusion

This study provided evidence that connects the literature about argumentation (Boğar, 2019) and the literature of real-world impact learning (Papert & Harel, 1991). Our findings suggest that development of argumentation skills may be facilitated through construction of authentic argumentation artifacts such as letters to legislators in this study. Through analysis of the relationships between student struggles, student suggestions, and design strengths we were able to develop some tentative design principles to enhance student success in this activity. First, limiting the selection of topic may be less powerful than providing multiple options. Second, unless students are familiar with the topic(s) at hand, it may be prudent to provide a robust set of background resources for them to leverage in developing their arguments. Finally, constructionist argumentation activities may require practice and scaffolding, particularly in helping students identify and understand their own biases in relation to the evidence in which they ground their arguments.

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Analyzing Teacher Learning in a Research Practice Partnership

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Abstract: Teachers are increasingly participating in RPPs with the goal of improving their schools and districts. This context provides teachers with unique learning opportunities as they directly take part in school improvement work, yet we know little about what teachers learn from their involvement in RPPs. This study explores teacher learning over the course of the first year of a multiyear RPP with a team of researchers from a local university.

Introduction

Research Practice Partnerships (RPPs) are long-term collaborations between practitioners and researchers in which the collective engages in school improvement work by investigating persistent problems of practice and solutions (Coburn & Penuel, 2016). RPPs are increasingly utilized for school improvement purposes because they address local problems of practice and enable greater use of research in decision making (Coburn & Penuel, 2016). Despite a growing body of literature and rise in popularity of RPPs, there is a need for more detailed research on the processes and outcomes of these partnerships (Klar et al., 2018). What teachers learn from participating in RPPs is one such outcome that requires more research. Previous studies have focused on the learning of district leaders (e.g., Rigby et al, 2018), but few previous studies have focused on teacher learning within RPPs. Since RPPs offer teachers the opportunity to engage in district-wide instructional improvement work, this raises the question of teacher learning in such a context. In this study, we investigate what teachers learn from these partnerships by examining the following research question: How does teacher's reasoning about improvement work shift over time as they engage in RPP work?

Conceptual Framework

This study is grounded in a situated theory of learning which identifies learning as shifts in participation within a community of practice (Lave & Wenger, 1991). A community of practice is a group that collectively engages in a shared repertoire of routines as they work towards a common goal (Wenger, 1998). In this study, we explore how teachers' participation patterns shift over time as they engage in a routine of school improvement meetings. Through these regular meetings, a community of practice is formed between the participants.

We define the teachers' participation in this community of practice as their contributions to the collective discussions. More specifically, we conceptualize these contributions as episodes of improvement work reasoning (EIWRs), an adaptation of Horn's (2007) episodes of pedagogical reasoning (EPRs). Horn (2007) defined EPRs as detailed instances of teacher reasoning, focused on issues or questions about teaching practice. We define EIWRs as episodes of elaborate reasoning about the purposes, obstacles, and methods of school improvement work. We make this distinction as teachers are participating in discussions about district-wide instructional improvement and not teaching practice.

Methodology

This study draws on a case study approach (Yin, 2014) and employs an embedded multiple-case study design. The data for this study comes from a larger multiyear RPP project in which a team of researchers from a large Midwestern university collaborates with several local K-8 school districts with the aim of investigating issues and solutions surrounding math education within each district. A subgroup of members from each of these teams meets regularly to plan the work of the respective whole RPP team. This study centers on these subgroup meetings because they prompt teachers to engage in rich discussions as they engage in meaning making (Horn, 2007) surrounding instructional improvement work. The four teachers on the Bay School District subgroup are the focus of this study. The district's subgroup also includes a district administrator, one university researcher, and one university-affiliated math coach, all of whom also engage in the subgroup's discussions.

Data Sources and Analysis

This study utilizes four data sources: (a) 26 hours of video recordings of 15 subgroup meetings, (b) transcripts of subgroup meetings, (c) transcripts of initial interviews, (d) transcripts of end-of-year interviews. The unit of analysis for this study is individual EIWRs shared by teachers during subgroup meetings and interviews. First, EIWRs were identified in each data source. Then, EIWRs were coded by topical content so that similar themes

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can be compared over time (Horn, 2007). Several categories of EIWRs emerged, such as problem identification, norms, roles, data use, and solution formulation, amongst others. Due to space limitations, only a small subset of EIWRs concerning problem identification is presented here.

Findings

Preliminary analysis indicates teachers' reasoning about relevant problems of practice shifted over time (see Table 1). In initial meetings, as the subgroup laid the foundation for improvement work, they discussed problems associated with the district's math program. During this phase, each of the teachers pointed to a different issue they thought contributed to unsatisfactory outcomes of the math program. In the first meeting, Lenny brought up the lack of cross-grade level collaboration opportunities for teachers. During the third meeting, Nicole spoke about low test scores, while Frankie highlighted the lack of math interventionists and coaches. During subsequent meetings, as they continued to engage in discussion surrounding problem identification, all three teachers zeroed in on the fact that the district's teachers lacked a uniform understanding of high-quality math tasks. Thus, as the teachers engaged in RPP work, their reasoning about issues associated with the quality of their math program shifted, becoming more unified and clearly defined. In the poster, we will show the trajectory of participation for each teacher during Year 1.

Table 1

Teacher's reasoning about issues associated with the quality of the district's math program

Teacher	Early EIWR	Later EIWR
Lenny	**Subgroup meeting #1:** "… I know that we've talked about before was talking across grade level teams, but then also, fifth grade being able to spend time [with] sixth grade and vice versa, some of those types of things."	**Subgroup meeting #4:** I think that that was the question that was asked in the interview is, what do you think a high-quality task is... Some people [are] like I don't know if I'm right or not... So then, having an opportunity to look at what other people are thinking to refine as a district what we think."
Nicole	**Subgroup meeting #3:** "…we just feel that there is a problem and we need to address that problem… the staff knows that there's some sort of… we are seeing them [MAP scores] flat line."	**Subgroup meeting #6:** "…teachers have to have a reason why they're picking, choosing something [a task]. Not just because they feel like it…. There has to be a reason."
Frankie	**Subgroup meeting #3:** "Like what's going on? Why is this not progressing, not changing?… reading has tons of interventionists and coaches... Well, we've brought up a lot of times, well what about math?"	**Subgroup meeting #7:** "…if we still have team members… that are still questioning high quality. Like what does it that look like, I think we definitely need to back up and like assess what we want to continue with because we want to make sure everyone's on the same page."

Data for one of the four teachers is omitted because she did not participate in initial meetings.

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Tensions in Supporting Equity During Sense-Making Activities in Mathematics

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Abstract: This paper demonstrates how pedagogical practices that are deemed to be equitable may lead to both inclusion and exclusion effects. We present an illustrative vignette of a mathematics lesson. The teacher demonstrated practices that are consistent with what has been suggested in discourse around epistemic agency as equity. However, the interaction manifested the assumptions of what count as sense-making in mathematics that have historically functioned to differentiate kinds of students.

Problems and objectives

There is widespread agreement that equity issues should be centered in recent educational reform efforts. Despite many discussions around "equitable sensemaking" and "equitable practices," however, scholarships around equity in mathematics education have scrutinized that pedagogical practices that claim to be equitable may instead reinforce systemic exclusion of certain kinds of students. For example, pedagogical practices that are designed to enable student intellectual agency may operate in ways that perpetuate the assumption of ability hierarchies in mathematics. Such exclusion is tied to larger discourse that is historically and systemically shaped—what Louie (2017) has termed "the culture of exclusion in mathematics education." This calls into question what counts as "equitable" in mathematics learning spaces.

In this paper, we examine how pedagogical practices that are deemed to be advancing equity may inadvertently lead to both inclusion and exclusion effects. The following question guides this study: What are the tensions of supporting equity during sense-making activities in the classroom? In particular, we demonstrate how practices that are claimed to be supporting epistemic agency can function in ways that reinscribe historic and systemic assumptions of what counts as mathematical thinking and ideal students.

Theoretical Framework

We adopt the theoretical construct "inscription practice" to elucidate how inclusion and exclusion can paradoxically occur during mathematics learning. *Inscription* refers to the process that a set of taken-for-granted values and orders are constantly enacted and reinforced, and the boundaries that define these values and orders are historically resembled (Popkewitz, 2004). Inscription is built upon a historicizing approach that juxtapose past and present (Foucault, 1977) to examine the set of assumptions that fabricate what is desired and make up particular kinds of people as ideal citizens. Mathematics classrooms are fundamental sites where inscription practices operate due to the assumptions of what counts as legitimate knowledge and sense-making in mathematics (Yolcu & Popkewitz, 2018). While valuing intellectual resources that students bring into classrooms and treating students as agents who are capable of making sense of mathematics is important, what remains at issue is the set of taken-for-granted assumptions that is constantly enacted and paradoxically denied students who act outside of the boundaries of these assumptions.

Methods

The study was conducted at a public elementary school located in a town in the United States Midwest. Slightly more than half of students were identified as economically disadvantaged, 40% as English learners, and 15% as students with disabilities. Fieldnotes were collected in Ms. Zoe's fourth-grade classroom (9- and 10- year-olds). A total of 17 weeks of data was collected

To explore how inscription practices occur, we adopt a historically-comparative approach (Stinson, 2017) to analyze the sense-making activities taking places in mathematics lessons. Classroom vignettes were analyzed with two different lenses. First, we identified the vignettes in which Ms. Zoe demonstrated substantive support of student epistemic agency. Second, we investigated the historically-resembled assumptions about mathematics abilities and learning manifested in these vignettes through building on the existing historicizing studies in mathematics education.

Findings and Discussion

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This section presents an illustrative vignette to instantiate how inscription practices occurred. The vignette records interaction between Ms. Zoe and four students: Elliot and Ricky (African American boys), Janet (an African American girl), and Taevy (a Cambodian girl).

Valuing student epistemic resources and sharing epistemic agency

Ms. Zoe set up a context for the students to make sense of skip-counting. She showed the students a box of 24 crayons. She guided the students starting with counting one row of crayons in the box (8 crayons) and proceeded to counting two rows (8x2 crayons). Then, she asked the group how they counted all of the crayons in the box. The students came up with different strategies of skip-counting. Elliot and Ricky counted it by 8, and Taevy counted it by 3. Ms. Zoe affirmed each of their ideas and ensured that their ideas were made public. She repeated, clarified the ideas, and wrote them down on her white board (e.g., She asked Janet, "So you kind of use the same method like Elliot, right? Did you count 17, 18, 19, … after 16?"). Different skip-counting strategies were affirmed. Then, Ms. Zoe introduced number-lines as a strategy to make sense of skip-counting. She handed Elliot her marker, asked him to draw his strategy of counting by 8. Then, Ms. Zoe drew Janet' strategy, and asked Elliot to draw Taevy's strategy of counting by 3. Before the end of the lesson, Ms. Zoe asked the students to draw their own strategies in their notebooks. Ms. Zoe positioned her students as sense-makers rather than knowledge absorbers; she not only invited students' ideas but also allowed them to keep the ownership of their ideas. The ways in which Ms. Zoe supported her students are consistent with scholarship that suggests fostering students' epistemic agency as essential in supporting equitable sense-making because it disrupts the conventional assumption that students' ideas are inferior.

Inscribing what counts as mathematics abilities

Elliot was the only one given the authority to hold the marker and show his idea. This shift of epistemic authority from Ms. Zoe to Elliot explicitly positioned him as intellectually capable. The history of the class suggests ongoing appreciation of Elliot's mathematical strengths. Elliot always finished his tasks accurately and faster than other students, and Ms. Zoe would push him to work on extra problems that were more challenging.

Elliot fit in with conventional conceptions of a good sense-maker in school mathematics. He not only solved problems quickly and accurately but was also good at asserting his ideas in public. He was always able to follow the problem contexts that Ms. Zoe set up for students to learn mathematical strategies, just like what occurred in this vignette. The other students in this group, however, did not quite fit in with such fabrication of good sense-makers. Both Janet and Taevy worked at a more deliberate pace, and Ricky often stopped working and got frustrated when encountering a difficult problem.

The values and expectations of mathematics sense-making that were manifested in this vignette do not simply function locally. These values resemble historic assumptions around to how students should participate in mathematics learning and what mathematical thinking is desired. Students whose ways of knowing and learning fit in with these assumptions have more opportunities to be positioned as good sense-makers, while students who act outside of these assumptions are frequently described as "at risk," "disabled," "unmotivated," "disadvantage," "not producing" (Kirchgasler, 2017). We call into question the assumptions regarding what counts as valuable thinking in mathematics classrooms along with prevailing discourse of epistemic agency. Our analysis of inscription practice suggests a need of complicating understanding of supporting equity in mathematics education.

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International Society of the Learning Sciences

Directed Actions Scaffold Gestural Insights in Geometric Reasoning

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Abstract: Spontaneous gestures often express thoughts that differ from speech. Priming students to perform *directed actions*, movements designed to foster conceptual understanding, may give a way for students to organize their thoughts by providing a gestural vocabulary. G*estural insights* are nonverbal expressions of movement that reveal students' mathematical reasoning even when they were unable to verbalize their insights. This case study demonstrates how body-based resources like directed actions can foster gestural insights that support conceptual thinking.

Introduction and Theoretical Background

During mathematical reasoning, teachers and students naturally communicate key ideas using descriptive language, verbal inference, and gestures of the arms and hands (Alibali & Nathan, 2012). These co-speech gestures are a crucial form of multimodal discourse that reflect cognitive processes. Researchers have shown that the knowledge conveyed through gestures can differ from and complement speech (Goldin-Meadow et al., 1993; Pier et al., 2019). These *gestural insights* are phenomena in which students' gestures exhibit mathematical insights that are otherwise absent in their speech. Specifically, this case study explores how embodied thinking in the form of gestural insights contributed to a student's mathematical conceptualizations while generating geometric proofs.

Spontaneous co-speech and co-thought gestures often express one's cognitive processing (McNeill, 1992). Nathan et al. (2014) found that performing cognitively relevant arm movements contributed to superior insights into mathematical proofs. Thus, scholars hypothesize that directing learners to perform movements may provide effective embodied interventions that improve reasoning and learning (Nathan & Walkington, 2017). *Action-cognition transduction* proposes that instructing learners to perform *directed actions* will influence one's reasoning in ways cognitively congruent with the actions performed through nonverbal means (Nathan, 2017). Therefore, we ask: How do directed actions contribute to gestural insights and mathematical understanding?

Methods

This case comes from a larger study investigating the impact of directed actions and predictions on mathematical reasoning and focuses on one conjecture — *The diagonals of a rectangle always have the same length* (Figure 1; Xia et al., 2022). The participant was prompted to first perform directed actions and then read the geometric conjecture, consider its veracity, and provide a verbal justification. Recordings of participants' verbal responses and actions were transcribed and coded for correct mathematical reasoning, gestural insights, representational gestures, and dynamic depictive gestures (Xia et al., 2022).

Figure 1
Directed Actions for the "The diagonals of a rectangle always have the same length." conjecture

Note. These directed actions are intended to convey a key insight related to this conjecture – that the diagonals must be congruent because they each are the hypotenuses of left and right triangles with equal arm lengths.

Results

Student 1's (S1; Figure 2) intuition reflects their assertion that the diagonals of a rectangle must be the same length (Line 1). Mimicking the second pose from the directed action sequence (Figure 1, Frame 2), S1 arms

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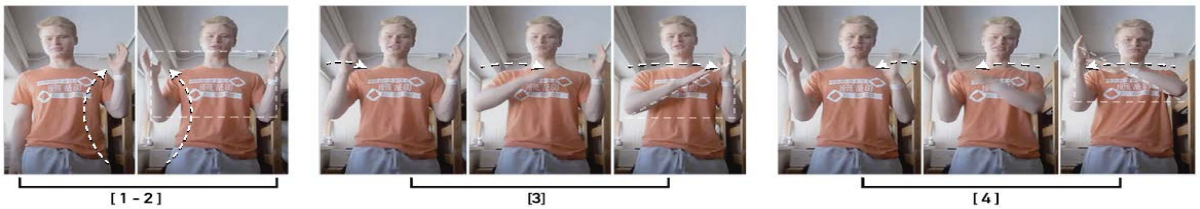
represent their mental construction of the rectangle (Line 2). Next, they rotate their right arm to create a diagonal while saying "I rotate one to create a diagonal" (Line 3). S1's gestures reveal their understanding that diagonals intersect the bottom corners of the rectangle and must therefore have the same base angles intersect the top corners of the rectangle (Line 4). S1 does not provide a generalized rationale for why this conjecture must always be true as it makes no mention of the mathematical properties of rectangles. Non-verbally, S1's gestures demonstrated that a rectangle has a set of congruent and parallel opposite sides (Line 2), expressing a generalized understanding that both diagonals are equal (Lines 3-4).

Figure 2

Transcript #1



[1] The statement is always true [2] because when I hold a, make a rectangle of my arms, [3] I rotate one to create a diagonal, [4] it's gonna hit my arm in the same spot, regardless of which side it's on.

Discussion & Conclusions

This case shows that students who were unable to provide verbal mathematical reasoning demonstrated their emerging understandings through gestures. With these findings in mind, we revisit the research question.

This case shows how mathematical understanding is conveyed through movement. S1's geometric construction depicts two equivalent diagonals originating from consecutive corners of the rectangle. This insight highlights how dynamic gestures expand students' ability to convey their mathematical understandings. S2 integrated the directed action sequence in their gestures in their mathematical reasoning. This integration suggests S2 may have recognized the cognitive relevance of the directed actions to the conjecture. Moreover, S2 expressed generalized features in their gestures that were not found in their speech. In this case, we see how directed actions scaffolded the student's geometric reasoning and revealed potential for embodied interventions to help elicit gestural insights that foster conceptual reasoning.

Gestural insights may demonstrate ways students are extending their zones of proximal development (Goldin-Meadow & Church, 1993). Studies on geometry proof processes—and mathematics more generally—focus on verbal descriptions of mathematical insights (e.g., Xia et al., 2022). Students' gestures reveal nonverbal ways of knowing that could be used to guide learner-centered instruction by expanding formative assessment practices to include embodied expressions of knowing.

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International Society of the Learning Sciences

Intertwining art and STEM: An analysis of STEAM activities

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Abstract: The integration of Art with Science, Technology, Engineering, and Mathematics (STEAM) has been growing in popularity, however, there are a variety of conceptualizations of what it looks like. This study explores images of STEAM by examining activities created by informal educators. We found that STEAM activities were conceptualized as using one discipline in the service of another, intertwined, or parallel. This provides concrete images of what STEAM can look like in educational settings.

Introduction

STEAM, or the integration of Art with Science, Technology, Engineering, and/or Mathematics, has become increasingly popular, for various reasons. STEAM is important for the economy, leading to increased creativity and innovation (Allina, 2018; LaMore et al., 2013) and job preparation (National Academics of Sciences, Engineering, and Medicine, 2018). Others argue that integrating art with STEM broadens participation of those traditionally underrepresented in STEM (Buechley & Perner-Wilson, 2012; Mejias et al., 2021; Peppler, 2013). Many argue for the importance of STEAM as it leads to new perspectives and ways of understanding that would not occur through disciplinary thinking (Bevan et al., 2020; Quigley & Herro, 2016; Siler, 2011). With burgeoning interest in STEAM, there is a need for more concrete images of what STEAM looks like in educational settings. We aim to add to the developing body of STEAM work by exploring the STEAM activities that informal educators created as part of their participation in a STEAM professional development program. We investigate the question: What are the qualities of participants' STEAM activities?

Theoretical framework and methods

We drew from a variety of conceptions of STEAM from the literature for our analysis. For example, in an interdisciplinary conception, two or more disciplines can work together without changing each other (Siler, 2011). Peppler and Wohlwend (2018) argue that STEAM should be transdisciplinary, where "…new understandings and artifacts emerge that transcend either discipline" (p. 88). This offers a view of STEAM integration where the disciplines not only support each other, but also work together in ways that move beyond the learning that could happen through disciplinary approaches. Mejias and his colleagues (2021) theorize STEAM along pedagogical and instrumental axes in four major quadrants (Mejias et al., 2021, p. 218). Their conceptualization of STEAM, including one-sided and mutually instrumental rhetoric, supported our analysis of how integrated the STEAM fields were in practitioners' activities.

The study's context was a STEAM professional development program developed for informal educators, (e.g., librarians, afterschool art and science teachers). It consisted of a two-day, in-person workshop followed by a mini-online course. The culminating project was to design a STEAM activity. The program was enacted with five different groups from geographic locations across the U.S. We analyzed 48 STEAM activities from all 47 participants who submitted written activity plans (one participant submitted two activities). We analyzed the data using emergent coding (Strauss & Corbin, 1998), looking for what images of STEAM the educators portrayed through their activity plans. From our analysis, three categories emerged: 1) In service of another discipline, which included STEM in the service of art and art in the service of STEM; 2) Intertwined; and 3) Parallel. These will be described in the findings.

Findings

We found three images of STEAM in the activities the educators developed. The first category was *in service of another discipline,* where one discipline was used to inform another discipline, but not vice versa (e.g., art in the service of STEM, where art was used to help learn STEM (thematically, materially, and/or conceptually). An example of *art in the service of STEM* was an activity where youth created a diorama of a rainbow to communicate their understanding of what causes rainbows. In this case, the focus was on learning about the science of how rainbows form and then art was used to help the students communicate their understanding of rainbows.

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The second category was *intertwined*, where the activity showed feedback between art and STEM, where the learning of Art and STEM depended on each other, continually informing each other throughout the activity. An example of *intertwined* was an activity where youth were given a problem to solve, in this case they were commissioned to design a wheelchair accessible ramp at a county fair. The ramp needed to be large enough to fit the needs of the people in the wheelchairs and also contain design elements relevant to the ideas and values of the members in the community. The activity positioned youth as architects so they could, according to the activity designer, "see how art and design both have a place in the STEAM content area" and identified various aspects of the activity as science (how the materials worked together), technology and engineering (how to assemble the materials), art, math and technology (how to design the solution), and math (determining the cost of the project and how to make it cost effective.

The third category was *parallel*, where the art and STEM explorations could be done separately and did not rely on, or inform, each other. An example of this was an activity where the youth learned STEM concepts in order to create a kite. The activity designer identified the following STEM concepts the youth would learn as they created their kites: forces (science), measurements (math), and how the shape and materials affect the kite's ability to fly (engineering). Once they created a kite, the youth could decorate it using crayons, pencils, or chalk with designs that were personally meaningful. In this activity, the art (decorating the kite) did not depend on understanding of STEM concepts, nor did it interact with these concepts in the functional design of the kite.

Conclusions and implications

We believe that there are places and times for a variety of types of STEAM activities, depending on the learning goals and needs of the youth. The purpose of this analysis was to explore a spectrum of images of STEAM, as there is much need for more concrete examples of STEAM in educational settings. As educators are increasingly being asked to consider designing and implementing STEAM, whether as a means to broaden participation in STEM, deepen engagement and understanding in STEM, or encourage creativity and critical thinking, we need to have a better understanding of the possibilities, as well as the constraints and affordances of varying approaches.

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Effects of Level Trajectory on Mathematical Gameplay

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Abstract: We investigate the effect of free-choice versus adaptively recommended level trajectories on gameplay for middle-school learners playing a 3D architectural game involving ratio and geometric reasoning. We compare data between groups examining students' game performance and level selection patterns to examine the potential impact of level trajectories on a learner's gameplay performance and process. Using data from an online-facilitated study (n=23) we find that students playing with an adaptively recommended level trajectory spend more of their time on the target math-related levels. We confirm this with data from an onsite-facilitated study (n=51) and propose that adaptive level recommendation guides learners toward game levels relevant to target learning objectives while allowing some freedom of choice.

Background

Designing a learning game with discrete game levels can be useful for isolating certain skills and compartmentalizing learning objectives, but with multiple game levels come sequence and presentation design choices. Story progression across levels can be linear, where players complete fixed sequences, or structured such that progression through the story emerges from and is impacted by gameplay, as designers prefer (Fullerton, 2019:101). Non-linear level trajectories can also be a function of difficulty, adapting to performance level. Level trajectory mechanisms like Dynamic Difficulty Adjustment can support overall game experience and reduce self-consciousness but may also lower a player's sense of control (Ang et al., 2017). Turning to learning games specifically, Shute et al. (2021) found that students' learning was not significantly affected by different game-level delivery, including four methods: adaptive, linear, free choice, and a control group. In their study involving a 2D physics sandbox game, game performance measures (e.g., levels completed) was not affected by the type of level trajectory, but rather the type of support—physics animations were found to have the most positive effect (Shute et al., 2021). We revisit the question of level trajectory effects in a 3D math game, exploring differences between (1) students freely choosing levels and (2) students recommended levels based on their competency.

Method

Study Procedure

In a 3-week experimental group-comparison study, 21 students each completed 7-9 thirty-minute gameplay sessions during a summer school program, monitored by teachers on site and facilitated by research team members by Zoom. To confirm our initial findings, we analyzed data from a later fall study, with onsite facilitators, a larger group of middle-school students (open-path: n=26, recommended-path: n=25), and more gameplay (fifteen 45-minute sessions). All students in the summer and fall studies began gameplay with 5 movement training levels (not involving the target math objectives) to familiarize themselves with basic movement and manipulation of objects in the 3D game world. We randomly assigned students to path "open-level," where students complete training levels and then choose which game level to play next, or "recommended-level," where a Bayesian network recommends levels via student performance on learning objectives in previous levels' game actions.

Results

Students in the open-level and recommended-level paths showed similar group averages for total level attempts, successful level attempts, and % of successful level attempts. Inferential statistics were used to assess the remaining three metrics, which appeared to differ between groups (time spent on movement training, total gameplay time, and % of time spent on movement training). An independent samples t-tests comparing open- and recommended-level paths for all 6 gameplay-related metrics revealed no difference between groups except for percent of time spent on movement training. As Table 1 shows, percent of time spent on movement training was over 20% higher for the open-level path with marginal significance ($t = 2.26$, $df = 22$, $p = 0.03$) and a large effect size (Cohen's $d = 0.93$, Hedges $g = 0.86$). Levene's test for homogeneity assumption showed that group variances did not differ significantly for any of the measures we investigated.

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Table 1
Game Performance Statistics for Students in Two Level Trajectory Paths (Online Facilitation)

	Open n = 11	Recommended n = 10	t	df	Sig. 2-tail	Mean Difference	SE Difference
Total level attempts	10.85	11.1	-0.66	22	0.52	-1.97	2.99
Successful level attempts	6.31	7.90	-1.25	22	0.23	-2.60	2.08
% of successful levels	60.77%	64.40%	-0.37	22	0.572	-4%	0.09
Movement training time	29.93	35.31	-0.62	22	0.54	-5.29	8.50
Total gameplay time	44.58	61.73	-1.23	22	0.23	-21.49	17.41
% of time spent on movement training	84.43%	63.80%	2.26	22	0.03*	24%	0.10

Note. *Significance threshold of $p<0.05$; time is reported in minutes.

As seen above, groups did not differ significantly in the other measures. We ran t-tests to assess whether the significant difference in % of time on movement training between groups held for both females and males. For males, the difference was marginally significant ($t = 1.956$, $df = 10$, $p = 0.079$), while for females, there was no significant difference ($t = 1.201$, $df = 10$, $p = 0.257$). To confirm this finding, we ran another independent samples t-test on data from middle school learners playing the same game in the onsite-facilitated study, this time with more students, more gameplay, and more careful facilitation (i.e., on-site). As seen in Table 2, students in the recommended path spent around 7% less of their gameplay time on non-math training levels.

Table 2
Game Performance Statistics for Students in Open-level and Recommended-level Paths (On-site Facilitation)

	Open-level mean n = 26	Recommended-level path mean n = 25	t	df	Sig. 2-tail	Mean Difference	SE Difference
% of time on movement training	24.63%	13.48%	2.70	49	0.01*	11.16%	4.13
% of level attempts movement training	31.92%	19.92%	2.67	49	0.01*	12.00%	4.49

Note. *Significance threshold of $p<0.05$; time is reported in minutes.

Discussion

One reason recommended-path students spent 7% more of their time on content-related levels may be that whereas students in the recommended-level path only saw new level choices appear as they completed levels, students in the free path had to navigate multiple menu steps to find new levels. If a student is drawn to readily visible levels, level recommendations would encourage new levels by displaying them and not requiring extra menu navigation. Second, unlike game levels, training levels lacked math problem solving. If students meet challenging game levels beyond their competency they may opt for the training levels which they can confidently complete. Students recommended levels adapted to their math competencies are likely more comfortable attempting new levels. We recommend designers consider an adaptive difficulty-driven level trajectory with recommendations to maximize learners' engagement with challenging content-related game levels, while giving learners freedom of level choice.

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Dynamic Modelling of Collaborative Sensemaking: A Case Study

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Abstract: How do explanations emerge and evolve in collaborative sensemaking? We present a preliminary attempt to model the evolution of collaborative sensemaking over a short timespan with high temporal resolution. We operationalized Sherin et al.'s (2012) node-mode framework of individual knowledge systems to a distributed knowledge system and examined its dynamics in high temporal resolution.

Introduction

In an attempt to examine why, and under what conditions, students generate coherent explanations in clinical interviews, Sherin, Krakowski, and Lee (2012) examined a large corpus of interviews with students about seasons and climate. Their analysis was situated within the Knowledge in Pieces (KiP) epistemological perspective (diSessa, 1993). Sherin et al. (2012) suggested that students' reasoning draws on a set of interconnected knowledge elements. They used the term *nodes* to describe elementary pieces of knowledge; and *modes*, to describe interconnected collections of nodes that are stable and are activated as a whole. They described sensemaking and reasoning as a process in which individuals create *dynamic mental constructs* - unstable and temporary knowledge structures comprised of *nodes* and *modes* that are activated and ad-hoc connected for the purpose of constructing an explanation.

The current study focuses on collaborative sensemaking, in which collaborators create and use a joint problem space (JPS) that provides a platform for meaningful communication in support of the sensemaking process. To construct their JPS, collaborators need ways to introduce and display knowledge in the JPS as well as methods to monitor differences in meaning and to resolve obstacles to the collaboration (Roschelle, 1992; Roschelle & Teasley, 1995). Inspired by studies of distributed cognition (Hutchins, 1995), we aim to model collaborative construction of explanations as drawing on a distributed knowledge system, and we suggest an operationalization of Sherin et al.'s mode-node framework for a distributed cognition, for example, a pair of students working in collaboration. We examine the dynamics of the collaborative knowledge construction with high temporal resolution. We use the term *shared nodes* to describe nodes introduced and accepted into the JPS, and the term *shared modes* to describe shared knowledge structures that are re-used in the JPS. The term *shared dynamic constructs (SDCs)* is used to describe the unstable and temporary knowledge structures that are connected for the ad-hoc purpose of constructing an explanation created in collaboration.

Methods

The data is drawn from a group interview with a pair of eleven-grade students who study advanced-level physics. The students knew each other and collaborated on previous occasions. The students were asked to discuss and explain why is it warmer in the summer than in the winter. This question was selected because it can be tackled using naïve knowledge, but it requires making sense of several natural phenomena and the connections between them, and thus answering it is far from trivial. Another reason for this particular choice was its use by several research groups in the past (Lelliott & Rollnick, 2010; B. Sherin et al., 2012) which allowed comparisons.

The interview was video recorded. The recordings were transcribed and specific episodes which were rich in *shared* knowledge construction were selected for analysis. The analysis involved the identification of *nodes* (Sherin et al., 2012), *shared nodes*, *SDCs* and *shared modes*. Relational expressions (such as "because", like, etc.) were identified and used to code attempts at knowledge construction and successful connections between *shared nodes,* both resulting in *SDCs*, as well as the creation of *shared modes*. A temporal representation of the collaborative knowledge system was created for each episode (here we present one).

Results

The temporal representation of the collaborative knowledge system in one episode (3:50 minutes) is presented in Fig. 1. The Y-axis of the graph shows the *nodes* that are used in this episode. The X-axis reflects the conversational turns, and colored dots identify the speakers using the respective *node* in their utterance.

The episode starts with the collaborators setting the stage for the process by introducing *nodes* into the JPS. Both partners contributed *nodes* and engaged in attempts at assembly, using *nodes* that they introduced into the JPS as well as *nodes* introduced by their partner. This symmetry in participation is an important feature of a

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collaborative interaction (Dillenbourg, 1999)and validates the construct of *shared nodes*. Following are attempts to combine the *shared nodes* into *SDC*s. Successful attempts are characterized by well-defined connections between the *shared nodes* in the utterance, via expressions like "because", "and then" or "is". They are marked in green in the graph. Conversational turns which included *shared nodes* without a meaningful connection between them were coded as "attempted connection", depicted in the graph as yellow connections between nodes. Those included for instance sentences in which there was an "if *node* A" phrase, but the "then" part was missing, or "let's say that *node* A and let's say that *node* B". Attempted connections were sometimes scientifically wrong. Interestingly, both attempted connections and successful ones resulted in the generation of *shared modes* identified as the re-use of previously developed structures in subsequent conversational turns. Some SDCs were created in collaboration and thus span more than one conversational turn (see turns 18-19 as well as 22-23-24), in line with our assumption that *shared dynamic constructs* are generated by a distributed cognition, similarly to the way an individual creates *dynamic mental constructs* (Sherin et al., 2012). This type of collaboratively-created SDCs was coded when the participants continued each other's ideas.

In this episode, a repetition of the question asked at the beginning of the interview (turn 27), intended to check if the shared knowledge structure provides an acceptable explanation, led to its collapse, but *shared nodes* that were created in the process were used in further turns in this episode and along the rest of the interview.

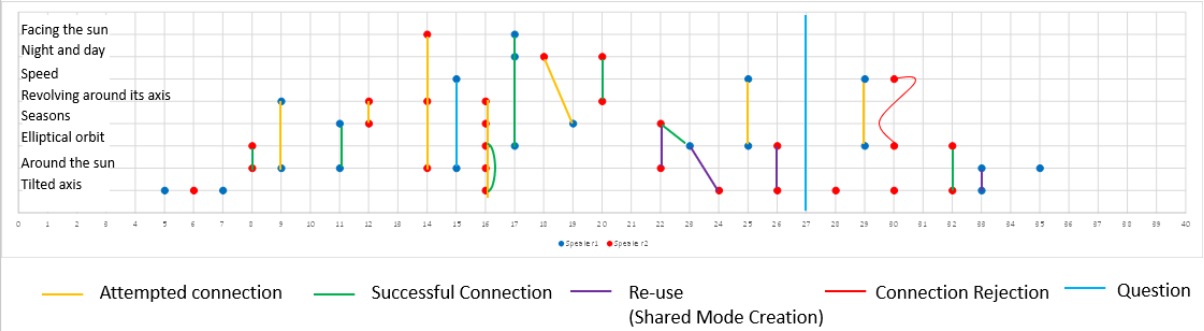

Figure 1
Knowledge Construction in Collaboration

Discussion

We operationalized Sherin et al.'s (2012) node-mode framework of individual knowledge systems to a distributed knowledge system and examined its dynamics in high temporal resolution. The analysis captures how the distributed knowledge system evolves in collaborative sensemaking and guides this process. While this is a preliminary attempt, we believe that it provides insights into the emergence of explanations in collaborative inquiry. Further investigation will aim to refine the model by specific attention to available materials and tools, and specific attention to the nature of the interaction.

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International Society of the Learning Sciences

Preparation for future learning and disposition development in a social studies-themed digital simulation game: A quantitative ethnography

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Abstract: We use quantitative ethnography and Epistemic Network Analysis to examine how the game mechanics of a social studies-themed digital simulation game may facilitate disposition development and preparation for future learning.

Introduction

Previous research indicates that *Offworld Trading Company* (*OTC*), a digital simulation game thematically aligned to social studies invites players to practice using disciplinary knowledge, skills, and concepts (DKSCs) associated with social studies to plan, take, and reflect on goal-mediated actions (Kessner, 2021). We are interested in how *OTC* might be leveraged towards two ends: (a) preparation for future learning; and (b) the ability and sensitivity elements of disposition development. We are particularly interested in identifying how game mechanics generate problem spaces in which these two goals might be facilitated.

Good games are excellent learning environments. They privilege experience before text, performance before competence, identity play, and systems thinking; and they present players with interesting, well-structured, and well-sequenced problems players solve by mastering and applying game-valued skills (Gee, 2003). Good games often align better than formal education environments to long-standing contentions of situativity theorists that what we learn cannot be disentangled from how and why we learn it (Gresalfi et al., 2009). For these and other reasons, games have maintained a level of popularity among both educators and researchers. In the context of social studies education, however, a mismatch exists between this interest and the available evidence of effectiveness, as well as conceptual guidance around what (kinds of) games are useful and why. Use of games in social studies education contexts may indeed represent a unique challenge.

Good social studies education prepares students for active participation within a pluralist representative democracy (Banks, 2006; Barton & Levstik, 2004). Civic preparation, Kessner and colleagues (2020) argued, should include citizens coming to see the world as designed and redesignable, and themselves as possessing agency over those designs in the form of designerly agency. Economics, the heart of which comprises problem framing and decision making, offers a particularly potent disciplinary toolkit for identifying, considering, and planning, taking, and reflecting on such design problems. Nevertheless, research on economics education remains decidedly scant relative to its fellows under the social studies umbrella; and while scholars have attended to the economics of the videogame industry as well actual in-game economies, we are unaware of serious scholarly attention to videogames as sites in which economics education may present.

We use quantitative ethnography (QE) (Shaffer, 2017) to examine small-group play of *OTC* to explore the following research questions:

1. To what extent might playing *OTC* influence learners' ability, as measured by the appropriate use of disciplinary discourse, to use economics concepts to attend to real-world problems, and what game mechanics might be associated with such development?
2. To what extent does playing *OTC* develop learners' sensitivity to economics in the real world, and what game mechanics might be associated with evidence of changes in this sensitivity?
3. To what extent does playing *OTC* prepare students for future learning in the domain of economics, and what game mechanics might be associated with positive evidence of preparation for future learning?

Theoretical framework

By *dispositions* we mean the bridging of the ability to do something and actually doing it. Dispositions comprise three elements: ability, sensitivity, and inclination (Perkins et al. 2000). Dispositions are also part of the fast-thinking system of the brain, which relies heavily on prior experiences for decision making (Kahneman 2011; Seligman et al. 2016), experiences which occur as embodied interactions with the world mediated by tools. Gee (2015) described this interaction as *conversations with the world*, cycles of thinking and action in which people identify goals, plan actions, and gather feedback on those actions from the world. Learners probe the world with actions, and the world "talks back". In videogames, players are embodied in the game world as avatars, which

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come with toolkits (Gee, 2015). It is with these tools and through these avatars that players (are able to) take actions in games. Thus, games provide a solid theoretical foundation for disposition development. The ways in which *OTC* presents core deep-structure problems relevant to social studies in myriad surface-feature configurations also, we contend, supports transfer of knowledge to novel real-world scenarios, which is essential to disposition development (Bransford & Schwartz 1999). Furthermore, we suggest that engaging with these problem spaces prepares students for future learning in the domain (Schwartz & Arena 2013).

Methods

QE leverages quantitative designs and analyses to make sense of complex qualitative discourse data (Shaffer, 2017). Recent games scholarship leveraging QE has explored themes from how an online game community forum facilitated participants' identity exploration processes (Barany & Foster, 2019) to the correlation between facial expressions and understanding of biological and complex systems concepts (Martin et al., 2019). QE represents particular affordances for the present study, as well. Games are immensely complex systems, making purely qualitative accountings of the connections between many diverse variables difficult if not untenable.

Participants for this study are a class of high school students enrolled in an Academic Decathlon (AD) elective course in a public school in the American South. This year, AD has an economics theme. Specifically, we are working with underclassmen enrolled in the course but who did not make the competition team. Students come from diverse backgrounds, and their varied levels of academic achievement, from "low" to "high," as measured by school-calculated grade point averages, indicates a wide and potentially representative sample of academic interest and engagement with school. While prior learning would be a concern in a traditional economics classroom, the English Language Arts teachers sponsoring this implementation of AD are trained neither as economists nor as economics educators, and they historically rely on senior students who already possess the requisite knowledge. The students who did not make the competition team, then, by definition are unlikely to possess significant prior knowledge.

The intervention consists of students playing *OTC* in diads during class time for one week. Instruction on relevant economics concepts will be taught by the researchers in a just-in-time fashion (Squire, 2011). Gameplay will be screencaptured, and student discourse data will be audio recorded. At the end of each lesson, students will be tasked with skimming news headlines for relevant social studies concepts, which they will bring to class the next day to discuss. Transcribed discourse data, gameplay data, and student work will be analyzed through Epistemic Network Analysis to identify connections between gameplay and student talk that either directly leverages disciplinary discourse or otherwise implicates discipline-relevant thinking.

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International Society of the Learning Sciences

Learning Geometry Through Collaborative, Embodied Explorations with Augmented Reality Holograms

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Abstract: Novel forms of technology, like shared Augmented Reality (AR) holograms, can spur the discovery of new hypotheses about cognition and how it is embodied and distributed. These holograms have affordances for exploration, collaboration, and learning that have never been seen before. In the present study, we examine the multimodal ways that high school students interact with shared AR holograms while exploring geometric conjectures. Through multimodal analysis, we fine both possibilities and important design considerations.

Introduction

Advances in Augmented Reality (AR) allow 3D holograms to be projected into students' real-world environments, controlled through intuitive hand gestures. Even more significantly, students can engage with these holograms collaboratively, with each student able to manipulate the holograms and see the effects of others' manipulations. These are literally new collaborative objects. We investigate students using AR goggles to explore geometry conjectures and describe the possibilities for collaborative embodiment and access to mathematical ideas.

Theoretical Framework: Collaborative Embodiment

Collaborative embodiment is defined as the ways students co-create actions and embodied ideas that become extended (Clark, 2012) over multiple learners. *Gestures*, spontaneous or purposeful hand and arm movements that often accompany speech, are a powerful way in which mentally-simulated actions can give rise to physical movements (Hostetter & Alibali, 2008). *Collaborative gestures* (Walkington et al., 2019) are gestures that are dependent on the gestures of interactional partners, like echoing or repeating gestures. AR and VR environments also happen at a scale where students engage in whole body movements – students might move around virtual 3D objects to take different perspectives (Walkington et al., 2021). Finally, students engage in collaborative forms of speech, using talk moves like Negotiating, Representing, and Planning (Andrews-Todd et al., 2019). It is through this multi-modal account of communication with speech, gestures, and collaborative embodiment that students generate shared mathematical meaning. We explore these research questions: (1) How do learners use resources like gestures, actions on virtual objects, body movements, and speech to explore conjectures in an AR environment? and (2) What barriers do students encounter to reasoning through collaborative embodiment?

Methods of Inquiry

Participants included 28 high school students enrolled in an enrichment program at a local university intended to support high school students likely to become first-generation college students. Twenty-three of the participants were female and 5 were male; 12 identified as African-American, 14 as Hispanic, 1 as White, and 1 as Other. Participant dyads were asked to reason about 8 geometry conjectures, without AR goggles on. Then they would put on the Microsoft HoloLens 2 goggles and justify 3 to 4 of the conjectures a second time. They used an app developed by GeoGebra for direct mathematical object manipulation (Hohenwater & Fuchs, 2004).

Results

The dynamic, 3D nature of the holograms offered powerful affordances for mathematical reasoning and embodied collaboration. In Figure 1, we see a dyad's second attempt to prove the sphere conjecture in Table 1, this time with the aid of the holograms. Having access to the 3D shape seems to give the students novel insights, and we see them using body movements to change the perspective they have on the sphere and to look at each other. We also seem them using gestures to reference the sphere and collaborative actions to dynamically modify the sphere, all while engaging in collaborative talk. The students exhibited substantial progress of their embodied understanding of 3D figures and how they interact with each other (Lines 1-16). However, students were not always able to use the holograms and their associated embodied resources and motions to reason more effectively. Multimodal analysis revealed that the students encountered issues with mathematical language in many episodes and struggled to decipher the culturally-bound, closed-ended, written medium of mathematical conjectures.

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Figure 1
Two participants reasoning about a conjecture about a plane intersecting a sphere at 0, 1, or infinite points. Red arrows were added to the image to show motion or change.

1. S101: I feel like we looked at that all wrong.
2. S102: Yeah, uh uh.
3. S101: Ooh, when I was thinking about –
4. S102: That would be true.
5. S101: When I was thinking about this in my head, I was like, "a plane is just gonna go around and around and around."
6. S102: So, it's true.
7. S101: It's true!
8. Researcher: Why do you think it's true or false?
9. S101: Because, if you really look at the plane – I'm making it bigger.

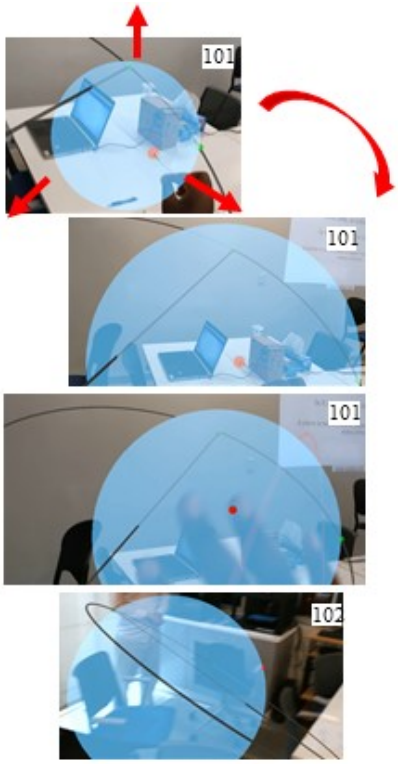
(adjust the sphere so that it is larger)

10. S102: There's many more ways you can intersect it at.
11. S101: It's more ways that it can go in and out!
12. S102: Yeah.
13. S101: Oh wow!
14. S102: There's like, many more ways.
15. S101: Okay, yeah, I was looking at this all wrong in my head. Now that I see it, I can say that it's true.

(gestures to the plane and where it is intersecting the sphere)

16. S102: Okay, yep, many more points that you can –

(steps back to view the plane intersecting the sphere)



Discussion

A variety of rich multi-modal forms of interaction come together in this shared AR environment to support students in creating meaning and constituting students' knowledge. AR holograms may be more powerful and appropriate for concepts that are inherently 3D, as these objects leverage AR's profound affordance for 3 dimensions, like our sphere simulation did. Finally, AR allows students to interact with and explore objects in novel and unconventional ways. However, if you bring traditional "school" tasks into an AR environment, students' reasoning and attempts at meaning-making can be restricted. Tasks in shared AR environments become particularly meaningful if they come from students and their embodied, collaborative experiences.

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Can Educational Researchers Help Reduce Accident Rates in a Big Construction Company?

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Abstract: It is not common for big construction companies to call upon educational researchers to collaborate with them in efforts at reducing worksite accident rates. In this paper, we describe one such collaboration, including the background and rationale for it, and the progress that the small team of educational researchers and construction company managers have made in the first 7 months of the project. We outline some of the processes through which strategies for addressing the problem have evolved, and consider how it may be possible for a project like this to manifest characteristics of the four dimensions of quality that Furlong and Oancea (2005) proposed for applied, practice-based educational research (epistemic, economic, technological, and capacity building and value for people). Our overall aim is to reflect on the extent to which educational researchers may be able to contribute to a more diverse range of applied research.

Introduction

Many educational researchers engage in applied research, but such activity is almost always firmly focused on the development of new knowledge for teaching and learning (Dodd & Epstein, 2012). However, there are cases where the research remit is broader and goes beyond addressing teaching and learning challenges. In this paper, we describe such a research project: one in which educational researchers collaborate with management of a big construction company in an effort to reduce accident rates in that company.

Background to and rationale for the project

The collaboration originated from a discussion between the fifth author, who is the Manager of the Safety Management Department of Toda Corporation, and the second author, who is a doctoral candidate and owner of a private tutoring school, who have known each other for many years. They discussed a pressing challenge being faced by Toda Corporation: how to reduce its accident rates. The company was established 140 years ago and is one of the major construction companies in Japan at the present time.

Although, compared to the average of all construction companies in Japan, Toda Corporation's rate of occupational accidents is lower, it is nevertheless at a level that is considered too high by those in the construction industry. Its frequency rate of accidents (which is measured as the rate of occurrence of an accident per million hours of work) was 0.51 in 2020, but its target rate is 0.30. Reducing accident rates is extremely important for a number of reasons, including the company's ethical responsibility for ensuring safety for workers and the general public, and its liability on many fronts – civil, criminal, and social – whenever accidents occur. In the past six years, the company has implemented a number of strategies, including the development of a new system of classifying the causes of human errors (based on Takagi, 2006), the appointment of a director to manage general safety and health, implementation of a database for accident information sharing, and use of web cameras for remote monitoring of work places. However, the company had not directly engaged with academic researchers.

The main purpose of the research collaboration described in this paper is to identify and address relevant human factors that may hinder or promote safety. In the original discussion between the second and fifth authors, they realized that although the company may have been addressing various work tools/resources and procedures to improve safety, they had not adequately considered human factors (e.g., worker perceptions, beliefs, and motivations). In subsequent discussions with the first author (who is the second author's doctoral supervisor), the idea of addressing such factors to promote greater safety was therefore developed.

Progress to date

At the time of writing this report (7 months from the start of a 2-year project funded by Toda), the "research team" involved in this collaboration comprises the first author (university professor in educational psychology), the second author, another two of the first author's doctoral students (who are able to participate only in very limited capacities because of their other work and study commitments), three part-time research assistants (two working with the first author – one of whom is the third author; and one working with the second author) and, on the Toda

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Corporation side, the fourth author (Deputy Section Manager of the Safety Management Department) and the fifth author. Two other senior staff members of the company participate in main meetings that are held.

Strategies in development

The educational researchers have proposed several strategies to the Toda staff which they are now working on together for implementation and evaluation. One of those is to make some modifications to the requirements for contract bidding and decision making. Many smaller construction companies bid for contracts to undertake work for Toda Corporation, but the safety performance records of such companies have not been taken directly into consideration in the award of contract work. This strategy is therefore to determine ways to realistically but effectively incorporate safety as a key consideration in bidding and awarding of contracts so as to better align the company's message of valuing safety and its management practices in awarding contracts.

Another strategy in development is aimed at improving the training provided to prevent worksite accidents, the most common of which involve injuries from the use of machinery, structural collapse, and falls when working in high places. Toda staff already know essentially why those accidents occur (e.g., taking careless or risky actions especially when in a hurry, ignoring safety protocols) and training of various forms is already in place. However, such training focuses primarily on information provision, and so workers may well learn about the dangers and what they are expected to do, but they may not sufficiently understand the direct relevance to their own selves and the seriousness of the consequences of such accidents. Hence, the objective of this strategy is to improve training methods to more actively engage workers in the learning process.

At the time of writing this report, surveys/questionnaires are also being developed to find out specific details about various aspects of workers' beliefs and perceptions, interactions, and work environments. Identifying variations in these, particularly in relation to accident rates, can then be used for the development of interventions to further reduce accidents. For instance, factors such as team leadership, sense of belongingness and cohesion, levels of trust, and coordination and sharing of knowledge may be related to workers' sense of responsibility not only for themselves but also those they work with (e.g., Fruhen & Keith, 2014). Finding out such information can help in the development of team building strategies and in the cultivation of safety-oriented worksite leadership.

Evaluating the success of the collaboration

Furlong and Oancea (2005) proposed four dimensions to consider when evaluating the quality of applied and practice-based research in education: (1) epistemic, (2) economic, (3) technological, and (4) capacity building and value for people. As this research is still in its early stages, it is not yet possible to properly evaluate its quality according to these four dimensions. However, we can consider how this research might be able to meet these quality dimensions, and examine some indicators that might indicate whether the project is progressing in the right direction. Where the epistemic dimension is concerned, the team is constantly considering the cause-effect chains associated with planned interventions and how it may be possible to reliably document and measure those. Concerning the economic dimension, the research project is focused on reducing the accidents rates of the company which, if achieved, would certainly bring multifaceted benefits to the company. Satisfying this dimension will depend on the effectiveness of strategies that are developed and implemented, and the extent to which favorable changes (i.e., reductions) in accident rates can be attributed to those strategies. We also believe that there is potential in research projects like the present one to provide knowledge, new ideas, and other useful contributions to the practice of education, and hence to satisfy the third, technological dimension of research quality. Finally, in preparation for writing this submission, we (the authors) undertook individual reflections on our perceptions about the progress of the project to date, including our own roles and progress in relation to work that needs to be done, and our feelings about what has gone well and what can be improved. These reflections, which were written down, provide clear indications that this research is contributing toward the fourth dimension of capacity building and value for people (our team). Thus, we have reason to believe that a collaboration like this with a broader research remit can meet the quality dimensions proposed by Furlong and Oancea (2005), but we will need to continue monitoring our progress until the project's conclusion to more accurately determine that.

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International Society of the Learning Sciences

Using Interest and Identity to Design for Mentor Persistence

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Abstract: Mentorship is identified as a successful approach to supporting youth in out-of-school learning. However, less attention has been paid to how to develop and support a mentor workforce. This study examines how to design supportive infrastructure that encourages mentors to persist in mentoring by providing opportunities for interest and collaborative identity development. Drawing on two case studies constructed from interview and interaction data, we demonstrate how these processes unfolded in a summer mentoring practicum.

Introduction

Mentors and mentorship are identified as successful approaches to supporting youth in out-of-school learning (e.g., Barron, Gomez, Pinkard, & Martin, 2014). Less attention has been paid to how to develop and support a mentor workforce, especially a diverse, STEAM mentor workforce. This study examines how to design supportive infrastructure that encourages mentors to persist, despite day-to-day difficulties. We explore this question in the context of STEAMbassadors, a summer mentoring practicum co-designed by community partners in two neighboring midwestern cities, with the goal of developing community college students into a diverse, out-of-school, STEAM mentor workforce, serving historically oppressed neighborhoods. Mentors participated in shared core training but were then placed, based on their interests, at different sites and given additional training to lead specific camps. They were assigned to sites in pairs or groups and participated in peer reflection sessions.

We argue that these layers of supportive infrastructure were consequential for mentor persistence, because, based on prior research, we conceptualize interest and collaborative identity development as supportive of persistence (e.g., Azevedo, 2011; Eccles, 2009; Hidi, 2006). Conceptualizations of persistence as a personal characteristic (i.e., "grit", Duckworth, Peterson, Matthews, & Kelly, 2007) have gained significant traction. However, we align ourselves with critics of this approach (e.g., Zembylas, 2021) who argue that focusing attention on individual grit misdirects attention toward "fixing" individuals rather than fixing inequitable ecosystems. We chose, instead, to focus on the designed ecosystem of STEAMbassadors, the interactions made possible by that ecosystem, and how these layers of context supported interest, identity, and persistence processes. We propose that mentors supporting youth in exploring topics of shared interest would support mentor persistence. Based on research on relational work among learners (e.g., Uttamchandani, 2021), we also propose a supportive role for peer-to-peer interactions among a cohort of mentors collaboratively developing their mentor identities.

Method

In Summer 2021, 30 mentors participated in our research. These mentors were part of the second STEAMbassadors cohort, who conducted their work one year into the Covid-19 pandemic. This meant that many pandemic restrictions were still in place, leading to hybrid or outdoor-only camps and low youth participation. We collected video of Zoom semi-structured pre- and post-camp interviews, and observations and video of group Zoom reflection sessions. We coded the video for themes related to interest, identity, difficulty, and persistence. For the reflection session data, we also conducted interaction analysis on moments identified as relevant to these themes, to examine how mentors were supporting one another by responding to each other. Finally, to illustrate themes in our dataset, we identified two focal mentors and conducted case analyses. These mentors were selected because their individual stories are rich and representative of other mentors and also because they came together in a significant interaction in a reflection session that represents how mentors supported one another.

Findings

Dante was a Latino male attending college to become an engineer. Prior to joining STEAMbassadors, he had worked as a summer camp counselor. He was also interested in becoming a DJ. Consequently, Dante was excited that, at his practicum site, there was a DJing station, run by a professional DJ. In his end-of-camp interview, when we asked him about time when he had helped a young person develop an interest, he said, "I would say it was with the DJ, where we had this one girl who was really into it, and she liked learning more about it from our DJ." This positive reflection contrasted with Dante's critical reflections on day-to-day frustrations at his practicum site. He said that the drop-in camp model made making meaningful connections with youth difficult, that outdoor

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recreation activities like skating competed with the STEAM learning stations for youth attention, and that the overall number of campers was low. However, he also described having close relationships with fellow mentors.

Kiara was a Latina female college student. She had many interests (art, science, math, acting), but was considering majoring in either business or computer science, with a focus in cybersecurity. Thus, she was excited to be assigned to a cybersecurity camp, a nature camp, and a hip hop history camp. She framed the cybersecurity camp as a positive experience learning alongside youth, since she hadn't yet taken a cybersecurity class. However, she mentioned challenges, such as low attendance and participation. She also mentioned frustrating interactions with peers, after she was asked to manage fellow mentors at her site, who were older and more experienced than she was. She said, "I don't really know how to explain it, but they wouldn't really give--do the tasks that I would give them or they'd agreed to." In contrast, Kiara also served as a peer reflection session facilitator and described this experience positively. She noted that in one particularly productive session, "[mentors] were able to communicate with us the struggles and where that frustration was coming from, so I think that was great." Kiara said she was glad to be able to support and validate other mentors' struggles and learn that it was okay to struggle.

In the reflection session that Kiara cited as productive, there was a consequential interaction between Kiara and Dante. It demonstrates how shared interests and experiences and opportunities for collaborative identity development with fellow mentors encouraged them to persist. In this session, Dante explained a struggle, saying, "[W]e came up with a great idea, we're going to do a leaderboard and everything, and they would get gift cards, and that just fell apart immediately." Kiara responded, "So what went wrong exactly, because I know gift cards, we have gift cards too, and that definitely get something going, at least the participation wise. So what do you think...made it fall apart?" Dante responded that the idea had not progressed over the weeks of his camp, and expressed frustration about that. At this point, other mentors asked questions and made suggestions. Dante and another mentor from his camp provided more details. Moments from this discussion were fraught, as Dante voiced several tensions. The tone of the conversation changed, however, when Kiara encouraged Dante to think about what a positive session might look like. This led Dante to focus on positives, including connecting with the girl who was interested in DJing and time spent with coworkers. Kiara's empathy for Dante and her challenge to him proved critical for him to focus on these positives and their role in shaping his mentoring identity and experience.

Discussion

We have documented here the supportive role that interest and collaborative identity development played in encouraging mentor persistence in STEAMbassadors. Although both Dante and Kiara experienced frustrations, both ultimately viewed the practicum positively. For Kiara, the opportunity to learn about cybersecurity alongside youth and help her fellow mentors articulate their struggles and successes outweighed her frustrations. For Dante, the opportunity to help youth explore DJing and form close bonds with fellow mentors also made the experience worthwhile. In both cases, reflecting as a group allowed mentors to bond over shared experiences and to collaboratively develop their mentor identities, rather than being isolated, as is sometimes the case for mentors who are the only educators at their organizations. These interest and collaborative identity development opportunities designed into the infrastructure of the program allowed mentors to work through difficulties and persist. Educators and researchers can draw on these findings to design intentional supports for mentors, including having mentors work with youth on topics of interest, giving them opportunities to be positioned as leaders, and making sure that they have the support of a peer cohort with whom to share and develop collaboratively.

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International Society of the Learning Sciences

Elementary Students' Epistemic Ideas Within Design-based Learning Projects

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Abstract: Students' epistemic ideas influence how they engage in science practices. This study employed the Epistemologies in Practice (EIP) framework to explore elementary students' epistemic ideas within design-based projects in a science classroom. Data were collected from multiple sources and analyzed qualitatively. Findings indicated that students meaningfully used their epistemic considerations while engaging in their design projects. It was also found that contextual factors such as task settings influenced how students prioritized their epistemic ideas.

Background

Scientists use their epistemic knowledge to evaluate the validity and accuracy of scientific products such as models and arguments to generate and advance scientific knowledge. In science classrooms, it has been suggested that students' epistemic ideas influence how they engage in science practices, such as scientific inquiry and problem solving, and understand the nature of science (Pluta et al., 2011). Therefore, science educators have been supporting the development of students' epistemic understandings by promoting their meaningful engagement in science (e.g., Ke & Schwarz, 2021; Kelly & Cunningham, 2019; Ko & Krist, 2019). To contribute to this issue, this study aimed to explore elementary students' epistemic ideas within design-based learning projects and investigate how contextual factors influenced students' epistemic considerations in action.

In this study, we employed the Epistemologies in Practice (EIP) framework (Berland et al., 2016) to understand elementary students' epistemic ideas within their design-based learning projects in science. The EIP framework emphasizes that "one's epistemology is made up of a flexible network of [epistemic] understandings that can be drawn from based on understandings of what is most appropriate and relevant to one's goals in the current setting" (Berland et al., 2016, p. 1085). From this perspective, we view students' epistemic ideas as contextualized and tied to specific content and context.

The EIP framework focuses on four considerations that are not only meaningful to scientific communities, but also to the knowledge building science classrooms (Berland et al., 2016). They are:

- What kind of answer should our knowledge product provide? (Nature): Students' considerations to this question range from *detailed description of what happened* to *causal mechanisms to explain the How and Why.*
- How does our knowledge product relate to other scientific phenomena and ideas? (Generality): This is related to students' understandings of specific experiences or phenomena with one another and with general abstractions. Students' considerations range from *specific scientific phenomena do not relate to one another or to the generalized science ideas* to *knowledge products are created from and should explain a range of phenomena.*
- How do we justify the ideas in our knowledge products? (Justification): Students' considerations range from *no need to justify* to *necessity of constructing, evaluating, and justifying the knowledge product with interpretation of the available information.*
- Who will use our knowledge products and how? (Audience): Students' considerations range from *our knowledge product is for the teacher to evaluate our understanding* to *we collaboratively construct and use our knowledge products with our audience.*

Curriculum Context and Research Methods

This four-month-long research was designed as a qualitative case study (Merriam, 2016). This study took place in a Grade 5/6 science classroom in a public school in Canada. Nineteen students and their science teacher participated in this study. During the research period, the students engaged in a design-based learning project on the topic of astronomy. In elementary classrooms, astronomy topics could foster curiosity and imagination and is an effective method of inspiring student motivation in science (Plummer et al., 2010). Despite attracting children's interests and affecting their everyday lives, research indicates that some astronomical phenomena are difficult for students to understand and challenging for teachers to teach (Plummer et al., 2010). To support their engagement in exploring other planets and their moons in the solar system, this unit was organized around a project: Design to further space exploration. In this project, students worked individually to design a new technology to further

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the current space exploration. Students knew from the beginning of this project that they would make a presentation and that their technologies would be evaluated by their classmates. Their designs were to be based on their experiences, knowledge learned in this unit, and information from online research on their topics.

Multiple methods were employed for data collection. For this paper, we mainly analyzed the data collected with classroom observation and student interviews. These data were analyzed qualitatively for thematization to understand students' epistemic considerations within their design projects. Our data analysis was informed by the EIP framework focusing on the four considerations discussed in the previous section. We first analyzed the data separately. Then, through critically comparing and examining each other's interpretations, we achieved collective data interpretations.

Findings and Discussions

In this section, we present preliminary findings on elementary students' epistemic considerations during their design projects. It was found that students in this study meaningfully used their ideas related to the four epistemic considerations in the EIP framework.

"What kind of answer should our knowledge product provide?" In this study, we found many of the student participants thought they should explain the *why* and *how* in their knowledge products (i.e., presentations). For example, one student shared during the interview "… this is going to happen, but how? We need to explain the how part, then people will understand what my technology is." Some students also related their epistemic considerations to the task requirements by comparing this design project with their previous ones: "we've never done this before. In this project, you really need to persuade … it is not like the trees [project] which you can only list what you found online … this one you really need to explain the *why* to persuade."

"How does our knowledge product relate to other scientific phenomena and ideas?" In this study, we rarely found students addressing *generality* in their presentations. Most of the students' design did not include connections to others' ideas. It is conjectured that it is due to the specific task setting in which students designed their own innovative technology. This finding confirmed that epistemic ideas are situated, contextualized and tied to specific content and context.

"How do we justify the ideas in our knowledge products?" All the students in this study realized that they needed to justify with evidence, yet their understandings about evidence were varied. For example, one student shared during the interview "we need to persuade with information, much information … the more information you have the better." Another student insisted "I want to keep mine concise … you do not need to talk a lot, a few pieces, but really good, is more powerful." They both realized the necessity of justification with evidence but had different ideas regarding importance of the quantity or quality of evidence.

"Who will use our knowledge products and how?" In the study, classmates were introduced as the audience who would evaluate students' design by examining whether the design would contribute to current space exploration. Instead of collaboratively constructing knowledge with the audience, students viewed their audience as ones who are consumers of their designs. This finding also supports that context impacts students' epistemologies that are in practice. Based on understandings of the context and goals in the current setting, students prioritize epistemic ideas they think most appropriate (Berland et al., 2016).

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International Society of the Learning Sciences

Using immersive augmented reality to guide families' observations and visualizations of pollinator habitats in outdoor spaces

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Abstract: Immersive AR technologies can support students' learning processes and deep engagement with outdoor science pursuits, yet few studies explore these technologies with out-of-school learners. We analyze how immersive AR features built into an outdoor-based mobile app shaped nine families' learning experiences as they explored pollinator habitats. Preliminary findings revealed that immersive AR scanning tools built into the *Pollinator Explorers* app guided families' observational practices of real-world objects through virtual overlays representing pollinator habitats.

Introduction and conceptual framework

Prior work on the use of immersive augmented reality (AR) technologies in outdoor spaces (i.e., hiking trails, schoolyards), posits that when designed using situated learning pedagogies, apps can support students' engagement, learning processes, and problem-solving skills (e.g., Georgiou & Kyza, 2017). Whereas this prior work has mainly focused on student populations, we aim to better understand how family learning processes (Ellenbogen, Luke, & Dierking, 2004) are shaped by outdoor-based immersive mobile AR (MAR) technologies, particularly because family groups comprise the majority of visitors to informal learning sites (Bell et al., 2009).

Eberbach and Crowley (2017) define disciplined noticing as "a critical dimension of observational practice and involves learning to detect the signal from the noise" (p. 24). In alignment with this prior work, we aim to provide families with a mobile learning experience that guides them to pick out and scientifically observe the different components of a pollinator habitat while being physically situated within the dynamic and complex space of an outdoor learning setting. With the addition of immersive MAR technologies into our mobile app designs, we strive to elevate these observations so that families are supported to "see the unseen" through digital elements overlayed onto real-world phenomenon (Zimmerman et al., 2021). As such, we ask the following research question: *How did a learning-on-the-move app's immersive AR features shape families' learning experiences and observations of pollinators and their habitats?*

Methods: Context, participants, and data

Using a design-based research methodology (Sandoval & Bell, 2014), we explore this first iteration of a learning-on-the-move MAR app designed to foster observations of healthy pollinator habitats at a rural nature center in the northeast United States. The *Pollinator Explorers* app is focused on a specific type of pollinator—solitary bees—and what they need to thrive in a forest and meadow habitat (where this app tour was situated). Families in our study used the app to tour six different stops around the outside perimeter of the nature center and collected evidence (through photos) of what these native bees need to live and thrive in this habitat. Two of the six tour stops included digital augmentation of science phenomena (i.e., bee nests inside of logs, microscopic pollen grain) layered over real-world objects to further families' observations and immerse them in more deeply understanding bee needs and habitats. We focus here on the immersive AR design features at the log nesting tour stop.

Nine families agreed to participate in the research (29 individuals; 14 adults, 15 youths). Families' self-reported racial affiliations were White (93%) and Black or African American (10%). Children (female: 47%, male: 27%, did not report: 27%) were primarily between the ages of 5-12 (73%). Family groups individually participated in the *Pollinator Explorers* tour for an average of 43 minutes. Families were provided with an iPad pre-loaded with the app, and screen-recordings were enabled throughout the duration of each family's tour experience. Additionally, one individual per family donned a GoPro video camera attached to a baseball cap to collect audio-visual data from the perspective of the learner. We implemented video-based qualitative analysis of the GoPro data using an interaction analysis framework (Jordan & Henderson, 1995) to understand the families' talk and gestures as they related to their experience with the first design iteration of the app. The research team created detailed narrative accounts of each family's tour with the app with a focus on moments when the app facilitated families' real-world observations of pollinator habitat components around them. The first author vetted the narrative accounts and selected to analyze families' interactions at Stop 3 (Log Nesting Locations for Solitary Bees) due to the immersive nature of the AR technology embedded within the app design at this tour stop.

Findings

From an analysis of the full video dataset, 100% of families completed the immersive AR activity to visualize potential bee nests inside of real logs at Stop 3. This design feature aided families' observational practices in two ways. First, families were guided to find an example of a potential bee nest site by locating two side-by-side logs nearby on the ground. After locating this real-world object, families next used the AR scanning tool in the app to "see" what a bee nest inside the logs would look like. In several families, we noted that affective responses (e.g., apprehension about a potential bee nest site) signaled immersive moments where the digital augmentation blurred with the real-world phenomena. In Table 1, two examples from our dataset portray the ways in which two family groups interacted with the immersive AR activity (**bold font** represents family talk related to real-world observations and app use; *italicized font* denotes our analytical interpretation of the data).

Table 1

Two Families' Interactions with AR Technology to Support Real-World Observations of Bee Nests

Dad Simon and sons, Peyton (12) and James (8)	Mom Sharon, Dad Ryan, Nicholas (8) and Eli (2)
Peyton: Wait. And we will scan them to learn more. **Oh, we're here.** *[app supports location of bee nest site]* **I don't want to go there if there's a nest**. *[affective response signals an immersive learning experience: the potential for a bee's nest in the logs became real through the AR scanning tool]* Dad: Stand up here and see what it does. Scanning. Oh, that's cool. Peyton: Oh my gosh. Dad: Oh, **so that's where the nest is?** Oh, wow. *[digital AR supports connection of science content with real-world observation of bee nest site]*	Mom: Oh, that's cool. Look at that, **it's showing us what's inside**. **Here, let's go closer so we can look at the real thing.** *[digital AR supports connection of science content with real-world observation of bee nest site]* Nicholas: Is it really active right now? Mom: I don't know. Nicholas: I'm scared it's active. *[affective response signals an immersive learning experience: the potential for a bee's nest in the logs became real through the AR scanning tool]*

Discussion and implications

Our preliminary work with the *Pollinator Explorers* app suggests the potential for guiding families to be more disciplined observers within these rich authentic learning environments (Eberbach & Crowley, 2017). We posit that the immersive blending of real-world phenomena with virtual augmentations—an activity previously argued to facilitate high school students' learning (Georgious & Kyza, 2018)—deepened families' scientific observations and awareness of surrounding bee habitats and behaviors. Future iterations of our work will expand upon these immersive AR experiences in different outdoor learning spaces to broaden our understanding of outdoor family science learning with MAR technologies.

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Technological Repurposing: Extending Pedagogical Design Capacity to Include Technological Adaptations

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Abstract: This report builds upon Brown's (2009) Pedagogical Design Capacity Framework, to describe instances of "technological repurposing" of technologically-enhanced curriculum developed with prospective mathematics teachers (PMTs). The presentation will highlight the progression of one PMT's understanding of compactness and how this contributed to making an innovative technological adaptation in a set of lesson resources developed to help middle school students make sense of Gerrymandering.

Introduction

Given the omnipresence of technology in today's mathematics classes, it is important to better understand what enables teachers to adapt their curriculum resources to meet their instructional goals. A number of influential policy documents in the U.S. have advocated for Mathematical Action Technology (MAT) (Dick & Hollebrands, 2011) to play a major role in mathematics classrooms due the its ability to present content in novel, more accessible ways (e.g., NCTM, 2018). The purpose of the study was to examine the effect of the instructional unit on the PMTs' abilities to revise technology-based curriculum materials to incorporate their own knowledge. My research question is, "In what ways do PMTs adapt technologically-enhanced curricular resources that they have engaged with as learners when they are tasked with thinking about how their future students might engage with the same or similar content?"

Theoretical framework

In Brown's (2009) *pedagogical design capacity* (PDC) framework, the constructs of *offloading, adaptation, and improvisation* are discussed. Brown describes *offloading* as the practice of utilizing curriculum as it is written and *improvising* as the work teachers engage in when utilize their knowledge to build new curricular resources. In this paper, I described certain acts of *adaptation* as acts of *technological repurposing* due to the way that much of the original technological components remained intact. I define technological repurposing as an acknowledgement of or adjustment made to an existing piece of technology that is meant to develop an understanding of a particular content goal which may differ from the original intent of the technology.

Methods

My analysis utilizing the PDC framework and my conceptualization of technological repurposing, included classroom video data, discussion transcriptions, and the PMTs' documentational work (e.g., their submitted lesson revision assignment). For the analysis at hand, I focus only on identifying technological repurposing in my students' lesson revision assignment. When the technological capabilities along with the questions prompts and informative content appeared to be copied, but then modified to support a new goal, I referred to this as *repurposing*.

Results

Of the eight participants, *repurposing* in five student submissions and was observed in the following ways(see Table 1): the slide was copied, then the text was changed to provide more information or ask new questions (*textual*) or the slide was copied and the MAT component was reset or reprogrammed to encourage the development of a new goal (*technological*). The technological repurposing was observed in three of the participants' work.

Table 1
Repurposing Summary

PMT	Description of Repurposing	Type
Brooke	- question prompts for new goal -preset dynamic technological feature	-textual -technological
Megan	-animated technology -changed questions prompts for new goal	-technological -textual
Ruth	-added background information	-textual

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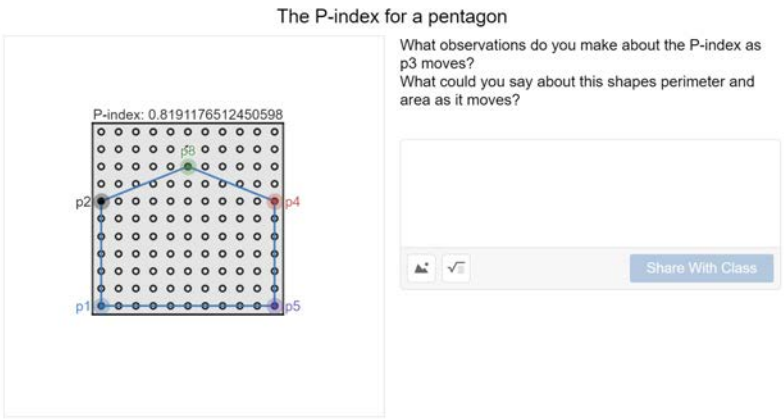
	-changed question prompts for new goals -preset technological feature	-textual -technological

Megan's technological repurposing

In Megan's submitted revised activity, she provides the following rationale for the repurposed slide below (figure 1),

"…I added the pentagon with the slider because I wanted students to narrow down their thinking and observations. I didn't feel like I made the connections between the area and perimeter and compactness and pp index very well. I thought by adding this and asking students to look at the difference in the pp index while considering how their area and perimeter changes, they might grasp that better…"

Figure 1.
Megan's repurposed slide



This adaptation differs from her experience as a learner with this material (figure 2) in which the goal was to simply, "describe some characteristics of the shape." In this slide, the (green) point p3 varies to highlight her goal.

Conclusions and discussion

The role of *technological repurposing* could be an important area of future research due to the necessity of technology integration in mathematics classrooms, but also because it is often necessary to adapt curricular resources to meet teachers' varying instructional goals. Though this study included, but did not focus on the role of sociopolitical context in the intervention lesson, this is an ongoing project to better understand how teachers utilize a wide variety of knowledge sources in their practice of planning.

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International Society of the Learning Sciences

Processing Team Feedback: Exploring Emotional and Cognitive Responses to Team-Level Feedback

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Abstract: Research on feedback in teams acknowledges the importance of feedback mechanisms to team success. However, although processing performance feedback in teams is seen as an important prerequisite to its effectiveness, the processes emerging after feedback reception have been overlooked in past research. This paper provides insights into the emotional and cognitive reflective responses of graduate students (N=111) to team-level feedback. The results of our explorative study reveal that (a) students from high-performing teams generally report positive activating emotions and generally reflect on feedback when prompted to do so, (b) many students from low performing teams were able to show adaptive emotional responses to team-level feedback, and (c) there is a complex interplay between feedback valence and affective and cognitive reactions to team feedback as evidenced and visualized by Epistemic Network Analysis model.

Introduction

The purpose of the present paper is to explore emotional and cognitive responses following team-level feedback of different valences. Specifically, we explore the extent to which members of high vs. low performing teams express (a) (de)activating positive or negative emotions and (b) feedback processing and feedback handling intentions (i.e., reflective statements and formulation of a general vs. specific focus and/or a general vs. specific strategy) when prompted to react to team-level feedback. We are primarily interested in examining how students made judgments about their emotions and states relative to their team performance (self-evaluation), and what they perceived that they needed to do to improve future team performance (adaptive inferences) using microanalytic protocols (Cleary et al., 2012). This paper contributes to understanding in three related areas: nature of emotions following team-level feedback delivery; relationships between feedback valence, types of emotions and feedback cognitive processing; and team-level considerations of feedback processing.

Methods

Subject and setting

The participants (N = 111) were last-year business students attending a Performance Management course at a French university. This simulation-based course aimed to provide students with opportunities for practice of and reflection on instruments and techniques to track, monitor and communicate about the employee performance. Students were assigned to teams of five to complete team tasks. Over 3 days, they functioned as units of a fictitious company that produced folded paper flowers colored with felt-tip pens.

Intervention

We used microanalytic protocols, a type of structured interview, to access students' emotional and cognitive responses to feedback. They target students' beliefs and processes after engaging in well-defined tasks. We used two questions: (a) a self-evaluating question (i.e., You have just received customers' feedback on the product that your team has been crafting for the last two days. What was your immediate reaction to this feedback?) and a strategic planning question (i.e., Moving forward, how will you use this feedback to improve your team performance? Please be as specific as possible). We received 111 responses for Q1 and 82 responses for Q2.

Measures

To understand how students perceived their feedback, meaningful units of analysis (i.e., phrases, sentences or series of sentences), were hand-coded using two coding schemes to affective and cognitive dimensions of feedback perception: team reflexivity coding scheme, and the taxonomy of academic emotions. Authors collectively coded all responses using a joint codebook and reconciled disagreements via social moderation.

The team reflection coding scheme was adapted from Gabelica et al. (2014) to capture the degree to which team members engaged in three cognitive (reflective) behaviors. Each student response to Q1 was coded as 0 (absence of reflective behavior), 1 (evaluating or reviewing team performance and strategies), 2 (looking for alternatives), 3 (Making decisions). Please see Table 1 for behavior descriptions and examples from the data.

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To code emotions, we adapted the taxonomy of retrospective outcome emotions from Pekrun's (2006) using a combination of categorical (e.g., discrete categories such as anger, happiness), and dimensional (valence: positive or negative; activation: activating or deactivating) approaches to emotion measurement. When emotions of opposing valence (e.g., excitement and anxiety) were expressed by the same subject, they were coded as 'mixed emotions.' Each student response was hence coded as: (1) positive activating, (2) negative activating, (3) positive deactivating, (4) negative deactivating, or (5) mixed emotions. Another important aspect of this study was the examination of prospective self-regulatory processes or 'feed-forward' to adjust based on received feedback. Students' forethought response to feedback were coded using Cleary et al. (2012) microanalytic self-regulation coding schemes: (a) a general focus, (b) a specific focus, (c) a general strategy, (d) a specific strategy.

Results

The results of our team-level qualitative analyses show that members of high-performing teams predominantly express activating positive emotions when asked for their immediate reactions to feedback. Additionally, they provide little evidence of initial team reflection compared to members of low-performing teams that express more team reflexivity in the first place (Q1). However, it seems that when members of high-performing teams are asked to think about how to use their team feedback for enhancement purposes, they start processing it cognitively. When prompted to strategic planning, they predominantly state (general) strategies to act on feedback. This trend aligns with and extend results from individual-level research on feedback and emotions (e.g., Winstone & Carless, 2019). Though positive feedback can elicit positive emotions, it could concurrently reduce their motivation to invest future effort, more specifically when not prompted to cognitively process feedback.

Low-performing teams seem to show more complex patterns of feedback processing. Half of those teams express positive, activating emotions. There are no teams that express team reflexivity statements and negative emotions. Further, team reflexivity rather occurs in teams that have most members expressing positive emotions. Half of those teams already engage in cognitive thinking/processing of feedback at the first stage (Q1). However, after the second question that prompts team strategic planning, even teams expressing deactivating negative emotions state a focus and a strategy. Half of those teams even express a specific focus for their next team task. It appears that members of those teams resolved their negative emotions and moved on to cognitively assessing and integrating data from their feedback. Further, in contrast to high- and medium-performing teams, the individual network for low-performing teams show that (de-)activated negative emotions are linked to strategic planning comments. This indicates that generally, low-performing teams can harness the emotional impact of their negative team feedback and plan productive actions accordingly. We find more diverse trajectories for those teams. Some teams seem to show ability to separate emotional and rational responses to feedback and show striving for improvement; others jumped immediately to rational responses, while a few remained stuck at the emotional level of feedback reception. We could speculate that team members of low-performing teams that did not process feedback cognitively had difficulty determining what actions they should take based on feedback given by external customers (Winstone & Careless, 2019).

Conclusion

Our results align with and extends the broader literature on emotion and learning (Winstone & Carless, 2019) which has shown that the premises that negative emotions lead to detrimental outcomes while positive emotions fuel positive outcomes, are too simplistic to explain the effects of emotions on cognitive reactions in team feedback situations. We have rather shown that interplay between affective and cognitive reactions to different types of feedback can lead to differential behavioral responses to team feedback.

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Student-Created Math Walks in Informal Learning Spaces

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Abstract: Math walks are a form of inquiry learning where students can observe and create mathematical meaning from their everyday surroundings. Here we report on a study of 5th and 6th graders in an informal learning setting where they create and present their own math walks covering concepts of ratio, scale, and proportion. The students may have developed more positive attitudes towards math and were able to meaningfully engage with powerful math ideas.

Conceptual Framework

Much of the research in informal math learning has examined how people use math in their everyday life (e.g., Civil, 2007; Nunes, Schliemann, & Carraher, 1993; Walkington et al, 2014). There is a lack of research on math in designed informal learning environments (Pattison, Rubin, & Wright, 2017), although this is a growing area of interest (Mokros, 2006). Math walks, or "math trails" as they are sometimes called in the literature, are walks that learners go on to experience and bring out the mathematical properties of their surroundings – including art, architecture, and nature (e.g., English et al., 2010; Richardson, 2004). Math walks may trigger and maintain students' interest in learning mathematics (Hidi & Renninger, 2006), increase math ability beliefs (Perez-Felkner et al., 2017) and lower math anxiety (Bai, Wang, Pan, & Frey, 2009). They also may allow students to engage meaningfully with math concepts, including using problem-posing as students are engaged as the creators of their own math walks (Wang, Walkington, & Dhingra, 2021). Creating walk stops can be an "on ramp" to learning math concepts that begins with students' lived experiences. In the present study, we investigate the following research questions: How does experiencing and creating math walks stops allow learners to engage meaningfully with mathematical ideas? How does it impact their math interest, math ability beliefs, and math anxiety?

Method

The study took place at a Community Center with ten 5th and 6th grade students participating after school over 4 1-hour periods. Nine students identified as African-American and 1 as bi-racial, with 2 males and 8 females. The math walk lessons focused on issues of ratio, proportion, and scale, and was facilitated by two teachers who taught math at the school associated with the community center. Students first went on a math walk at the Community Center that had been co-constructed by students at the Center and researchers and video-recorded by a professional videographer, starring the students. Then they worked in groups of 3 to create their own math walk stop, using a process where they first would notice and make observations, then brainstorm different questions they could pose given their observations, and then choose one question to pursue. They would create the walk stop by taking and annotating pictures and giving a formal presentation of their stop to club members and other stakeholders. Students took previously-validated pre- and post-surveys measuring math interest, anxiety, and ability beliefs.

Results and Conclusion

Although none of the pre-/post differences reached statistical significance, effect sizes were examined given the small sample size and likely lack of appropriate power. Results suggest an increase in students' math interest (from 3.9 to 4.5 on a 5-point scale, $d = 0.75$), an increase in math ability beliefs (from 3.6 to 4.2 on a 5-point scale, $d = 0.60$), and a decrease in math anxiety (from 2.4 to 2.0 on a 5-point scale, $d = 0.46$). An examination of students' final presentations and their artifacts (Figure 1) revealed the novel and creative ways in which they were experiencing math in their surroundings. They engaged with issues of ratio in the dance room of the Center, posing questions about the size of the mirror versus the size of the floor. Another group examined how glue sticks could be used to create an informal measurement unit to better understand the size of a classroom at the Center. During their post-reflections, students highlighted how much they appreciated the collaboration and the freedom to select sites and mathematical ideas to focus on and explore. They also readily pointed out strengths of their peer's work. Math walks seemed to have immediate, positive impacts on kids' views of mathematics and the worlds, but an important question is how and whether this effect could be sustained. In current work, we are also examining video footage of student discussions. We are interested in the kinds of support it takes to move students to create more novel walk stops that differ substantially from the examples they saw in the professionally-made videos, and that more strongly express their personal mathematical curiosities as they interact with the world around them.

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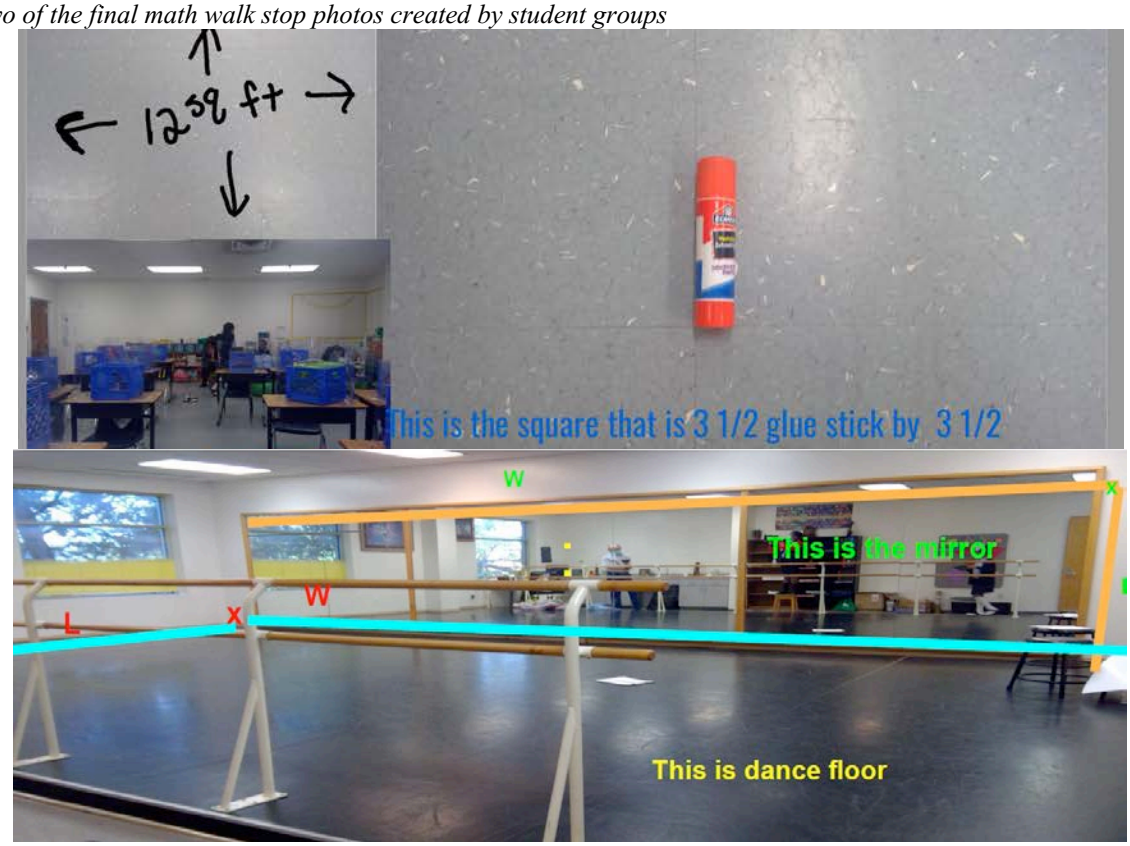
Figure 1
Two of the final math walk stop photos created by student groups



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Managing Deference, Leadership, Vision, and Voice: Dilemmas from Antiracist School-University Partnerships

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Over the past two years, our university-based team and leaders at two elementary schools have partnered to collaboratively design and instantiate antiracist school communities.[1] Our partnership with the first school, Eastwood, emerged from and evolved according to their needs, rather than following any explicit vision.[2] Over time, it became clear that our implicit visions for an antiracist school were not aligned. We approached the principal at the second school, Lawrence, with a firmer sense of what we were interested in working on together. She responded enthusiastically, and with a seemingly shared vision, we dove into partnership. But again, as time passed, we had difficulty holding to our vision. With this poster, we aim to engage conference participants in discussions about how to negotiate a shared vision in school-university partnerships, in the context of antiracist work in which competing visions and understandings are especially likely to present not only conceptual difficulties but also ethical, interpersonal, and deeply personal challenges. We give particular attention to negotiating the role of parents of color,[3] who are increasingly seen as essential players in antiracist school transformation but whom schools are rarely equipped to authentically engage as partners (Ishimaru, 2020).

A participatory approach to building antiracist school communities

Our approach to building antiracist school communities is rooted in two bodies of thought. First is scholarship emphasizing the cultural wealth, knowledge, and capital in communities of color (e.g., Yosso, 2005). Students and parents of color have intimate understandings of how "the school system is marginalizing, criminalizing, and otherwise failing our Black and Brown kids" (Oluo, 2019, p. 124). These understandings uniquely position them to resist oppressive systems with determination, joy, and hope, and to radically reimagine just and humanizing schooling. Their voices and perspectives are thus indispensable for efforts to advance antiracism in education.

We complement this asset-based, anti-deficit perspective on students and parents of color with scholarship outlining participatory methods for studying and enacting educational change toward justice (e.g., Bang & Vossoughi, 2016). This scholarship emphasizes the importance of dismantling typical hierarchies among students, parents, teachers, school administrators, and university researchers. Participants must learn to coordinate their varied knowledge, practices, perspectives, and goals to forge new ways of thinking, doing, and being. These new ways must support participants to learn with and from one another, across differences, rejecting the dehumanizing "racialized institutional scripts" that denigrate the knowledge, authority, and power of students and parents of color (Ishimaru, 2020, p. 121).

Taking a participatory approach to partnership implies that no party, including university researchers, should enter collaborative work seeking to impose their vision on others. We have instead attempted to build a shared vision with our partners. While we have found easy agreement around the goal of building antiracist school communities, what such communities are has proven to be slippery and abstract, and our efforts to collaboratively establish a more concrete vision—particularly with school principals, who have mediated our access to students, parents, and teachers—have been unsuccessful, as we describe below.

Eastwood: general agreement but misalignment on specifics

The majority of Eastwood's students are students of color. The staff, meanwhile, is 90% white. In the spring of 2019, Eastwood teachers and administrators asked for our support in their efforts to become an antiracist school community. That summer, members of our team led a six-day retreat, during which they pushed Eastwood principal Amy and other school staff (who attended on a voluntary basis) to acknowledge their own racist assumptions and to change rules for behavior in the school's hallways, which made the school feel prison-like. The following school year, Amy invited us to lead portions of the monthly meetings of the school-based leadership team (SBLT). We agreed, expecting to use that time to develop a shared vision of an antiracist school and pursue concrete plans for enacting that vision, with parents as full partners. But, as we worked together, it became clear that Amy did not share our expectations. For example, meeting time was often filled with Amy's priorities, which were shaped by district requests and mandates (e.g., the looming deadline for the mandatory school improvement plan). Furthermore, as the partnership continued, we realized that although we had come together around the general goal of building an antiracist learning community at Eastwood, we had specific misalignments which reflected different underlying conceptions of what an antiracist learning community was and how to build it. For example, the kind of collaboration with parents that we came to articulate as central to our work did not align with

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Amy's understanding of antiracist change, although she had been able to honestly agree with our initial vague statements about parents as partners. In particular, she seemed to prioritize what she called the "inner work" of "looking in the mirror and saying, I'm racist." Her understanding of this work did not seem to require interaction with families as much as internal reflection. Our point here is not to evaluate the merits of focusing on "inner work," but to observe that this focus got in the way of working with parents of color as partners in a meaningful way to change school policies, relationships, or instruction.

Lawrence: waiting to be "ready"

Lawrence was demographically similar to Eastwood, except for being significantly smaller. We began our partnership at Lawrence with some of the lessons we had learned at Eastwood in mind—namely, a need to begin with an explicit discussion of vision and the role of parents. This discussion was optimistic; as a small neighborhood school with most families living just a short walk away, Lawrence was well-positioned to bring parents in as partners. Further, principal Nadine made routine home visits, showing that she valued relationships with parents and families; she also identified developing stronger relationships between teachers and parents as an important area for growth, noting that many teachers were afraid of contacting parents and that these fears were likely racialized (given that most Lawrence teachers were white while most parents were not). But in subsequent months, each time we raised the idea of inviting parents to our meetings with faculty and staff, Nadine argued that faculty and staff weren't "ready." This may have been in part because of concerns we had discussed about the possible harm of bringing parents in only to have their experiences and concerns belittled (although some team members had also argued that parents of color were used to having that happen, and that we should manage this possibility in the moment rather than allow it to prevent us from engaging with parents and caregivers). Another concern Nadine repeatedly raised was that faculty and staff needed to work on their relationships with one another first, because if they did not feel comfortable having critical conversations amongst themselves, they could not be expected to have such conversations with parents. As the pandemic deepened and with it, teachers' isolation, this concern became increasingly salient for Nadine. Again, our purpose is not to evaluate its validity, but to note that it stopped us from bringing parents and caregivers into our partnership for more than a year.

Discussion and implications

At both Eastwood and Lawrence, the university team struggled to balance deference and leadership. On the one hand, we recognized that Amy, Nadine, and their colleagues were in their schools every day and had intimate knowledge of their students and staff. Consistent with our principles for collaboration, we wished to honor this knowledge. On the other hand, these same principles required us to press our partners to bring parents to the table, honoring *their* voices and building on *their* knowledge. This was not necessarily a problem; we saw pushing our school partners beyond their comfort zones as part of our role, and our partners valued that. However, we have spent more than a year at each school and still have yet to succeed in engaging parents in anything more than preliminary conversations about antiracist change at their children's schools.

Building knowledge about how to navigate the challenges we have described is absolutely essential if efforts to study and effect educational change are ever to center the voices and perspectives of parents of color, as participatory approaches to research and design suggest. More generally, better understanding how to democratically negotiate a shared vision is essential to many kinds of partnership in education. We look forward to discussing these issues with conference participants.

Endnotes

(1) Our team includes Carl Grant, Mariana Pacheco, Kathleen Nichols, and Laura Roeker, as well as the two of us.
(2) All names are pseudonyms.
(3) We use "parent" expansively, including any adult who takes caregiving responsibility for a child or children. We use "of color" to refer to people who identify as members of racially minoritized groups, including Black, Indigenous, Hispanic/Latina/o/x, and Asian Pacific Islander Desi Americans.

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Teachers Noticing Student Interest: A Micro-interactional Foundation for Interest-driven learning

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Abstract: This study shares a descriptive framework for noticing student interest, building on extensive scholarship in teacher education on Teacher Noticing. Scholarship presented here documents differences in educator narratives of student interest, which has implications for how they then go on to sponsor it in their immediate learning environment. The overall contribution of this work is a nascent framework for operationalizing educator noticing skills to support student interest.

Introduction

The concept of teacher noticing, or the awareness educators bring to features of student understanding, has been taken up heavily across the field of teacher education (as a resource for preservice and in-service teacher development, e.g. van Es & Sherin, 2008) and the learning sciences (see Walkoe & Luna, 2020, for a review and critique). However, as Russ (2018) points out, these efforts have concentrated on domain-specific constructs, like skill and conceptual development, and not as much on domain-general constructs, like interest. The guiding logic of teacher noticing holds that educators cannot appropriately respond and adapt to student understanding unless they first notice it.

Background

Van Es & Sherin (2002) theorize teacher noticing in three parts: identifying what's important, making connections between what's happening in the classroom and existing pedagogical knowledge, and reasoning within the given context. Following Russ's observation that teacher noticing literature often ignores domain-general constructs, like interest, we attempt to remedy this by building a descriptive framework showcasing what teacher noticing might look like. We argue that noticing student interest is the first step toward sponsorship of youth interests (Ito, et. al, 2020), and therefore warrants further examination.

Methods

We draw upon interview data with out-of-school educators collected as part of a program evaluation performed during the summer of 2021 in partnership with Design, Make, Learn, an arts nonprofit in Long Beach, CA. We adapted van Es & Sherin's (2002) framework to include noticing student interest, in line with a constructivist grounded approach (Charmaz, 2000). Following two rounds of grounded open coding, we matched educator stories of student interest with the emerging descriptive framework.

Data: Descriptive Framework for Noticing Learner Interest

Summary Table

Framework: Level of Expertise and Rationale	Educator Narrative of Noticing Student Interest	Analysis and Next Steps
Expert: Teacher stories are fully analytical, supporting their noticing with evidence, interpretation, and empathy.	**Frida:** So I was thinking that doing leaf prints would be fun. I just had them bring out paper and pencil and collect leaves. And we sat down here, you know, on the steps, and basically did leaf rubbings and talked about artists that came up with that kind of kind of art, you know, so like Max Ernst and all the Dada surrealists, so I talked a little bit about the historical context about that. Some students had never done [leaf rubbings] before so I thought it was interesting and then we went into "let's figure out what else makes a print?", so the kids tried dandelions--you know, the yellow? The dandelion or the grass [became options]... They tried dirt and soil and bark, random other leaves and flowers. [cut for length]	Frida's noticing story demonstrates d/Discourse of both interest and educator noticing. She begins by empathizing and projecting about student interest ("I was thinking that doing leaf prints would be fun"), which she uses as the foundation for her educational design. Then, she describes the embodied implementation/practice of the educational design. And, in the course of that implementation, she noticed youth interest in the materials, and how their use could be extended to meet the original design objectives (leaf-rubbings). This noticing results in collective exploration of new, ambient materials (dandelions, grass, dirt, soil, bark, leaves, and flowers) as (literally) organic extensions of the original learning objective.

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Proficient: Teacher stories call out student interest and support with corresponding evidence and interpretation, but may also judge these moments as "good or bad"	**Cesar:** ...we were using paint markers and lettering alphabets and tracing paper. We had a student...and he's like, this is something that my brother does, and then he got super into it. So I showed him all these different tools. And so [we were doing] old English lettering, which is like a big part of LA culture. But it really grew out of protest art and it was based on, you know, medieval lettering. So you know, that's all part of the discussion. But the thing is, it's so ingrained in the culture here that kids don't even know where it comes from. So he's just like, Oh, my brother does that. Let me learn what my brother does... it's one of those things where it's like, all I'm doing is serving your culture back to you.	Like Frida's story, Cesar's story shows a clear design intention for learning, evidenced by the choice of tool and activity as relevant to the historical/social context of implementation. Additionally, Cesar notices the youth's connection to their family as signaling interest, which he feeds for the student by situating the interest in history and immediate cultural uses ("...old English lettering is a big part of LA culture"). In this way, Cesar follows student interest to historically and socially contextualize the students existing knowledge and family practices as instrumental to domain-specific learning in art.
Intermediate: Teacher stories call out student interest, but lack "corresponding evidence or interpretations".	**Nathan:** We were doing an improv workshop for an organization that dealt with at-risk youth. ...there was one young man who started and he was literally kind of slumped back in the corner with his arms crossed the hoodie on.... And then the very last exercise we did was called, it's called freeze tag...So this young man came up and tagged one of the teachers and then stepped in and he started rapping. He just created this whole improv rap, that was a story... Just watching the progress of him, very quiet, individual to just being the center of attention.	Nathan identifies the activity itself as the source student interest, and is surprised (positively) when the student uses the activity to play to an area of individual strength (interest). Nathan is able to interpret student body language as dis-interest, and participation as interest. However, the introduction of interest-based student learning is happenstance, and largely due to the risk-taking of the student, which Nathan notices and appreciates, but does not elicit.
Novice: Teacher stories are predominantly descriptive, describe students becoming interested only, without rationale. There is little pedagogical response.	**Carter**: We had a concert, I played drums and [another teaching artist] was playing guitar and flute. And we had a bit of a performance at the end of the day, and this particular student. However, after that specific concert workshop, I remember he came up to me as like, 'oh, wow, that was really interesting. I'm kind of interested in like, learning how to play an instrument, or drums or something.'	Carter is able to identify student interest when they explicitly articulate it, but does not relate any plans to feed, broaden, or extend that interest. Additionally, Carter interprets student interest as activity-based (e.g, related to drumming), when it may actually be broader or more specific than that.

Discussion & Implications

Our analysis shows that van Es & Sherin's framework for teacher noticing can be usefully adapted to include noticing domain-general constructs, like interest. This work has several potential implications for educator learning. First, it is notable that this data on educator noticing comes from an out-of-school learning environment (a summer STEAM program), because an important extension of scholarship on teacher noticing would be to include pedagogies at work in informal environments. Second, this framework adaptation to a domain-general construct represents an important step forward for considering teacher noticing. Third, and most importantly, this framework opens a pathway into understanding how youth interest does or does not get noticed by educators, which we theorize as an essential first step to the sponsorship of youth interests.

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AI Voice Tutor Usability Study: Understanding Impact on Math Self-Efficacy and Metacognition Among Middle Schoolers

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Abstract: We present CAI, a voice-based intelligent tutor that helps middle schoolers learn pre-algebra concepts. Users interact with CAI by solving math problems presented by the AI-tutor, each with a varied mode of narration and type of feedback. We describe the design, methods, and findings from our testing with middle schoolers. We provide insight into how voice-based intelligent tutors can impact motivation and metacognition, yet also require personalization and complementary video-based instruction to improve their performance.

1. Background

Previous research demonstrated discrepancies between human and AI-based tutoring systems in their granular feedback and their ability to target relevant and frequent student responses (Kolchinski et al., 2018). Our research aims to understand how designing a voice-based AI tutoring system might close the equity gap in accessing human tutors. Current online learning platforms offer video-based lessons, yet these are limited in interactivity. Thus, AI tutors can enhance learning by providing personalized feedback, adapting to student responses, and enhancing AI tutors' presence and motivational support among middle schoolers. We prototyped an AI-tutor named CAI to have two primary tone-based narrative styles and five types of instructional feedback. As a pilot study, we explored the research questions through user testing with five middle schoolers employing CAI: (1) What impact does an AI tutor's narrative styles (standard vs. motivational) have on middle schoolers' math self-efficacy and metacognition? Which style do they find more compelling? (2) What impact does an AI tutor's types of feedback have on middle schoolers' math self-efficacy and metacognition? Which type do they find more effective? (3) What are the techniques for designing features of an AI tutor?

2. Prototype design

We used Voiceflow, a conversational app prototyping tool, to prototype AI-tutor named CAI. Because the ability to learn through multiple channels concurrently increases the chance of remembering knowledge compared, we applied the cognitive theory of multimedia learning (Mayer et al. 1998). Accordingly, we integrated voice, text, and visuals to explain math concepts. For tasks, we created three scenarios employing a combination of two components: speech style and feedback type (Melis & Andres, 2005) (See Appendix A).

3. Methods

We conducted the usability testing with five middle schoolers based on convenience sampling—demographics in Appendix B. A demographic survey included questions on math self-efficacy. Following the survey, four pre-algebra math tasks were given; in each, CAI explained a pre-algebra mathematical topic followed by a question. All math concepts and questions were provided at a similar difficulty level. Based on the students' responses, CAI provided five types of instructional feedback: knowledge of result (KR), knowledge of correct result (KCR), answer until correct (AUC), instruction-based elaboration (IBE), and extra-instructional elaboration (EIE). Task 1 to 3 served as treatment conditions with differing AI-tutor's narrative styles and types of feedback; Task 4 served as a control condition where the students underwent a video-based instruction (Khan Academy) followed by a math question provided on Google Quiz form. After completing all tasks, the students took a post-experiment survey to provide feedback on the AI tutor's design features. An overview of the research is described in Table 1.

We conducted the Friedman test on motivation and metacognition. To add qualitative understanding, we analyzed each task's observation notes by color-coding and creating affinity diagrams. Furthermore, to analyze desirable design components for an AI-tutor system, we ran descriptive statistics for the post-experiment survey. For the post-experiment interview, open coding was followed by affinity diagrams of thematic elements.

Table 1.

An overview of the research design

Stage	Topics	Activity	Measurement

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Pre-experiment	N/A	An ice-breaker question on the preference of AI-tutor character	Pre-experiment survey on demographics, previous math learning experiences, and self-efficacy (7 questions)
Task 1.	Calculate the mean	AI tutor experience 1 (motivational narrative, feedback type 1: KR, AUC, EIE)	A post-task survey on usability (4 questions), motivation (5 questions), and metacognition (4 questions)
Task 2.	Find the median	AI tutor experience 2 (standard narrative, feedback type 2: Reflection time, KCR, IBE)	
Task 3.	Calculate percentage	AI tutor experience 3 (motivational narrative, feedback type 2: Reflection time, KCR, IBE)	
Task 4.	Calculate probability	Control task experience (google form with a quiz, combined with a video from Khan Academy)	
Post-experiment	N/A	Post-experiment interview	Post-experiment survey (4 questions)

4. Results

The testing highlights can be viewed here: videos 1 and video 2. For motivation, the Friedman test showed no significant result. In the qualitative analysis, we found four main themes: (a) metacognition, (b) motivational moments, including persistence and resistance to learning, (c) learning process, (d) CAI's positive and negative performance. Motivational moments were observed in all four tasks, and persistence in learning was most salient in Task 1. As Task 1 included AUC feedback, students were given a choice to take multiple attempts, and all took multiple attempts. For metacognition, the Friedman test was not statistically significant. However, in descriptive statistics, we found that AI-tutor conditions had a more significant impact on metacognition than the control. The observation data revealed that metacognition was more frequently observed in AI-tutor conditions (T1=28.1%, T2=34.6%, T3=29.2%) than the video-based (20%). In Task 2, students showed metacognition most frequently and two students attempted to fill in the knowledge gap by scrolling up to the explanation.

A few design implications were found. For narration, three participants preferred the motivational narrative. For feedback type, four identified instruction-based elaboration as the most effective. It provided information on "what to do to get the correct answer" and guided them with a formula that "makes it easier to solve problems." In the post-experiment survey, they thought the AI-tutor was helpful in terms of pacing learning (M = 4.4, SD=0.55), explaining solutions (M = 4.4, SD=0.55), and providing feedback when they got questions wrong (M = 3.8, SD=1.79). Regarding the positionality of AI-tutor in comparison to video-based instruction and human tutors, they rated 2.8 (SD = 1.30) for CAI's similarity with human tutors and 3.4 (SD = 1.14) for whether they learned better compared to video-based instruction. In the interviews, the pros of AI-tutors included the opportunity to ask questions, interact, and receive feedback based on progress. In contrast, what was found to be a deficit in AI-tutors (the limitations of speech recognition) was found to be a pro in video-based instruction.

5. Discussion

The findings revealed that the video-based instruction and CAI provided complementary benefits rather than counteracted. As a pilot study, we discuss two main issues for prototype redesign. (1) Personalization of AI-tutor: This study showed high variance between the participants in motivation and metacognition, reflecting individual students' confidence, math ability, and preference. User control over personalized AI configuration is suggested: allowing users to control the speech rate, tone, pause time, as well as AI's involvement level and intervention frequency. (2) Strengthening AI-tutor's impact on metacognition: With reflection time and instruction-based elaboration feedback, students showed improved metacognition. They also indicated that an AI-tutor's respect for learning pace and explanations of solutions to be effective. Additionally, we found potential in AI tutors' "non-judgmental" support in learning math. Thus, AI-tutor redesign should define and validate design features that affect metacognition. The study's limitations were the sample size, short experiment time, and students' attention span. As we confirmed methodologies, we aim to address the limitations with a larger sample in future.

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International Society of the Learning Sciences

Learning in Your Own Direction: Examining Relationships Between Non-Sequential User Choice and Learning

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Abstract: This study sought to address an aspect of learner control known as non-sequential user choice. Leveraging open driver education resources, this research explored how learners' chosen learning sequences and the time they spend with each learning resource relate to performance on an assessment of learning. The study examined learning outcomes for subjects with free choice over learning sequence based on time spent and chosen sequence. Analyses yielded a significant regression model and raise the possibility that time spent and chosen order may be able to predict performance.

Introduction

The open learning movement has grown significantly in recent years as a result of work in both the public and private sectors. Inherent in the open learning movement is the notion of choice-based learning: that is, that learners can and should be given substantial control over their learning processes. Unfortunately, significant gaps remain in the research literature examining the effects of giving learners extensive control, particularly with regard to learners' control over the sequence of the learning process (Koseoglu & Bozkurt, 2018).

Background

Non-sequential user choice is defined as the ability for individual learners to use a set of learning materials in a non-linear fashion (Chou, 2003). Existing research has found mixed effects of this type of choice. For instance, Taub et al. (2020) found that a moderate amount of choice led to larger learning gains than high- and low-choice conditions, while Nebel et al. (2016) found motivational benefits but not improved learning gains. The present research seeks to further explore this issue, with a focus on the effect of users' specific choices and pacing.

Methods

Materials and data sources

The open learning materials used for this study were developed to target specific gaps in drivers' knowledge of advanced car safety systems as identified by McDonald et al. (2016), and leverage the mental model-oriented design framework from Beggiato & Krems (2013). They are divided into three main sections focused on Adaptive Cruise Control (ACC): Understand, Challenge, and Play.

Participants & Study Procedures

42 college undergraduates were recruited via mass email and tasked with learning about ACC. Only individuals who were familiar with conventional cruise control but *unfamiliar* with ACC were included in the present study. Participants were required to use all three learning resources, but were able to choose the order in which they interacted with them, as well as their pacing. The order in which the resources were listed on the choice screen was counterbalanced. After choosing a resource, participants could interact with it for as long as they wished. Following engagement with all three resources, participants' knowledge of ACC was assessed using a post-test assessment developed by Valentine et al. (2018) for this set of learning materials.

Analysis

Post-test scores were calculated for each subject, and those scores were used as the outcome variable in a multiple linear regression analysis (alpha = .05). The regression analysis involved four predictor variables: chosen order, time on the Understand resource, time using the Challenge resource, and time spent with the Play resource.

Results

Descriptive statistics

The large majority (36/42) of the participants chose to use the Understand (U) resource first. Of the remaining six subjects, four chose to use the Play (P) simulation first (P,U,C), and two chose to solve the Challenge (C) problems first (C,U,P). Subjects who chose Order 1 (U,C,P) scored slightly lower on the post-test (M = 11.35)

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than did those who chose Orders 2 (U,P,C), 4 (C,U,P), or 5 (P,U,C; M = 13.00, 13.75, and 13.375, respectively), but these mean differences were not tested for significance due to the small number of subjects in each order. Orders 3 (C,P,U) and 6 (P,C,U) were not chosen by any participants. Participants spent far more time using the Play (M = 635.02s) and Challenge (M = 467.02s) resources than the Understand resource (M = 106.74s).

Regression analysis

The multiple linear regression analysis found a significant regression equation ($F(4,37) = 3.930$, $p < .05$) with an R^2 of 0.298, indicating that order and timing variables predict a significant proportion of the variation in post-test score in this sample. Participants' predicted post-test score is equal to 8.745 + .002a -.002b + .023c +.446d, where Challenge time is coded as *a*, Play time as *b*, Understand time as *c*, and chosen order as *d*. Although the overall model was significant, Understand time was the only individually significant predictor of post-test score.

Discussion

Non-significance of chosen order

The present research sought to examine the relationships among chosen learning sequence, time spent on learning, and performance on an assessment of learning. The results indicate that timing and chosen sequence can be used to predict post-test score, but time spent on the Understand resource was the only individually significant predictor. Surprisingly, chosen learning sequence was not an individually significant predictor of post-test scores.

One possible explanation is the homogeneity of learning sequences chosen by study subjects. As a result of this homogeneity, it becomes much more difficult to detect any significant predictive value of chosen order. The descriptive statistics point to the possibility that choice homogeneity obscured an effect, with learners who chose Order 1 (U,C,P) scoring lower overall on the post-test assessment. This suggests that Order 1 could represent a poor choice of sequence and that participants may be performing worse on the post-test as a result.

Potential significance & future research

These findings present an intriguing extension upon previous research by Bamberger and Tal (2005) and Taub et al. (2020). Namely, that previous work suggests that the *provision* of choice matters in learners' performance, while the present research indicates that the specific choices learners *make* in those situations may not be crucial.

Although chosen order was not found to be an individually significant predictor of post-test performance, descriptive statistics suggest that its influence may have been obscured by the homogeneity of participants' sequential choices. Studies with a larger sample size or forced sequencing may be better equipped to investigate the effects of specific learning sequences, as well other types of choice, varied levels of choice guidance, and different learning contexts/materials.

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International Society of the Learning Sciences

Makerland: Mathematics in Makerspace resources to enhance Maker-based Learning

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Abstract: This work investigates the Math concepts that are applied when using the resources of a Makerspace. The research highlights Math concepts that are usually employed throughout the modeling, prototyping and production processes. An exploratory study was conducted on a Brazilian high school, and the results indicate that students can identify the Math concepts and that the systematization of these subjects can be used as a learning object.

Introduction

Recent studies show that different factors lead students to have poor performance in Mathematics. Ziegler & Loos (2017) indicate that the difficulty that students have in their learning is related to the lack of connection of the subjects covered at school with the real world. Niss and colleagues (2017) point out that the need for Mathematics to be taught within a functional context has been the basis of educational reforms in some countries.

To collaborate with this discussion, this paper seeks to relate Mathematics in the Makerspace resources with the Mathland metaphor presented by Seymou Papert (2020), that compares the Math language learning process with the way a person learns French when growing up in France. Thus, inspired by the term coined by Papert, this work presents the Makerland metaphor, when considering that the Makerspace and its resources are elements to enhance the learning of Math concepts while students develop their projects.

Based on this reflection, two complementary points in the prototyping of learning objects stand out. The first is the development of projects that aim at the explicit application of Math concepts. These projects are related to the production of resources that aim the learning of the subject during the planning, execution and presentation stages. The second point is the learning of Math concepts in the use of Makerspace resources during the prototyping and production process. In the Laser Cutter, for example, the relationship between the speed of the equipment while cutting a resource and the laser power, as relationships between variables and Cartesian coordinates, are usually applied. This paper discusses this second point.

Theoretical foundation

Considering the great advance of new information and communication technologies, Seymour Papert's theory of learning, Constructionism, stands out. The theory is based on Piaget's Constructivism and highlights that learning happens more effectively when students are co-authors of their own knowledge and share it with their peers (Blikstein, 2008). The constructionist learning theory was forged on the exploration and teaching of Math concepts through technological resources and contributed to point out a new path for Math Education.

Thus, the Logo Language was created by Papert's research group for a teaching process where students and educators are learners, and everyone learns from their mistakes (Papert, 2020). Similarly, the Makerspace's prototyping resources also provide for the creation of Microworlds (Papert, 2020) for learning Mathematics. In this sense, Maker-based Learning helps learners deal with unexpected problems for which there are no pre-established explanations, acquiring the necessary skills to participate in the construction of new skills (Gavassa, 2020).

So, when it comes to Math Education in Brazil, the country has undergone significant reforms. In 2018, the Brazilian Ministry of Education approved the Common National Curricula Base (CNCB – BNCC in Portuguese), a document that defines the essential knowledge that all K-12 students have the right to learn. In the field *Mathematics and its technologies*, the BNCC conceptualizes the subject as:

> "Human science, the result of the needs and concerns of different cultures [...] and a living science, which contributes to solving scientific and technological problems and to underpin discoveries and constructions, including impacts on the world of work". (BRASIL, 2018, p. 267)

In the Brazilian reality, the Mathematics subject is organized into 5 Thematic Units (TU). They are: (i) Numbers: developing skills related to numerical thinking; (ii) Algebraic Thinking: identifying the dependency relationship between two quantities; (iii) Geometric Thinking: interpreting and moving a figure on the Cartesian plane; (iv) Quantities and Measures: building and expanding the notion of measure by studying different quantities; (v) Probability and Statistics: building sample space for equiprobable events.

In addition, the CNCB also includes Computational Thinking (CT) in the scope of Mathematics. The CT is an approach used to carry out thinking processes and can be applied in areas of knowledge that go beyond Computer Science.

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Methods

An exploratory study was conducted with 21 students, users of Makerspace, from a high school in a state capital in Brazil. A questionnaire was designed for this study by observing the routine of students when prototyping their projects in the Makerspace. The first questions in the questionnaire investigated how much students perceived the use of Math concepts in the Makerspace, and at which stage of project development their use was noticed. The remaining questions related to a preliminary study, which identified the main Mathematics issues that are explored during the use of resources in the Makerspace. These subjects were organized in Thematic Units.

Collected Data and Discussion

The responses from the questionnaire revealed important insights into the interaction of students in the Makerspace using Math concepts. 57.1% of students indicated the most important equipment for their projects is the Laser Cutter, followed by Low Tech Resources, 3D Printer and finally Robotics & Automation. Regarding the perception of the use of Mathematics in the process of carrying out projects, 57.1% stated that its use is very frequent and 19% reported that it was only frequent.

Regarding in which stage (Modeling and/or Production) students noted the greatest use of Math concepts, 61.9% of respondents said that for them in both stages Mathematics is used, and 38.1% said that during Modeling stage only. Finally, Table 1 shows which Math concepts students perceived being explored while using Makerspace resources, according to the organization of the scope of the subject in Brazil.

Table 1

Math concepts that students perceives being explored in each resource

	Laser Cutter	3D Printer	Robotics & Automation	Low Tech Resources
Numbers	6.8%	5.7%	6.7%	3.7%
Algebraic Thinking	23.8%	19.7%	15.6%	6.2%
Geometric Thinking	16.0%	13.9%	15.6%	19.8%
Quantities and Measures	31.6%	37.7%	28.9%	40.7%
Computational Thinking	21.8%	23.0%	33.3%	26.9%

The table indicates students understand that Quantities and Measures is the most used TU in Modeling, Prototyping and Execution processes. This result points to the perception of the importance of this TU when dealing with material resources, which require calculations related to measurement units.

Conclusions

This study sought to analyze the relationship between the application of Math concepts and the resources available in the Makerspace, from equipment to software. The application and analysis of the questionnaire pointed to the relationship between the Mathland metaphor and the proposal of a Makerland where resources used in the Makerspace are Microworlds and topics related to Mathematics are naturally explored.

The students identified the use of Math concepts during the Modeling, Prototyping and Production processes and their perceptions aligned with what was identified in the preliminary study. Next steps of this study include systematically organizing these issues so that they can be explored in an objective way when students carry out projects in the Makerspace, so that assessment and evaluation can take into account what is applied and learned during the prototyping process.

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International Society of the Learning Sciences

Viviendo Aquí: Designing for Transformative Agency through Museum Exhibit Curation with Latinx Youth

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Abstract: This paper showcases preliminary research on the process of curating a museum exhibit with Latinx youth. During the 2020-2021 school year, a group of Latinx teenagers developed an exhibit with a local museum. They reported feeling excited to see themselves and their stories represented in their mostly white community. This paper explores preliminary analysis of their engagement with the museum project and the potential community curation holds for disrupting whiteness perpetuated in public spaces.

Introduction

Community curation has emerged as a common practice for museums working to engage community members in the interpretation and storying of artifacts. However, the boundaries of museum curation and the communities that curation is meant to reflect raises questions about the relationships between communities, artifacts, and curators, particularly when the stories being curated center issues of justice (Black, 2010). This paper showcases preliminary research on the collaborative curation of a museum exhibit to showcase the lives and stories of Latinx youth. Viviendo Aquí which took place over the 2020-2021 school year, included a series of 14 workshops where youth designed and curated a museum exhibit featured at a U.S. mountain-west museum. Youth participants engaged in conceptualizing, planning, and designing the Viviendo Aquí museum exhibit. Our research included: How do activities engaging youth in exhibit curation afford opportunities for transformative agency? How do youth use material, relational and ideational resources? What hybrid practices were developed and what opportunities did those provide for reconfiguring power relations within the museum and the community?

Background

For this study, we drew on notions from sociocultural, cultural-historical, and practice theory to begin interpreting boundary work of community curators. We understand youth participants as experts in distinct communities of practice with boundaries that contrast those of historically white institutions. Youth became agentic actors who drove expansive learning (Engeström, 2001). To make sense of the trajectories of identification and participation (Polman, 2012) of those involved in curation boundary work, we adapted Nasir and Cooks' (2009) framework of material, relational, and ideational resources. We examined how resources act as mediational means, influencing identifications and participation of youth and educators in this context (Polman, 2006; Wertsch, 1998).

Methods

Drawing from participatory, community-based research, the Viviend Aquí exhibit took place in three phases over the 2020-2021 school year during the COVID-19 pandemic. Viviendo Aquí was designed as a series of 12 two-hour workshops that were held in a hyflex environment that took place both person and online depending on the constraints presented by the pandemic. A core design group of three teenage co-designers collaborated with one undergraduate research assistant, two university researchers and one museum educator to design the exhibit. 41 middle and high school students participated in the final phases of the project. All youth participants and the undergraduate researcher were bilingual and identified as Latinx, Chicano, Mexican, and Mexican American. The final exhibit was displayed from April to June of 2021 and drew more than 1,500 visitors. Researchers collected audio recordings, artifacts, and interviews and used ethnographic approaches to establish themes across the data.

Findings

Initially, the researchers, museum educator, and teen designers met to understand the museum context and co-design workshops that would engage additional youth participants. Throughout workshop sessions the designers developed ideas to support participants in telling their stories. The design team questioned the histories of museum practices and defined the questions the exhibit would address. Participants and their families were invited to the exhibit on its opening night (see Figure 1). Below, we describe one boundary practice youth added to the exhibit design to leverage their own material, relational, and ideational resources within the museum context.

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Figure 1
Museum Exhibit and Shadow Box

In the first weeks of their engagement with the exhibit, the design team decided to focus on supporting youth participants to tell the "stories of their lives and cultures" in the mountain west. As they engaged in storytelling, the youth voted to focus on "stories of the senses—stories that focused on taste, touch, smell, sights, and sounds"—that they felt defined and represented their experiences across the localities where they had lived, learned, and engaged with family and friends. While these sensory stories led them to design potential exhibits around food, clothing, music, and family gatherings, the design team eventually recognized that they wanted to engage more deeply with the materiality of museum exhibits. Due to the pandemic, the museum's archives and makerspaces were closed to visitors, which meant that participants had fewer opportunities to engage in traditional museum design practices. However, these barriers meant that designers were offered more opportunities to bring in their own ideas for engaging in building their exhibit.

The design team engaged in conversations about the colonizing practices of museums. To disrupt these practices, Teyo, a teen designer, suggested using shadow boxes to allow participants to "tell their stories." The shadow boxes, which had not before been used in exhibits at the museum, featured materials that participants collected or made and offered youth opportunities to represent their ideational resources—their cultural identities, stories, and relationships—and take on roles as designers. For example, Figure 1 illustrates the ways that Leigha, a high school participant, chose to share the story of her family's immigration. She explained, "I was born in Durango, Mexico; my parents, my sister and I came to the U.S when I was 4 years old. The scorpion represents where I come from…Durango is known as the 'land of the scorpions.'" The shadow box acted as her own miniature museum in which she leveraged material resources to depict cultural and familial identities. She went on to explain that she chose the paper cutouts to represent her family members because it was a way to "show how we're so close." Connecting these figures acted as a means of representing her family's bond, one that was forged both through the hardships they faced when immigrating to the U.S. and through their love of their culture and the mountains that characterized home in both Mexico and in the U.S.

Significance

Expansive learning is characterized by transformation (e.g., Engeström, 2001). By learning about museum curatorial practices and then disrupting those practices to build new boundary practices defined by their own material, relational and ideational means, the youth who participated in Viviendo Aquí were able to reconfigure what it meant to be a museum curator. As Ana, one of the youth designers explained, "I felt like a designer … we can show other people that we, the Latinx community, doesn't struggle all the time. We also have our culture that's very important to us." As Nasir and Cooks (2009) suggest, when youth have opportunities to engage the multitude of resources embedded in their cultural identities, they can leverage their identities toward more expansive and agentic forms of learning and representation.

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Training a text classification algorithm to predict the presence of dispositions and learning shifts in students' self-reflection

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Abstract: The body of literature on how to best leverage learning analytics to measure students' acquisition of 21st-century dispositional skills is in emergent stages. This project, based on over 800 student self-reflections, leverages natural language processing and qualitative data analysis to attempt to train a text classification algorithm to predict the presence of dispositions and learning shifts in students' self- reflection.

Rationale For The Algorithm

Society is facing an increasingly uncertain, turbulent, and changing world. The needs of the 21st century are different, and institutions, schools, and academics are building models of a 21st-century future that focuses on the soft skills and dispositions needed to thrive (Dede, 2010). This impacts educational researchers, who challenge us to rethink what we are teaching and what we are measuring so that we can support students as they confront the challenges and opportunities before them.

Stanford University's Hasso Plattner Institute of Design (the d.school) focuses on a similar direction. In 2016 the d.school conceived of eight design abilities essential to enabling students to thrive, persevere, enact change and take risks in the uncertain and changing world (Carter, 2016). These eight design abilities are both a theoretical frame and central to the pedagogical practices enacted in d.school classes.

Yet, measuring student learning of 21st-century skills and dispositional abilities can be very challenging, especially at scale (Dede, 2010), and metacognitive practices such as self-reflection or thinking routines are a commonly cited methods (Richhart, Church, & Morrison, 2011). Fortunately, emerging learning analytic techniques such as applied natural language processing and machine learning text classification can automate the analysis of a large corpus of student data in natural human language (Martin & Sherin, 2013)

This poster describes a formative study of qualitatively coded student self-reflections from d.school classes between 2018 and 2021. These reflections were used to train an Auto ML Text Classification algorithm to identify self-reflections that demonstrate the d.school design abilities and other shifts in learning.

Creating The Algorithm

In 2018 the Teaching and Learning team at the d.school instituted an effort to make their students' thinking visible. They leveraged a Making Thinking Visible thinking routine from the Project Zero Lab at Harvard Graduate School of Education (Richhart, Church, & Morrison 2011). The thinking routine, I Used To Think… Now I think… is a routine for reflecting on how and why students' thinking has changed. Students are prompted to reflect on their d.school class and write a response using each sentence prompts: "I used to think…" and "Now, I think…" Approximately 40% of the classes participated. Within those classes, compliance varied between 50-and 70%. Seven hundred fifty-two total statements were collected between 2018 and 2021.

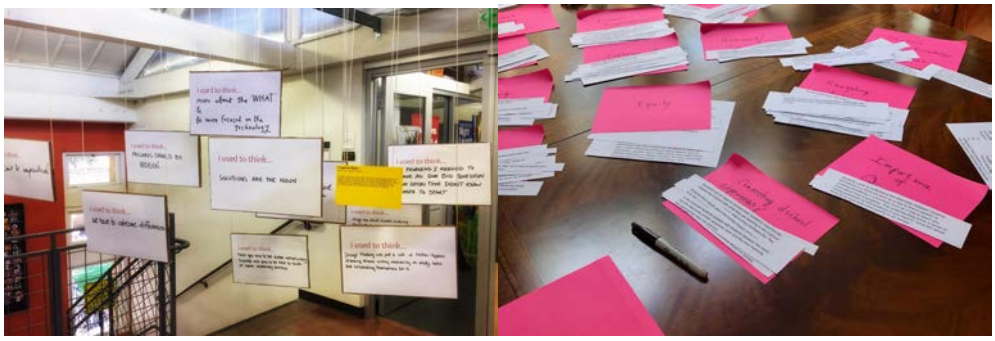

Figure 1: Photos of I Used to Think, but Now I Think statements. *Left: Worksheets on display at a community event. Right: Statement classification according to grounded theory code.*

The research team coded the statements using inductive and deductive approaches and used an inductive and grounded theory approach. First, each reflection was read to capture a sense of the response. Next, the data

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was synthesized into initial categories: agency, creativity, purpose, failure, ambiguity, and collaboration. The themes shifted as statements were added to the data set each year. Finally, five grounded theory-informed codes emerged: Changes in Mindsets and Worldview, Changes in Knowledge and Tools, Changes in the World, Changes in Perspective, and Personal Change. Additionally, 752 statements were coded using a deductive approach aligned to the eight d.school design abilities.

The 752 statements were used to train a Google Cloud AutoML Custom Text Classification algorithm. Auto ML uses a machine-learning algorithm built via neural architecture search to analyze the meaning, structure, and sentiment of natural language data. It allowed for creating a supervised learning, multi-label text classification model. After importing the dataset, Google Cloud validated it and conducted a series of quality checks. The tool randomly withheld 20% of the data to utilize 10% for validation and 10% for testing. Once the dataset was validated and imported, the data was initiated to start training the model, and then its strength was evaluated, and it was manually trained to hone precision. An additional 82 student self-reflection statements were used to test the model against d.school educator predictions.

The AutoML Custom Text Classification algorithm was selected after experimenting with other Natural Language Processing tools. AutoML leverages Neural Architecture Search to build the custom model by automating the design of neural networks. This allows for greater precision than the research team's ML skills might otherwise have enabled.

Learning From The Algorithm

Initially, the research goal was to understand two things: (1) can qualitative coding of student self-reflections be used to train supervised classification algorithms to predict the presence of the design abilities and learning shifts in students' self-reflections? and (2) does training the classification algorithm result in alignment between what the supervised classification algorithms predict in student self-reflection and what educators predict?

Preliminary results for this research indicate that the answer is “yes” to both of these research questions. Qualitative coding can be used to teach text classification algorithms to identify the eight design abilities and other learning shifts in student self-reflection. The average precision of the model is 0.876, although there is variance in the precision for each of the individual classifiers. This high average precision (*1 is the highest*) suggests that the model largely predicts what d.school educators predicted in the training data.

Additionally, the algorithm highlighted at a 95% confidence threshold that many of the 13 classifiers had very high prediction accuracy but also a reasonable rate of false negatives. Meaning that when the algorithm says a classifier is present, it likely is, but it may well be when it says it isn’t present. This finding suggests that our mental model of what a classifier indicates may be too varied and inconsistent.

This is a work in progress and an ongoing body of work. Nevertheless, this small study indicates that text classification has a role in research and shows promise in assessing 21st-century abilities and dispositions. The next steps in the study include (1) assessing the inter-rater reliability between the algorithm predictions and the parallel teacher evaluations by measuring Cohen’s kappa. (2) determining if the algorithm can continue to reasonably predict the presence of classifiers in unstructured student self-reflection, and (3) exploring how researchers can refine their mental model of a qualitative code through analysis of algorithmic decisions.

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International Society of the Learning Sciences

Inquiry of (Re)configurings: Toward a Review of Posthumanist Methods for the Study of Learning

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Abstract: Educational researchers are increasingly adopting posthumanist approaches, questioning methodological assumptions toward the study of learning. Yet, it remains under documented how researchers align methodological doing to this aim. The present poster presents two studies that employed posthumanist perspectives and how they led to think methodologically with theory. The paper points to the need for a systematic review of posthumanist methodological approaches and decisions for the study of learning.

Introduction and background

Scholars across fields of educational research are increasingly adopting posthumanist perspectives (e.g., Kuby & Rowsell, 2017), claiming more recently for the need to articulate how these perspectives contribute to studying learning (Peppler et al., 2020). Posthumanism proposes a notion of social life and, therefore, of learning that decenters the human to attune to the inextricable connection between people and the physical world. To decenter people, research methods become "(re)configurings of the world" (Barad, 2003, p.816; sic): performative entities of the research process that make and remake the world. The tools and approaches for viewing aspects of the world actively contribute to what the world becomes both socio-historically and ontologically (Barad, 2003).

However, the reconfigurations that researchers and methods undergo in the process of aligning methodological doing toward the study of learning with posthumanist perspectives remains under documented. Following Sørensen's (2009) call to inquire about methodological shifts that posthumanist perspectives require, we asked: *How do methods align with posthumanist perspectives? What do they allow to capture?*

We drew on two of our own studies and analyzed how participant observation and video data analysis were reconfigured when applying a posthumanist lens. First, we examine participant observations and field notes around the informal presence and use of 15-16 years-olds' mobile phones in two high schools in Chile as a complex relational production space. Then, we turn to an inquiry that aligned video-based research to move toward flattening power relations between humans and non-humans in the context of computational crafting. Both studies provide insights into methodological reconfiguring based on posthumanist perspectives, such as considering human and non-human practices, and changing the *point of* view by filming from above. Our analysis points to the need for a systematic review of posthumanist methodological approaches for studying learning.

Methods

We selected two studies for analysis that were part of our own research because we have deep understanding of their methods evolution. The first study was the *mobile phones in schools* project, an ethnographic study in two stated-funded schools in Chile examining the negotiation process of 10th-grade students' phone use in school. Posthumanist perspectives informed tracing of how people, phones, discourses, and identities played a role in phone use and negotiations. The second study was the *computational crafting* project, which investigated fiber crafts as a context for computational learning in a middle school context. Posthumanist perspectives informed the data collection and analysis to highlight relational reconfigurations of people and craft materials that produced opportunities for computational learning. We analyzed how the studies looked for relationality, integrated researchers' points of views, and flattened movements to gain an understanding of how important aspects of posthumanist theoretical orientations informed methodological understanding of studying learning.

Findings

Mobile phone in school used a relational and socio-material approach (Burnett et al., 2012), in which phones were part of entanglements of positional identities, practices, objects, and discourses. The theoretical commitments led to field notes on what occurred *within* and *throughout* the phones' physical presence in the classroom, with teachers, peers, and objects (i.e., textbooks and calculators) in classes, and peers and parents outside of them. The theory guided focusing on relationships and connections of phone use within and across the classroom. students were invited to bring their phones into subsequent interviews to talk about and recreate observed practices. Preliminary analysis of observations during fieldwork (Figure 1) pointed to the complexity of relationships and identification of events, which then were further co-analyzed with students and teachers. That analysis showed that phones had a key role in how classes were being organized and how students were (dis)engaging in classes.

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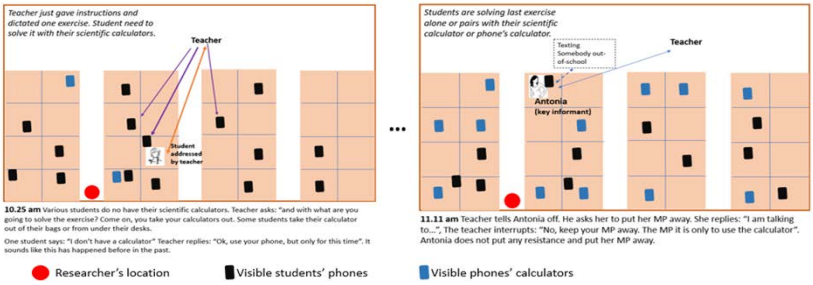
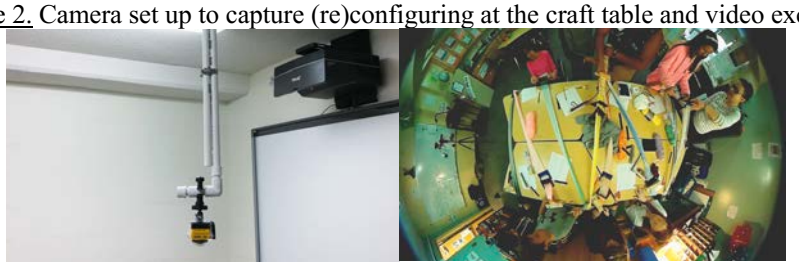
For instance, the phones acted as an entertainment source to ease self-declared moments of frustration, or as a substitute for non-existent educational tools in the study classrooms. The visual analysis (Figure 1) also pointed to negotiation and emerging practices that were *initiated* by the phones *themselves.* The relational and posthumanist perspective traced the emergent *discursive-materiality* (Barad, 2003) of the phone as a personal object, a communication device, and a contested educational tool.

Figure 1. Visual analysis of observational data with field notes (excerpts) in school 1, Chemistry class.



Computational crafting aligned with the Baradian (2003) notion of (re)configurings of relationships of people and things. Video data recorded the craft table from a birds-eye-view angle, showing what people and materials did to each other as they came together to shape opportunities for domain learning (Figure 2). The data analysis looked at patterned coming together of people and materials that produced computational moments. For instance, in weaving loom-youth movements produced conditional statements one dimension at a time: youth drew the threads of the loom vertically in space (either up or down) and paired this movement with a horizontal movement as they moved their yarn across the loom from left to right or from right to left. The study analyzed (re)configurings of the patterns and what happened when repetitions broke down. While youth called them mistakes, a human-centered reading that assumes a deficit notion, the analysis showed that (re)configurings physically expanded computational possibilities (e.g., including a range of additional pairings of loom-youth movements).

Figure 2. Camera set up to capture (re)configuring at the craft table and video excerpt.



Discussion

The posthumanist methods that we analyzed looked for relationality (e.g., human and non-human practices within the classroom), integrated researchers' points of views (e.g., changing the research process on the fly), and flattened movements (e.g., filming from above). A posthumanist lens made it possible to reframe deficit orientations into generative opportunities for learning. This study suggests the need for a more in-depth review of researchers' experiences and decisions across the wide range of posthumanist educational research.

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International Society of the Learning Sciences

Accessible Computational Thinking in Elementary Science

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Abstract: Computational thinking (CT) is ubiquitous in modern science, yet rarely integrated at the elementary school level. Moreover, access to computer science education at the PK-12 level is inequitably distributed. We believe that access to CT must be available earlier and implemented with the support of an equitable pedagogical framework. Our poster will describe our Accessible Computational Thinking (ACT) research project exploring professional development with elementary teachers on integrating computational thinking with Culturally Responsive Teaching practices.

Computational thinking (CT) is ubiquitous in modern science, as scientists work with ever larger and more complicated data sets and turn to algorithms and computer programming to sort and analyze data more effectively (Restuccia et al., 2017). Despite its importance, the explicit teaching of CT and computer science concepts in PK-12 schools is typically only accessible through foundational computer programming classes that are not offered until high school and are offered in schools that primarily serve affluent students (Code.org et al., 2021). Meanwhile, research suggests that computing should be integrated into curricula earlier and more widely: elementary schools serve all students and so can be important spaces to increase student interest, identity, and capacity in computer science (Code.org et al., 2021). Given this and how integral CT is to modern science, we argue that CT should be integrated into elementary science education.

We believe that integrating CT into elementary science education requires attending to equity. White men are significantly overrepresented in most STEM fields, especially in computer science, engineering, and the natural sciences (Fry et al., 2021). This lack of diversity has consequences for scientific and societal progress; for example, the underrepresentation of women and Black, Latino/a/x, and Native American (BLNA) people in computing leads to the development of biased algorithms that reproduce societal inequities (Noble, 2018). Moreover, access to computer science education at the PK-12 level is inequitably distributed, with BLNA students and students who are eligible for the National School Lunch program having the lowest access to computer science courses (Simoni, et al., 2016).

Therefore, we believe that access to CT in science education must be available earlier, more broadly, and implemented with the support of a pedagogical framework specifically targeted towards equity. Various frameworks—such as Culturally Relevant Pedagogy (Ladson-Billings, 1995), Culturally Responsive Teaching (Gay, 2002), Culturally Sustaining Pedagogy (Alim et al., 2020), and Culturally Responsive Computing (Madkins et al., 2020)—can inform equity efforts in computer science education (Madkins et al., 2020). For our work, we are adopting the framework of Culturally Responsive Teaching (CRT) as articulated by Gay (2002). In brief, this approach involves teachers being involved in their student's communities and cultures, designing lessons that reflect diverse cultures, and valuing their different ways of knowing and being (Gay 2002).

For our NSF-funded Accessible Computational Thinking (ACT) project, we are designing and implementing a professional development (PD) program to support elementary educators in integrating CT into science lessons using CRT practices. We will be working with elementary teachers from schools in both the southwest and northeast of the United States which have significant populations of BLNA students. These teachers will participate in summer PD workshops on CT and CRT, during which they will adapt existing science lessons to integrate CT with CRT practices. Over the subsequent school year, we will support teachers in implementing CT-integrated science lessons with CRT practices. We will provide ongoing PD meetings and collect data through classroom observations, teacher interviews, and assessments.

The below two figures represent visuals presented on our poster. Figure 1 provides a conceptual depiction and Figure 2 provides a timeline of our project's first two years.

Figure 1

A Conceptual Diagram Relating Science, CT, and CRT for our project

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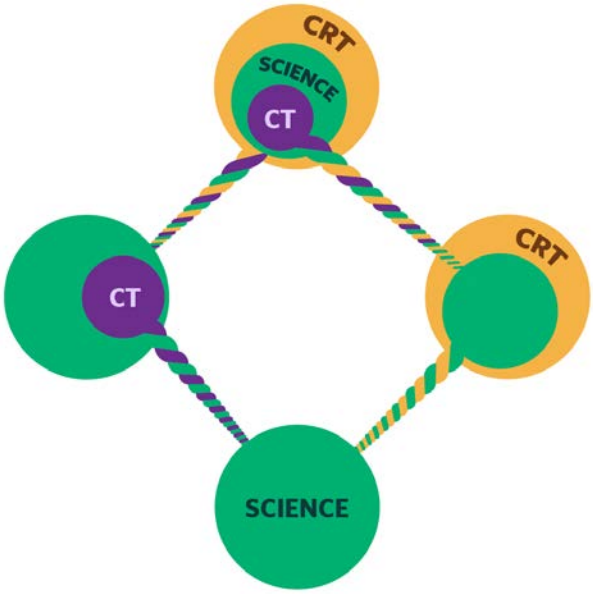
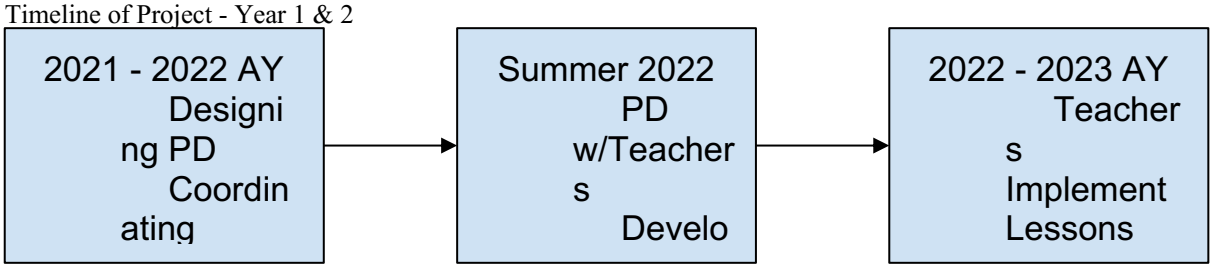


Figure 2
Timeline of Project - Year 1 & 2



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Local-global Maker-places: Toward an Instrument for International Maker Education

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Abstract: After the establishment of a makerspace in any context, sustainability is becoming increasingly important. As an international group of early career scholars with experience in maker education, we engaged in a series of reflective conversations that called us to consider visions for makerspaces as sustainable maker-*places*. We offer a representation that cuts across visions for sustainable maker-places with the intention to begin to develop an instrument for international maker-education.

Place-based approach toward international-maker education

As ecological challenges continue to affect human life, questions related to preparing people to identify local solutions to global problems gain importance. During the past decade, maker educational approaches have found international resonance with maker environments rapidly spreading across settings (e.g., Blum-Ross et al., 2020). Such environments foster local communities and are situated in national and international socio-historical discourses and materialities. They are local instantiations of international scale. Although maker education is well represented in the learning sciences, international perspectives are underrepresented.

Guided by place-making as a theory of learning that highlights how people co-construct spaces as personally and socially meaningful (Taylor & Phillips, 2017; Marsh, 2020), the authors came together in search of language for developing a framework for supporting a sustainable global future for making that is rooted in local communities and centers the artifact across ecologies (e.g., Peppler et al., 2021). Distinct from spaces, we note that "places bring together people who engage in a common activity, may share a particular history, or identify with a locality in a particular way" (Taylor & Phillips, 2017, p. 594). We argue that makerspaces are made into maker-*places* by the individuals and communities that co-construct them. At this project proposal stage, to begin work toward a framework for thinking about the place-ness of makerspaces (i.e., the makerspace as a maker-place), as an international group of early career scholars, we engaged in a series of reflective conversations that considered visions for sustainable making and makerspaces within our local contexts, revolving around the question: *Considering your history with maker education, what vision do you have for a sustainable future for making?* The goal of this early ideational work is to suggest the development of instruments for the design of makerspaces as maker-places that account for the local historical, cultural, and social dimensions of maker-places as sites for learning as well as the possibility for making to support innovative responses to global challenges.

Conversations toward a shared vision of international maker-places

The author team is an international group of early career scholars spanning North America, Western Europe, and Western Asia. We chose to come together as our work deals with making in disparate and related ways in contexts with an array of similarities and differences. As we came together, we took cues from autoethnographic trends that frame critical reflection as a form of methodology (e.g., Morley, 2011). We asked ourselves a series of discussion questions and ultimately crafted a single question for individual reactions. After responding to this prompt individually, we came back together to discuss, react to, and revise visual representations that team members had generated (see Figure 1 for the result of this discussion). Then, we revised our individual responses to capture reactions to the visual representations. The visualization served to support our conversation toward creating a design tool for maker-places that are sensitive to local and global forces.

Toward sustainable futures for maker-places

For making to remain sustainable, maker educators will need to consider multigenerational approaches that support learners in building and sustaining community. Teachers and mentors, family members, and community stakeholders must work together to continue to provide opportunities that are relevant for learners and their families, encourage individual and collective development, and make visible potential future pathways. Next, physical materials play a fundamental role in maker-places, contributing to the co-development of places and people, STEM domain learning, and gender equitable pathways within STEM. Integrating understanding of

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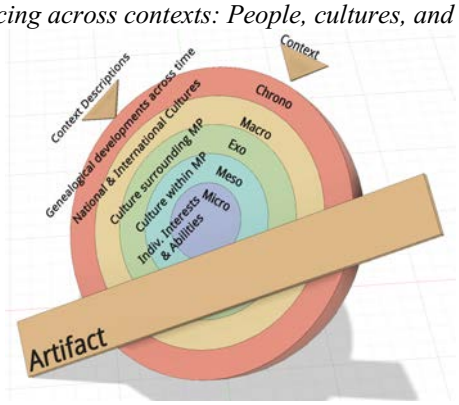
ecological, economic, and socio-historical dimensions of maker materials can inform localized material ecologies that break global inequitable material lifecycles toward local sustainability. Additionally, a sustainable future for making requires attending to the interactional dimensions of making spaces into maker-places, including social, historical, and material relations. This future requires attending to the parallel settings and places in which people interact and connect (i.e., online, home, out-of-school settings) so as to forge greater connections across these settings for meaningful learning experiences. Furthermore, maker-places should attract local people and keep them coming back. While designing such maker-places, we should consider three levels of context: micro, meso, and macro (Marsh, 2020). The skills and interests of the target group in the micro context; the culture, beliefs, and interests of the local community in the meso context; and the national and international developments in maker education in the macro context. When considering the various contexts maker-places should engage with, we combine ideas from Marsh (2020) and Peppler et al. (2021) in Figure 1.

Figure 1

Artifact slicing across contexts: People, cultures, and temporalities



Discussion

By coming together from different parts of the world and bringing perspectives on creating sustainable maker-places, the author team provided a representation to support design. The representation highlights the importance of considering both the maker (micro context), their immediate community (meso context), and the space for making (exo context), as well as the global histories (macro context) and current challenges (chrono context) in designing maker-places. The representation, as approximated in Figure 1, serves as a nascent tool to prompt us as authors and conference attendees to ideate ways to encourage makers to deliberately engage with and across the layers of place-making. The visualization is an intermediary step toward the design of a *Maker-Place Design Tool* (MPDT). We intend for the visualization to inform the analysis our collective observations and experiences in maker educational settings toward generating exemplary vignettes that represent each layer of sustainable future maker places. The vignettes are intended to inform the creation of the MPDT. The MPDT will include prompts, statements, and case studies to support maker-place researchers, designers, and educators to engage in discourse across contexts as they produce artifacts toward sustainability. Although early in development, the MPDT promises to provide both practical and theoretical support for maker-place makers to thoughtfully engage with and across layers and to consider their *place* in *making* solutions and designing futures.

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Exploring Elementary School Students' Clusters in Blended Mathematics Learning

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Abstract: Blended learning is effective in enhancing meaningful learning in online and face-to-face learning environments. For adaptive learning supports, teachers should understand the diversity of students and identify student clusters with different educational needs in blended learning. This study explored the clusters of Korean students in a mathematics class, collecting blended learning data for one month. This study found three clusters: (1) students with the need for integrated support, (2) students with positive affective characteristics and high-level, self-regulated learning skills, and (3) students with high-level academic achievements and online learning participation. Thus, this study determined unique characteristics of Korean students that were typically overlooked by teachers.

Introduction

Blended learning can be effective to overcome the limitations of a traditional school system that does not sufficiently consider the diversity of students. Students have more autonomy in online learning activities because they can decide when, where, and how to learn, whereas teachers can provide adaptive support in face-to-face learning environments. To enhance the effectiveness of blended learning, teachers should understand the educational needs of students, which are the basis of differentiated instruction or personalized learning (Boelens et al., 2018). Learning analytics helps teachers effectively and timely identify the needs of students, using data collected from online learning platforms and digital devices. Teachers can explore student groups who share similar characteristics and behavior patterns to provide different learning tasks and adaptive support for each group (Han et al., 2021).

Although learning analytics is helpful for adaptive learning support in blended learning, previous studies have seldom explored clusters of elementary school students. Thus, it is necessary to investigate the diversity of elementary school students by analyzing multiple data sources such as academic achievements, online learning participation, affective characteristics, and self-regulated learning skills. In addition, there is a lack of research on East Asian students who may have different characteristics and educational needs from those in Western countries. To design personalized learning or differentiated instruction for Korean students, this study intended to explore clusters of elementary school students, using data collected from blended mathematics learning.

Methods

Participants

This study was conducted during the COVID-19 pandemic at a blended learning research school in Busan, South Korea. A total of 70 fourth-grade elementary school students participated in the study as part of their mathematics class, using the online learning platform MS Teams. All participants used a laptop provided by the government for online learning at school or home.

Data collection

This study collected data on mathematics learning (i.e., addition and subtraction of fractions) for four weeks. The data included academic achievements, subject interest (Sang et al., 2020), achievement emotion (Lichtenfeld et al., 2012), self-efficacy (Pintrich et al., 1991), self-regulated learning skills (Pintrich et al., 1991), and online learning participation. The surveys of affective characteristics and self-regulated learning skills had high reliabilities (Cronbach's alpha = .81 ~ .95). Data of online learning participation included the frequencies of submitted tasks, viewed tasks, and submitted quizzes.

Data analysis

The principal component analysis (PCA) was carried out to identify key components from data collected in blended learning. The PCA revealed four components: academic achievements, affective characteristics, self-regulated learning skills, and online learning participation. Using the four components, we conducted the two-

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stage cluster analysis including a hierarchical cluster analysis and a K-means cluster analysis. After finding three clusters, One-way ANOVAs and Kruskal-Wallis tests were carried out to investigate how the clusters were different from each other.

Findings

This study found three clusters of elementary school students regarding academic achievements, affective characteristics, self-regulated learning skills, and online learning participation. Cluster 1 (n = 35) had low grades (M = -.38, SD = .78), negative affective characteristics (M = -.63, SD = .7), low self-regulated learning skills (M = -.47, SD = .74), and low online learning participation (M = -.54, SD = .61). This cluster requires integrated support from an instructor because the students showed lower achievements in diverse aspects of blended learning than others. Cluster 2 (n = 20) had the highest academic achievements (M = .76, SD = .25) and actively participated in online learning activities (M = 1.14, SD = .63), but did not show high or positive results in affective characteristics (M = .15, SD = .78) and self-regulated learning skills (M = -.25, SD = .56). Cluster 3 (n = 15) had positive affective characteristics (M =1.26, SD = .43) and high self-regulated learning skills (M = 1.44, SD = .54), but their academic achievements (M = .37, SD = .64) and online learning participation (M = -.27, SD = .91) were not high. ANOVAs and Kruskal-Wallis tests showed that Cluster 1 had significantly lower academic achievements (H = 35.34, $p <$. 001) and more negative affective characteristics (F = 41.23, $p < .001$) than other clusters. Cluster 2 more actively participated in online learning than other clusters (H = 31.84, $p < .001$). Cluster 3 showed significantly higher self-regulated learning skills (F = 46.39, $p < .001$) and more positive affective characteristics (F = 41.23, $p < .001$) than other clusters.

Conclusion

This study determined three clusters of elementary school students in blended mathematics learning. The results indicated that students have different educational needs, requiring adaptive learning support and differentiated instruction. For Cluster 1, systematic support is necessary because students showed low achievements in diverse aspects of mathematics learning. Teachers and school counselors should collaborate to help students overcome the low achievements, which may be caused by instructional methods, mathematics curriculum, and family issues, as well as the COVID-19 pandemic. In addition, teachers should pay more attention to non-cognitive achievements of Cluster 2. The findings related to this cluster are consistent with the conclusion that Korean students show high achievements in mathematics but low confidence and interest (OECD, 2013). For Cluster 2, teachers should support their motivation by providing authentic tasks and enhancing their autonomy in blended mathematics learning. Teachers also need to explain and demonstrate self-regulated learning skills, such as how to plan, monitor, and control the learning process and environments. Lastly, teachers should encourage students in Cluster 3 to participate in online learning activities more actively. Teachers can provide feedback to prevent students from overestimating their participation and achievements, using the dashboard of an online learning platform. Future research is necessary to explore clusters of students in diverse contexts, to identify their educational needs and provide adaptive learning support.

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Tinkering in Parallel: Pathways for Professional Learning in Education

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Abstract: This study explores professional learning that occurred during a summer program in which educators engaged with a series of tinkering activities facilitated online. Analysis revealed two primary themes: (1) generative starting points with multiple pathways for exploration, and (2) resolution of sticking points through social connections. An analytic frame of parallel process, adapted from counseling psychology, highlights the way these themes simultaneously speak to learning through tinkering and to professional development.

This study explores the learning experiences of a group of STEM educators who completed an informal online professional development program in summer 2020 that featured a series of tinkering activities.

Background

Educators must develop a skillset that is well grounded in learning theory and empirically supported pedagogical techniques, yet also flexible enough to respond to students' needs (Athanases et al., 2020). Learning to facilitate tinkering activities is a prime example of this challenge, since these activities are open-ended and invite creative exploration rather than fixed lesson plans (Vossoughi & Bevan, 2014). The ways educators have adapted to pandemic challenges underscore the need to conceptualize learning in terms of repertoires of practice that are flexible, responsive, and grounded in supportive pedagogical relationships (Gutiérrez & Rogoff, 2003).

Research design

Data come from 23 interviews with 12 educators who engaged with a series of tinkering activities facilitated online by the Exploratorium: Exploring Spinning, Chain Reaction, Cranky Contraptions, and Video Sensing. Activity prompts were introduced by email, and participants were encouraged to document their process and connect with others on social media. Interviews were semi-structured and were designed to elicit narrative accounts of participants' tinkering experiences. Analysis began with open coding to identify high-level topics that were salient across narratives; subsequent analysis elaborated upon each code in turn. Here we focus on two crosscutting themes that emerged in the second phase of analysis: (1) generative starting points with multiple pathways for exploration, and (2) resolution of sticking points through social connections.

Findings

Generative starting points with multiple pathways for exploration

In all 23 interviews, educators described the need to find a personally meaningful starting point to begin engaging with each activity. Generative starting points were associated with a sense of emotional resonance and playfulness; emotions that frequently came up in participants' narratives included excitement, inspiration, and curiosity. Because starting points were linked with personal sense making, many participants favored prompts that were open-ended enough to leave space for creative exploration while also providing a clear sense of direction. We believe these tinkering activities engendered fruitful learning in part because they were amenable to a variety of starting points and multiple pathways for exploration. We identified five types of starting point that generated engagement; Table 1 provides a description of each type, including observed frequency.

Resolution of sticking points through social connections

In 17 of the 23 interviews, educators described encountering sticking points in their exploration. These moments were characterized by intense frustration and interruption in the flow of engagement with an activity. Sticking points typically arose when participants encountered limitations, either in the material resources available to them at home, or in their individual knowledge about a particular tool or resource. In these moments, there was a disjunction between their original idea or vision and the implementation of that idea, which led to emotional overwhelm and impasse. For many participants, resolution was facilitated by social interactions, either with family members in person or with colleagues online. In these connections, participants found emotional support to persist through difficult moments. While sticking points typically arose for technical reasons, their resolution tended to be characterized not by technical troubleshooting, but by a shift in perspective and emotional regulation brought about by supportive, encouraging interactions and relational care. Perhaps surprisingly, many participants reported

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that the frustration of sticking points turned out to be a valuable part of their learning, and that they subsequently felt a greater sense of satisfaction and excitement about their tinkering experiences after they had worked through these difficult moments with emotional support from others.

Table 1

Five Types of Starting Point

Type	Freq	Description
Physical Materials	21	With focus on the properties of physical materials, participants thought creatively about how to use materials that were readily available at home and explored emergent interactions between materials.
Previous Experience	19	With focus on previous experience, participants activated existing knowledge and used past exploration as a template for new efforts or as motivation to try something different.
Practical Goals	10	With focus on a practical goal, participants designed an object to accomplish a personally meaningful task and structured their tinkering according to that goal.
Narrative Elements	8	With focus on a vivid image or character, participants created aesthetically appealing stories to guide exploration and link their creations with personally meaningful themes.
Scientific Concepts	8	With focus on a scientific concept, participants investigated physical phenomena and tested various factors or parameters related to a particular phenomenon.

Discussion

Since our participants were educators who engaged with these activities for the purpose of professional development, we note that each theme discussed above may serve a dual analytic function, simultaneously speaking to the nature of learning through tinkering and to the nature of professional development. Tinkering is recognized as a valuable mode for students' STEM learning (Resnick & Rosenbaum, 2013); here we note that it may be just as valuable for professional learning. The benefit of activities that include diverse learning pathways and ample opportunities for social collaboration may be equally applicable to facilitation of tinkering in STEM education and to provision of professional development. When considering educators as learners, it is useful to attend to both sides of their dual role in professional learning. Learning through tinkering allows educators to explore affordances of activities with their own practices in mind, developing a flexible pedagogical repertoire. Emphasis on adaptive practice is useful to address parallel challenges that arise in student learning and professional learning, such as shared challenges of adapting to pandemic constraints. In the context of counseling psychology, parallel process refers to dynamics in clinical practice that are mirrored in professional supervision (Sarnat, 2019). This concept is a useful analytic frame to conceptualize the value of tinkering for professional learning, where an educator likewise holds a dual role with respect to teaching and learning.

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Exploring the Interaction between L2 Learners and AI Translator in English Writing

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Abstract: This study investigated how L2 learners interact with an artificial intelligence (AI) translator for English writing and explored the effects of the English writing skills on interaction patterns. L2 learners (n=21) wrote an essay in English using an AI translator. As a result, three clusters were found: English writing, Korean writing, and Interactive writing. The interaction pattern was different according to the expression scores. The results provide implications in designing interactions between learners and AI.

Introduction

In the era of digital transformation, learners should develop literacy in terms of how to interact with new technologies like artificial intelligence (AI) tools. Learners who effectively interact with AI tools may exhibit higher performance and learning gains than those who overly depend on or ignore AI tools. AI literacy education is necessary to help learners to develop competencies to well collaborate with AI tools for an authentic task. Despite the importance of interacting with such tools, there is a lack of in-depth research of exploring the interaction between learners and AI tools, which can provide implications not only for the development of AI tools but also AI literacy education.

Based on activity theory, this study explores how L2 learners interact with an AI translator while writing an English essay. Although the AI translator is easy to use, learners may interact with it in different ways according to their English writing skills. Learners with low English writing skills are likely to have higher needs of using the AI translator. This study explores the activity system of interaction between an L2 learner and an AI translator, consisting of multiple actions and operations (Kuutti, 1996). The following research questions are addressed: (1) How do L2 learners interact with the AI translator in writing an English essay? (2) How are the interaction patterns related to L2 learners' English writing skills?

Research methods

Participants

A total of 21 undergraduate and graduate students (13 female, 8 male) participated in this study. All participants were studying different majors and also had different competency in English writing. Participants exhibited differences in content (M=2.81, SD=.981) and expression (M=3.05, SD=.865) scores of English writing competency.

Procedure

First, we explained how to use the AI translator, Papago (https://papago.naver.com), and allowed participants to sufficiently explore the tool. Second, for the assessment of English writing skills, participants individually wrote an English essay without the AI translator. Finally, they wrote another English essay, whose topic is different from the previous one, with the AI translator. We recorded the second writing activities on video to analyze how learners interacted with the AI translator.

Data collection and analysis

The video was analyzed by applying Jordan and Henderson's (1995) human-computer interaction analysis framework for analyzing the interaction patterns of learners. We developed a coding scheme consisting of actions and operations to analyze video data. The coding scheme includes planning, composing, and revising actions including sub-actions. The video data were independently analyzed by two researchers and then discussed to resolve differences in coding results (Cohen's Kappa = 0.792). To identify interaction patterns of L2 learners and the AI translator, we analyzed the percentage of time spent on each action and then carried out K-means cluster analysis. We found three interaction patterns and then conducted the Kruskal-Wallis test to examine the differences in the actions according to the interaction patterns. In addition, two researchers evaluated English writing with a rubric consisting of content (Cohen's Kappa = 0.712) and expression (Cohen's Kappa = 0.734). The possible score of English writing ranged from 1 to 5 for each of the content and expression.

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Results

Interaction patterns between L2 learners and AI translator

The cluster analysis results revealed three different interaction patterns between L2 learners and the AI translator: (1) Korean writing with limited use of the AI translator, (2) English writing with limited use of the AI translator, and (3) interactive writing with the AI translator. The Korean writing cluster (n=8, 40%) wrote the entire text in Korean and then entered it into a AI translator. The English writing cluster (n=7, 35%) wrote most of the text in English by themselves, but if necessary, Korean at the level of words and phrases was entered into the AI translator. Lastly, the Interactive writing cluster (n=5, 25%) displayed the high proportion of time spent revising translation results. Kruskal-Wallis tests indicated that the Korean writing cluster had significantly more "writing in Korean" action (H=17.449, p<.000), and the English writing cluster had significantly more "writing in English" action (H=17.166, p<.000) than other clusters. The Interactive writing cluster exhibited the highest proportion of actions for "revise and use" (H=9.316, p<.009) than other clusters. Other actions were found not to be statistically significant.

Differences in interaction patterns according to learners' English writing skills

The results of the Kruskal-Wallis test to analyze English writing competency by interaction patterns revealed the difference in the content score was not statistically significant (H=1.803, p=.406). However, the expression score (H=6.113, p=.047) was statistically significant between the clusters. In particular, the English writing cluster displayed the highest expression score, while the Korean writing cluster showed the lowest. Both the learners with high and those with low English writing scores had a limited percentage of interaction with the AI translator. It was found that learners with both high and low scores had low interaction with the translator; however, there was a difference in the number of inputting words in their writing task.

Table 1

English writing skills by clusters

English writing skills	Interaction patterns						Total	
	Korean writing		English writing		Interactive writing			
	M	SD	M	SD	M	SD	M	SD
Content	2.38	.09	3.14	.17	3.00	.20	2.80	.98
Expression	2.50	.12	3.57	.11	3.00	.00	3.00	.84
Total	4.88	1.13	6.71	1.80	6.00	1.00	5.80	1.54

Discussion

This study found that L2 learners interacted with the AI translator in three different ways. While some learners interacted with the AI translator well, others spent a lot of time on writing an English essay without the AI translator. Learners with low English writing skills tended to overly depend on the AI translator, so they seldom revised its outputs. In contrast, learners with high English writing skills were not easily satisfied with the translation outputs, so they might consider how much they would use the AI translator for English writing. Some learners actively interacted with the AI translator, whereas others seldom used it due to the lack of usefulness. This result is consistent with Chartterjee and Bhattacharjee (2020), who argue that attitude toward AI tool has a significant impact on behavioral intention of the individuals to adopt AI in education. Future research is necessary to investigate how the interaction patterns influence the development of L2 learners' English writing skills. This study implies that AI literacy education should focus on the interaction between learners and AI-based tools.

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Meaningful Movement towards Campus-Based Outdoor Learning: Characterizing Pre-Scenery with Stakeholder Perspective

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Abstract: This study seeks to characterize what matters to stakeholders as a school moves towards campus-based outdoor learning. Results from a survey (n=87) demonstrate stakeholder alignment in relation to a long-standing outdoor education movement and emerging movements responding to COVID-19. Discussion considers the polylogic of local communities that work to inspire, enable, and sustain commitments to campus-based outdoor learning.

Traditionally, public and private schools alike have separated outdoor education from formal education (Adkins & Simmons, 2002). Against this backdrop, utilizing an urban school campus to organize and sustain outdoor learning opportunities embodies an uncommon and noteworthy institutional commitment. We seek to characterize this commitment as an ontology in motion (Akkerman et al., 2021) by exploring both what outdoor learning currently is and what it is becoming within the institution as well as the community in which it is embedded. Therefore, as part of an ongoing partnership with a US K-8 charter school committed to campus-based outdoor learning, we explore the aspirational goal of organizing a majority of instructional time outdoors. This study specifically explores institutional and community stakeholders' perceptions of outdoor learning and well-being in order to (re)consider what matters to each group and in wider relation to shifting educational norms associated with COVID-19 mitigation strategies. We employ a descriptive strategy to characterize what at hand or about to happen as these outdoor learning commitments emerge and, in turn, to answer the following questions: (1) what are stakeholders' general perceptions of outdoor learning? (1a) How do these perceptions compare? (1b) how do stakeholders perceive outdoor learning as a response to COVID-19; and (2) how do stakeholders perceive their own current well-being in the midst of COVID-19?

Methods

This study reports efforts to attune to what is happening and what matters in the present (Akkerman et al., 2021). Campus greening represents a meaningful movement in motion that involves both physical environments and social constructs like well-being. To understand stakeholder perceptions of taking learning outside, a survey of internal and external stakeholders examined their perceptions of outdoor learning and community well-being.

We developed and distributed an online survey via emails to all internal school stakeholders (e.g. parents, teachers, admin) and a sample of external stakeholders who live in the three zip codes nearest the school. The survey generated data about demography, outdoor learning, nature relatedness, and well-being. We developed outdoor learning items based on the relevant literature. We utilized validated scales for nature relatedness (Nisbet & Zelenski, 2013) and well-being (Stiefel et al., 2020), the latter of which was created in response to COVID-19. Fifty-one adult internal stakeholders (6% response rate) and 36 adult external stakeholders (4% response rate) responded. Meanwhile, 201 students also responded (55.8% student response rate). For analysis, we generated descriptive statistics for all RQs and ran independent samples t-tests to compare perceptions (RQ1a).

Results

In general, a majority of all stakeholders perceived benefits to outdoor learning (RQ1) (see figure 1). We note that participants unanimously responded that outdoor learning is moderately to extremely effective at promoting social and emotional well-being. Similarly, respondents agreed a little (25.3%) or agreed strongly (67.5%) that students who participated in outdoor learning would build positive social and emotional well-being. We also sought to describe the influence of COVID-19 on participants' perceptions of outdoor learning (RQ1b), and found that 82% of participants somewhat agreed (14%) or strongly agreed (68%) that they would support campus-based outdoor learning. An independent samples t-test found no significant differences between internal and external stakeholders on this question, demonstrating a strong, shared perception of immediate and direct relevance.

We also compared the positions of different stakeholder groups on outdoor learning in terms of its effectiveness and influence on student outcomes (RQ1b) (see Figure 1). With respect to effectiveness, responses suggest general stakeholder

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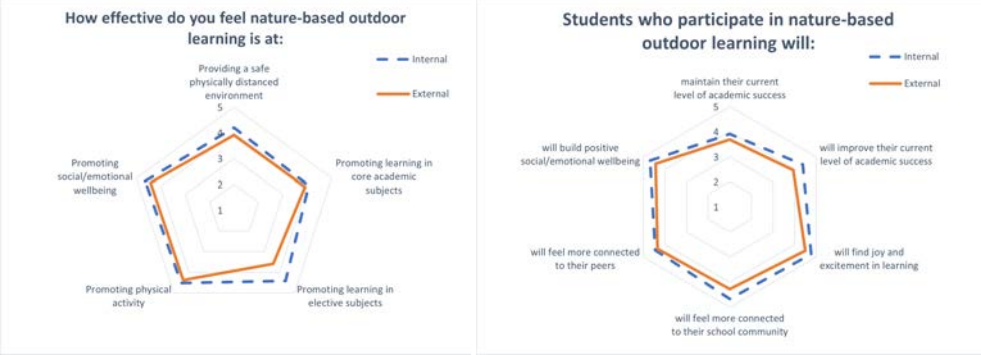
alignment. An independent samples t-test found significant differences for one aspect only--the effectiveness of outdoor learning to promote learning in elective subjects ($p<.001$)--which often reflects differences in relation to barriers (e.g lack of technology). With respect to student outcomes, responses again suggest general stakeholder alignment around three positive student outcomes. However an independent samples t-test found statistically significant differences ($p<.05$) among stakeholders with regard to increasing students' current level of academic success and students feeling more connected to their school community.

As a final consideration, we examined individual well-being (RQ2) and found that adults generally labeled their wellbeing good (internal 64% thriving, 0% suffering: external 56% thriving, 0% suffering). Meanwhile, student results (35% thriving, 6% suffering) suggest stronger adverse effects associated with the pandemic. The immediate and direct relevance of outdoor learning cannot be understood apart from a sense of well-being anchored to ongoing health threats and pandemic mitigation.

Figure 1

Internal and external stakeholder perceptions of campus-based outdoor learning effectiveness and student outcomes



Discussion

This study represents an initial, methodic approach to listening and learning from stakeholders as their local school makes meaningful movements towards outdoor learning and the results establish a pre-scene that accompanies the school's commitment to "take it outside" by greening campus-wide outdoor infrastructure. Results demonstrate strong, positive alignment on campus-based outdoor learning both as a part of formal education and as an influence on physical activity and well-being for students, particularly in relation to COVID-19. These preliminary findings are promising but also remain limited. First, a small sample size, particularly for external stakeholders, precludes generalization about community perceptions but results justify recruiting more participants in subsequent implementations. Second, while the survey results are consistent with a meaningful movement in motion, items written by researchers, risk objectifying this movement and can be qualified locally through a complementary ethnographic approach to understanding the community context, which we consider in closing.

In conclusion, Akkerman et al. (2021) underscore that an ontology in motion must attend to participants' positions, purposes and possible futures at specific points in time (actuality principle). We conjecture that stakeholder perceptions about what matters in relation to (post-)pandemic schooling does not unfold exclusively in a normative space of outdoor learning, but rather in the polylogic space of local communities that are continually in motion, amplified by COVID-19-related challenges (cf. Leander, 2002). As an effort to attune to what is happening and what matters presently for these stakeholders, this study considers multiple logics that work to inspire, enable, and sustain commitments to campus-based outdoor learning.

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An Adaptive, Agile Learner-Centered Computer Science Curriculum Design Approach Based on Deep Knowledge Tracing

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Abstract: While the focus of the curriculum is on the students, their voices are rarely heard in the creation or adaptation of the curriculum. It is often impractical and difficult to try to address the needs of each student in a single curriculum. With the use of Deep Knowledge Tracing (DKT), we propose a learner-centric curriculum design that is adaptive and agile, performing interventions on an individualized basis.

Introduction

A curriculum should enable learners, teachers, and managers to know and fulfill their obligations in relation to the programme or course (Grant, 2019). Yet, as the central focus of the curriculum, student voices appear to have little impact on its design or adaptation (Jagersma, 2010). Though students may submit suggestions through course evaluation questionnaires, it is unlikely that such adjustments will be made in time and on a personalized basis. This paper proposes an adaptive and agile approach to learner-centered curriculum design. Following the assessment of specific learning objectives, the curriculum is then adapted according to the student's learning model, which is determined by pre-instructional and post-instructional tests. We implemented our technique using Deep Knowledge Tracing (DKT) on an online course study platform for several undergraduate courses in Computer Science (CS). Our design approach will incorporate students into the curriculum design process, develop a study plan tailored to the needs of the individual student, and provide educators and administrators with an increased understanding of the design and instructional methods of the courses.

Theoretical background

Student Voice

The importance of student voice has been demonstrated both by the role of students in learning processes as well as the positive correlation between student voice and better academic performance (Jagersma, 2010). The Curriculum-ideas-Analytics (CiA) program, for example, uses Knowledge Forum and text mining tools to navigate and incorporate student voice into curriculum design (Teo et al., 2021). However, despite the success of existing approaches in identifying issues from students' voices, few of them suggested practical approaches to improve current curricula. Additionally, students' suggestions are sometimes difficult to articulate precisely.

Adaptive Learning and ACT Theory

Adaptive learning, or intelligent tutoring, uses computer algorithms and artificial intelligence to orchestrate the interaction with the learner and deliver customized resources and learning activities to address the unique needs of each learner (Kaplan, 2021). The theoretical basis of adaptive learning is ACT theory, which holds that cognitive skill acquisition involves the formulation of thousands of rules-relating task goals and task states to actions and consequences (Anderson, et al., 1995). ACT-based intelligent tutoring applications such as Cognitive Tutors for Mathematics have been prevalent in thousands of US schools (Ritter, et al., 2018).

Deep Knowledge Tracing (DKT)

Knowledge Tracing (KT) is a strategic approach in which machines are employed to model the knowledge of a student as they interact with their coursework. As one of the most prominent KT approaches, Deep Knowledge Tracing (DKT) makes use of Deep Neural Networks to simulate a student's learning behavior and achieves significant improvements in prediction performance over traditional KT models, such as Bayesian Knowledge Tracing (BKT) (Piech et al., 2015). DKT offers greater modeling capability for complex cognitive processes, and it identifies one instance for all skills, whereas BKT identifies an instance for each (Montero et al., 2018).

Methodology

To illustrate the iteration of our methodology, we include three activities: pre-instructional quiz, instructional activity and post-instructional quiz in each module of the curriculum for a CS course *Introduction to C Programming*. During each iteration of curriculum design for a module, we follow four steps (Figure 1):

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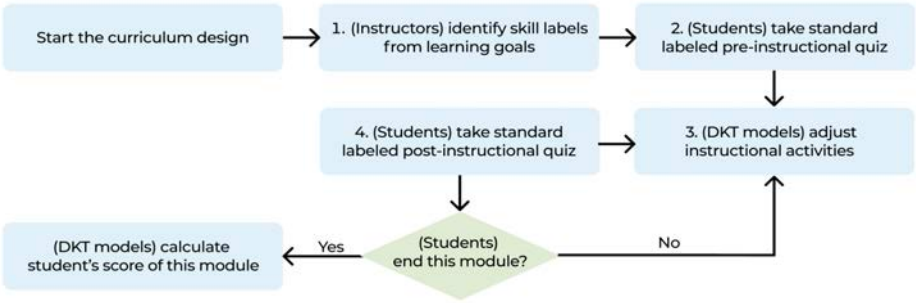
1. ***Identify learning goals and break them down into skill labels***. Labels are the meta inputs of DKT models. As the different learning goals are composed of one or more skills, we disaggregate each learning goal into skill labels, which act as a common unit of measurement and analysis.
2. Assess students via a standard labeled pre-instructional quiz. Questions in the pre-instructional quiz encompass all the skills that students will learn in this module, and DKT calculates a baseline model by using the student's mastery of each skill to recommend personalized instruction for the student.
3. Adjust the instructional activity using the data of pre-instruction activities. The instructional activity is categorized by skill and includes lectures, practice questions, and readings. A student who is weak in a particular skill will be assigned more instructional activities according to the DKT model.
4. Assess students via a standard labeled post-instructional quiz. There are different questions in the post-instructional quiz, but the difficulty and skill levels are the same as those in the pre-instructional quiz. Following submission of the quiz, DKT will update the student's learning model. Students are now presented with the option of completing this model's study and receiving their module score or engaging in the instructional activities suggested by the updated learning model and retaking the quiz. A participant is not restricted to taking this quiz a specific number of times, however, when they begin a new attempt, questions will be refreshed.

Figure 1
The Four-Step Iteration for Each Module



Ongoing and future works

Currently, we are creating skill labels and labeling existing activities and questions. In spring 2022, 200 undergraduate students who register for the class will use the system without DKT modeling and recommendation. Data collected from the study will serve as training data for the DKT algorithm in addition to the control group. We hope to undertake a curriculum design experiment with DKT in the fall semester of 2022.

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Real Work with Real Consequences in an evolving classroom context: Consequential and Connected STEM Learning

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Abstract: In this DBR study, we explore how one middle school STEM teacher designed for real work with real consequences by supporting students' agentive and productive participation in community-based engineering activities across virtual, hybrid, and face-to-face settings across multiple project cycles.

Introduction

This study focuses on innovative pedagogical practice informed by theories of consequential learning and rightful presence in STEM and enacted by one middle school teacher in an evolving classroom context across three project cycles. Specifically, we explore how the teacher sought to support students' agentive and productive participation in community-based engineering activity as Covid responses evolved in her district. The research question guiding our analysis is, *what can we learn about how to support real work with real consequences in classroom settings by examining one teacher's instructional practices as she aimed at engaging her students in real, consequential energy engineering across virtual, hybrid, and in-person STEAM classes?*

Drawing on Jordan et al. (2021), we believe that supporting real work with real consequences means designing for PDE with consequential and connected learning. Productive disciplinary engagement (PDE) (Engle & Conant, 2002) involves students in making intellectual progress on the real problems of a given discipline. To foster PDE, teachers should give students opportunities for problematizing disciplinary concepts and authoring solutions to problems they or others raise, hold students accountable to each other and disciplinary norms while providing resources and scaffolding. While PDE is a necessary component of real work with real consequences, it is not sufficient. Jordan et al. (2021) argued that the concept of PDE alone lacks the elements of consequentiality and connectedness needed in "risky design work" (p. 251). *Consequentiality* means that students are not invited guests into someone else's world, but are rather rightful participants and problem solvers in a shared world of real problems that they, the students, can have a hand in shaping and solving (Calabrese Barton & Tan, 2020). *Connected learning means* that learning and work is connected with community beneficiaries, community purposes and a "social infrastructure of care" (Greenberg et al., 2020).

Method

The context for this design-based research was a 7th grade STEAM class in a public Title I school located in a metropolitan area of the southwestern U.S. in a Latin@-dominant community. In the summer prior, the teacher, Ms. Catrell, participated in a research experience program focused on agrivoltaics (coupling solar power with food crops) and creating equity-oriented curricula that positioned youth with agency in community-based engineering projects. School closures left Ms. Catrell with both the disappointment of frustrated plans and the opportunity to plan responsively with the evolving contingencies of pandemic schooling. In fall 2020, the class met virtually. In spring 2021, learning was in a hybrid setting; the teacher met FTF students in the classroom and used Webex to bring virtual students in simultaneously. In fall 2021, a new cohort returned to fully in-person instruction. Data interpretation relied on analysis of recorded classroom interaction focused on the teachers' instructional practices within and across the virtual, hybrid, and FTF instruction (~19 hours), as well as interpretive analysis of artifacts. We first classified learning activities that met our criteria for "real work", those that coupled PDE with opportunities to plan and enact disciplinary projects that benefit the community beyond the classroom. We then analyzed the teacher's pedagogical actions, coming to see her expansive framing of the activities as central to her support of real work across the 3 settings (Engle et al., 2012).

Findings

We identified three instructional units in which episodes of real work were evidenced in coupling disciplinary activity and consequential and connected engagement across the virtual, hybrid, and FTF settings: Unit 1- Growing plants, Unit 2- Designing with PV panels, and Unit 3 - Imagining a solar future (See Table 1).

Table 1
Community-Based Engineering Activity Across Three Settings for Learning

Context	Disciplinary Activity	Real Work
At Home Fall 2020	● U1: Grew plants at home, conducted plant research and community ethnography on ● U2: Designed & built PV racking system from construction paper & found materials ● U3: Solar home hack design challenge; solar panel kits to prototype a device they chose	● In preparation for the garden they were planning for their community ● Prototypes for a system they planned at scale when returned to school ● Redesigned devices in their homes for energy equity and sustainability
Hybrid Spring 2021	● U2: Constructed models of 3D solar art installations inspired by architecture guests ● U3: Wrote solar futures stories set in a local park; support from guest speakers	● Created installations they imagined for neighborhood contexts ● Imagined futures in which community is inspired by their work
Face-to-Face Fall 2021	● U1: Designed, built and planted garden bed; analyzed and interpreted garden data ● U2: Built full-scale PV racking systems for garden; re-designed prototypes with build kits ● U3: Wrote localized solar futures comics	● Neighborhood high school collaborators helped graph data ● High schoolers acted as critical peers for STEAM students' video pitches and solar future comics

The three learning settings posed myriad challenges to Ms. Catrell's and the students' efforts. The three settings sometimes forced, sometimes afforded, ways for the teacher to position students as consequential learners. Ms. Catrell supported students' PDE through expansively framing activities as significant, not as discrete moments of learning but over the long term, in a variety of places, for a variety of people. As an illustrative example from the virtual setting, the challenges to doing real work at home occasionally forced Ms. Catrell to shift focus from the consequentiality of work in the here and now to the benefit of their current work to the community over time. In one conversation, she drew the students forth in time through the end of online learning, through the end of the school year to the anticipated end of Covid restrictions, encouraging them, "Next year…what you build and leave for people...[we're setting a firm] foundation so that what we do next year will be better than what we could have done this year. Can you imagine leaving that legacy?!" This move to help students envision a bright future they helped create seemed especially appropriate to facing the challenges of online learning, but could also be a strategic practice in any setting, strengthening the connections between present and future.

Discussion

Ms. Catrell's instructional moves suggest that expansively framing across time, places, and people supports real work with real consequences. However, studies of expansive framing to date have largely been concerned with creating encompassing contexts for transfer of intellectual knowledge and skills. Ms. Catrell's expansive framing went further. Through moves appropriate to each of the three settings, Ms. Catrell framed place not only as locations in which students would apply knowledge but also as contexts that could be transformed by knowledge. She framed people not only as audiences for student learning but also as partners and beneficiaries of student action. If we want teachers to cultivate rightful presence and consequential learning in their classes through real work, we should consider how we can support them in framing students as changemakers purposefully acting to benefit the socio-cultural and geographic communities where they live.

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Sociomateriality of apprenticeship learning in ecological fieldwork

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Abstract: Learning in and through fieldwork usually occurs as apprenticeship in a situated, real-life context. This Interactional Ethnography of an ecology fieldwork initiative in Hong Kong adopts a microethnographic discourse analysis (ME/DA) using video recordings from point-of-view (POV) glasses. Analysis of university ecologist and secondary biology student micro-interactions illustrates how the ecologist shuttled between two sociomaterial 'presences' weaving scientific reasoning with the physical manipulation of natural objects in the field.

Introduction

Learning in and through fieldwork usually occurs as apprenticeship in a situated, real-life context. Students in the field encounter authentic problems across a range of tasks supporting development of expertise across knowledge, skills, and dispositions in a community of practice (CoP). Sørensen (2009) argued, however, that this traditional framework does not fully account for how learning transpires as "knowledge emerges at different places" due to "the relation between circulating humans and immobile references" (p. 180). Studies in the materiality of learning are examining interactional and spatial "heterogenous assemblages" (Fenwick, 2015). This Interactional Ethnography (IE) addresses the 2022 ICLS call for "elucidating theories and processes of learning and teaching" with a microethnographic discourse analysis (ME/DA) of one ecology fieldwork session in Hong Kong involving secondary school students and university ecologists (Green et al., 2020). Ecologists view the skill of species identification as the basic prerequisite for understanding biodiversity and environmental issues; however, students can normally exhibit such skill only at higher taxonomic levels, not at species levels (Randler, 2008). Mentally relaying species names and morphology is a key goal for apprentice ecologists (Kontkanen et al., 2016). This study of the sociomateriality of fieldwork asks, *how do university ecology experts circulate between materiality and scientific reasoning to facilitate students' species identification in fieldwork and their thinking like ecologists?*

Methodology

IE is founded on sociocultural conceptualizations of learning *in situ*. This ME/DA study adopted Sørensen's (2009) concept of materiality as a lens to examine the spatiality of learning and "sensitively account" for the multiplicity of "forms of knowledge and presence" in a natural environment (p. 189). Analysis centers on an excerpt from the second of two field-trip components (mid-2021) in a place-based secondary biology initiative in Hong Kong. Field trips involved a rocky shore transect survey (~1 hour) at an intertidal section of a beach in close proximity to the school. Senior secondary students (n=21-22; 15-16 yrs) were grouped with 2-3 pre-assigned peers. Six university scientists specializing in rocky shore ecology (4 ecologists, 2 research assistants) led the fieldwork with two schoolteachers. Group materials included sampling quadrats (1 gridded, 1 blank), clipboards, record sheets, a species ID sheet, a graphical food web, magnifier, forceps, and small box. Participants consented to recording with four tripod-mounted static cameras at the backshore capturing transect group macro-interactions while personal, first-person point-of-view (POV) glasses and audio pens worn by selected group members and the university ecologists captured micro-interactions (~26 hrs total). Transcriptions (Cantonese to English) were reviewed by an interdisciplinary team of educationalists and ecologists. An event map (Figure 1) with spatial mapping of macro-level geographical distributions traced the historical roots and trajectory of a telling case study of one university ecologist and a senior secondary student co-constructing knowledge for identification (Table 1).

Analysis and results

The identified rich point (Table 1) illustrates a complex intertwining of talk and materiality. ME/DA unpacks synchronous, micro-level discourse and proxemics. It begins at 26:11 when the Cantonese L1 ecologist (pseudonym Jenny) picks up an *Echinolittorina radiata* (Obj 1) within the quadrat and, holding it in her palm, asks a group member (pseudonym Kelvin, Cantonese L1) to identify. He offers an incorrect response, "塔結節濱螺" (*Echinolittorina malaccana*). In the absence of a species ID sheet as a cognitive prompt (26:16), Jenny enters a deductive process to enunciate the differences between the two species of the same genus, initially by focusing on species-level features (surface colors of spires; aperture features; 26:18). She picks up a second organism (Obj

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2) located outside the quadrat as a contrasting example. Holding it in her fingertips in front of Kelvin, she points out specific species features. When Kelvin incorrectly identifies the organism again, Jenny moves it closer to his face (26:48) asking him to carefully 'read' the key characteristic of *Monodonta labio*. Assessing that he was yet to attain the identification skill at species level, Jenny finally redirects him to find his species ID sheet.

Adopting Sørensen's (2009) framing of three forms of presence (authority-subject, collective, agent), the 'authority-subject presence' as delineated by normative teacher-student power relations and reliance on a validated teaching instrument (species ID sheet) is transformed into 'agent' presence through the rhythmic intertwining of progressively closer proxemics aligned with schema-structured discourse. By engaging the student in the situated, discursive process of connecting features of discovered field organisms (Objs 1 & 2) to the expert's internal dichotomous schema for identification (Table 1; Figure 2), the ecologist facilitates the apprentice's (re-)performance of knowledge in collaboration with the expert (ibid). When this fails, she re-employs the standardized picture-based identification key to support 'imitation' (26:51), which is less cognitively challenging. By repurposing the classroom object in the field, they return to an authority-subject presence.

In the apprenticeship of ecology, fieldwork provides the expert a familiar space for creating different presences to facilitate learning and to assess an apprentice's proximal development. This ME/DA telling case study illustrates an ecologist 'shuttling' between two sociomaterial 'presences' by weaving scientific reasoning discourse with the physical manipulation of natural objects and learning artefacts in the field. It contributes to theorizing micro-processes of apprenticeship in ecology and supports the inclusion of university scientists in school-based fieldwork.

Table 1

Excerpt of discourse and associated video frame grabs of key event and rich point (J: Jenny; K: Kelvin)

Time		Discourse (translated from Cantonese)	Material assemblages
26:11	J	It is not the "塔" (*malaccana)* one/ do you have that paper ((species ID sheet))?/	
26:16	K	((I)) haven't brought it	
26:18	J	((laughs)) OK/ haha ((pause))/ the *Echinolittorina malaccana/* we just said is really triangle/ oh/ there is one here **((picks up organism))**/ this type **((holding between fingertips))**/ first/ it is much deeper in color/ also/ it has granules at the bottom/ and the whole of it is pointy/ but most of those here are this one ((showing an *Echinolittorina radiata*))/ it is round/ so/ if you turn this one open/ can see it is a bit pointy/	**On palm, rock level (Obj 1)**
26:44	K	*Monodonta labio*	**Between fingers, chest level (Obj 2)**
26:45	J	It is round here/ and then gets pointy/ what did you say?/	
26:47	K	*Monodonta labio*	
26:48	J	Does it have teeth ((*donta*))?/ Have a clearer look/ **((moves organism closer to K's face))**	**Fingertips, eye level (Obj 2)**
26:50	K	No/	
26:51	J	Yes/ so/ it is neither *Monodonta labio*/ it **is also** *Echinolittorina*/ but it is not *Echinolittorina malaccana*/ it is *Echinolittorina radiata*/ Yeah/ so/ therefore/ we need to fetch your paper ((species ID sheet))/	

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-Embracing Diversity and Connectivity for Entrepreneurship Education Innovation: An Observation Study of Co-Creation Pedagogy for Design Thinking Capacity Building Program of Higher Education

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Abstract: With the growing popularity of design thinking capacity building initiatives for entrepreneurship education, educators are striving to explore technology-supported learning environments and pedagogy to achieve the inter-disciplinary, easily accessible, and student-oriented entrepreneurship education innovation. The lingering effects of unfinished learning amid the COVID-19 and mixed-mode learning have become part of a new normal, we designed and implemented a novel learning framework to put co-design pedagogical structures in place that allow educators, students, and stakeholders to form new learning experiences and create innovation together. Through the case study we designed and implemented in three universities across different regions, we propose and investigate an approach that enables micro-level analysis of knowledge creation model for student's design thinking capacity building as well as macro-level understanding of learning dynamics for entrepreneurship education. This study presents a pedagogy-based template, and the findings have implications for the design of technology-empowered educational interventions and pedagogical innovation.

Keywords: Collaborative Learning, Entrepreneurship Education Innovation

Introduction

Under the global COVID-19 pandemic, policy makers, educators, and students are challenged by the high cost of this prolonged period of remote learning, from rising rates of student learning loss. The global pandemic has set back normal learning routine for all students. However, it is well noted that the pandemic dramatically fuels global growth of entrepreneurship program. This wide phenomenon is practically evident in higher education institutions.

Entrepreneurship education has become a strategically important part of the university learning experience as it engages students with pressing real-world problems, develops design thinking, and broadens their life skills both for academic and non-academic advancement (Hansen &Wyman, 2021). More specifically, how to equip learners with the design thinking capacities for knowledge creation and innovation has become a great challenge facing education. The OECD has undertaken national reviews of the impact of higher education institutions in supporting entrepreneurship. Recommendations include the encouragement of an entrepreneurial mindset, problem-based learning, enhancing interdisciplinarity, and linking students with the local, regional, and international community (OECD, 2019).

Gaps: "Can entrepreneurship be taught?"

Over the past two decades, universities provided students with business entrepreneurship course and experiential programmes alongside extra-curricular activities. However, business schools struggle to teach entrepreneurship because there are not unified standards in entrepreneurship courses, such as course content, anticipated learning outcome, program delivery. Researcher, educators, and students think there are ambiguity in standardizing the curricula as it is important to tailor entrepreneurship education to specific learning environment, business contexts, and community needs.

Entrepreneurship education has been embedded in a design thinking lens, as evidenced by the increasing number of that have roots in design element (Garbuio et al. 2018; Glen, Suciu, and Baughn 2014). Yet there is limited understanding and empirical research of the conceptual underpinnings and the implementation of such practices. Additionally, whether fully online, hybrid, or in-person with social distancing constrains, these learning formats represent a substantial departure from normal study year.

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Objectives and Research questions

To address the above learning, research, and practical gaps, this study seeks to explore these issues by examining the following research questions (RQs):

- RQ1: How student groups differ in design thinking capacity building learning mechanism during knowledge mapping, knowledge transfer and knowledge creation process in the three case studies?
- RQ2：How Co-Design pedagogy plays a critical factor in providing the collaborative learning environment from multi-stakeholders for student learning outcome achievement?

Scholarly Value

By explicitly linking co-design learning process to knowledge creation for entrepreneurship capacity building, this paper introduces a novel educational framework that provides a valuable pedagogical structure for entrepreneurship education. We provide theoretical links to build up a conceptual framework on one observation study featuring cross-sector Co-Design as participatory pedagogy and propose recommendations with a multi-stakeholder learning model which empowers learning pathway in future learning ecosystem and suggest a wider applicability so that the framework will be valuable also for other teaching and learning program for higher education as well as inform ongoing relevant program re-design and improvements. Our observation study focused on how students worked together with their program advisors, peers, and user groups to co-design a prototype from defining the real-world problem to deliver the value with the community members.

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Argumentative characteristics of equal and active participation in project-based learning

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Abstract: Equal and active participation is a desirable team state in the process of collaborative learning. In this study, we analyzed an argumentative aspect of equal and active participation in project-based learning: an 8-day online innovation workshop. Epistemic network analysis revealed that learners engage in elaborative discourse when they participate equally and actively. Furthermore, such time can be clustered into two types which have a distinct mechanism for facilitating participation.

Introduction

In project-based learning, learners collaborate in teams to work on projects in real-world contexts. Although the quality of collaboration severely influences the learning outcomes, learners are not always able to collaborate effectively, which raises needs to support their collaboration. One of the important aspects to analyze quality of collaboration is participation (Weinberger and Fischer, 2006). Over a course of project, the level of learners' participation fluctuates depending on their motivational, emotional, and cognitive states. At the team level, equal and active participation is desirable. Although existing research investigates and the process leading to equal or active participation and how it is sustained in other learning situations (Sinha et al, 2015), deeper understanding is needed particularly in project-based learning, where learners explore questions, generate ideas, and critique and improve their ideas through discussion. To this end, we investigate argumentative patterns in periods when teams participate equally and actively in an authentic case of project-based learning.

Methods

This study used video record of an 8-day workshop on innovative solutions to the challenges of a super-aging society, held at an off-campus educational program in Japan. There were 34 participants, including students and working adults, in six teams of five to six people. The entire workshop was conducted online using Zoom, Slack, and Apisnote. Apisnote is a digital sticky note system for information structuring (https://www.apisnote.com/).

We selected the second day and the seventh day for our analysis and processed 27 hours of video record to computationally identify the start times and end times of each speaking turn, and manually transcribed them. Next, the entire period was divided into 3-minute segments, and the amount of speaking time and the number of turn-taking of each team member in each segment were calculated. We define an equally-participating segment (ES) as a segment where coefficient of variation of both the amount of speaking time and the number of turn-taking among team members are below median of those among all segments. Similarly, actively-participating segment (AS) are defined as a segment where sum of both the amount of speaking time and number of turn-taking among team members are above median of those among all segments. There were 46 segments that are both ES and AS (equally-and-actively-participating segments, EAS), which accounts for 8.3% of the whole segments.

Then, we chose 30% of all segments which include all of the EAS and coded the utterances in these segments for the epistemic network analysis (Shaffer et al., 2016). We employed coding scheme of Kuhn et al (2020) with modification to adjust to our data, which includes Agree, Counter, Claim, Clarify, Elaborate, Elicit, Socio-emotional interaction and Residuals. We compared EAS and other segments to clarify differences in argumentative characteristics between them. Besides, we clustered and compared EAS based on coding results using k-means algorithm with silhouette approach for identifying the ideal number of clusters.

Result and Discussion

As shown in Figure 1 left, there was a difference between the EAS and other segments on the X-axis, which is statistically significant ($U = 4267$, $p = 0.00$, $r = -0.5$). Links between Elaboration and other codes were particularly strong in EAS. This means that members listen to each other and make new claims based on the other's claim in EAS. This type of utterances might help to maintain the attention of more members towards ongoing discussion topics by rewarding and integrating their contribution, which facilitates equal and active participation of team members as a result.

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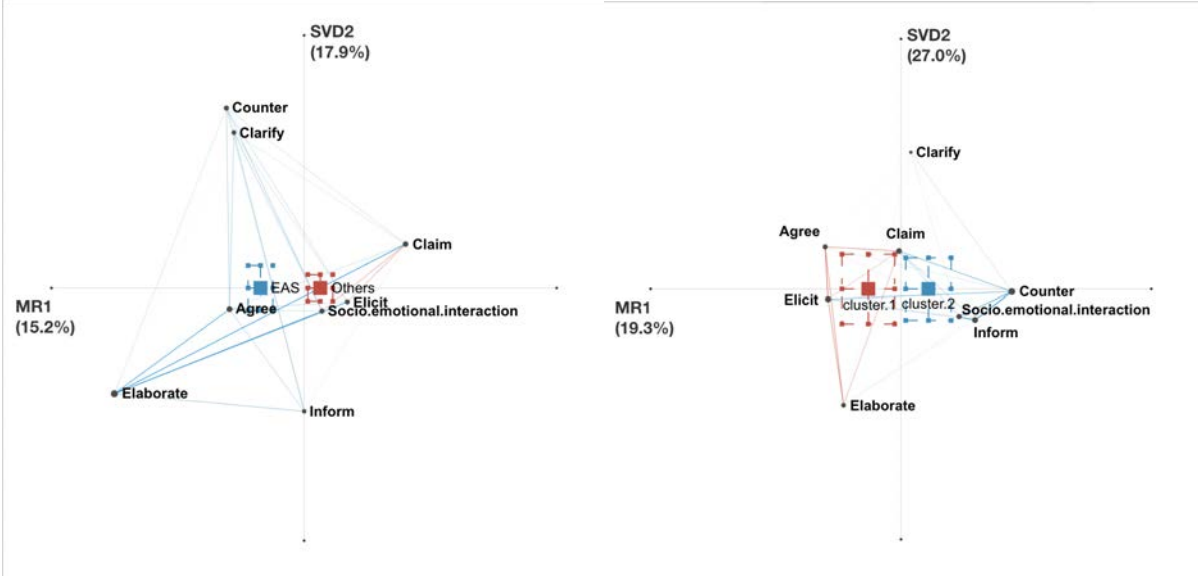
Furthermore, k-means clustering of EAS resulted in two clusters (average silhouette coefficients = 0.19). The difference between two clusters is shown in Fig.1 right, which is statistically significant on the X-axis (U = 409, p = 0.00, r = -0.56). In cluster 1, links between Agree, Elaboration, and Elicitation were strong, while in cluster 2, links between Counter, Inform, and Socio-emotional interaction dominate. In cluster 1, some members tried to build a common understanding of ongoing topics by confirming their perceptions or tried to make consensus through questions eliciting others to share their opinion (Elicit and Agree). These were followed by new claims (Elaboration) based on the common understandings or the consensus that they had just made, advancing discussion rapidly as a result. On the other hand, in cluster 2, teams typically make critical arguments (Counter) while utilizing supporting facts (Inform) or laughing (Socio-emotional interaction) to form friendly moods. In this way, team members could express their critical views which provoke others' explanations while avoiding interpersonal conflict. Stories of both clusters seem to be related to the equal and active participation of teams. Attentional and coordinative factors seem to be at play in both clusters; an advance in a topic which induces new consideration and development of common understandings or consensus which ensure common grounds in cluster 1, and a critical view which requires explanation and supporting evidence and a friendly mood which maintain an interpersonal relationship in cluster 2.

Figure 1

The comparison plot between EAS and other segments (left) and between clusters of EAS (right)



Our initial result suggests a mechanism that equal and active participation occurs and sustains in project-based learning. As well as increasing cases for validating our findings, future works will compare teams that experience more or less of certain types of equal and active participation and reveal underlying factors explaining their differences, which leads to a concrete way for supporting collaboration in project-based learning. Also, the effects of experiencing different types of equal and active participation for learning outcomes are of interest. In our case, teams that experienced the cluster 2 type of EAS more received higher evaluations for their final products from participants in the workshop, which suggests different effects among types of equal and active participation.

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Developing Computational Thinking via Knowledge Building

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Abstract: This study explored the impact of knowledge building pedagogy within a collaborative learning community on students' understanding of computational thinking (CT). The participants were 101 middle school students who attended a 6-week course to work on Scratch programming guided by knowledge building principles. An international challenge test on computational thinking called "Bebras Challenge" was employed to evaluate students' CT. Primary findings indicate that students significantly improved their CT skills in the end of the course.

Introduction

Computational thinking (CT) involves adopting a set of problem-solving skills and techniques which software engineers use to design programming code, including the core competence to break down complex tasks into simpler components, algorithm design, pattern recognition, generalization and abstraction (Wing, 2006). While integrating CT has already in K-12 school in many countries, it is still at its early stage in Taiwan due to lack of innovative teaching and pedagogy. Under this context, a community-based learning site, MIT's Scratch, has become one of the popular learning environments to develop learners' CT in K-12 courses in Taiwan recently. Accordingly, a recent call for education reform in Taiwan has begun to transform curriculum guidelines by asking teachers to provide more learning opportunities for students to learn together collaboratively. Learners thus are expected to contribute collaborative ideas and work creatively in their community. While using Scratch as a programming learning context can help learners develop CT (Zhang & Nouri, 2019), educators in Taiwan are still on their ways to explore diverse pedagogical approach and to engage students in developing CT competency in a collaborative learning environment.

In this study, we adopted knowledge building pedagogy and engaged students as a knowledge community (Hong & Scardamalia, 2014) to work on Scratch programming via collaborative grouping and re-grouping strategies. Through interactive discussion and mutual assistance among group members, students were guided to collaboratively complete the programming problems/tasks assigned, learn problem-solving skills and develop the core competence of computational thinking. By facilitating the whole class as a knowledge community, we investigated if such learning environment can foster the development in CT.

Method

Context

Participants were middle school students (n=101) from two classes (7th grade and 8th grade) in an urban city in Taiwan. They enrolled in a 6-week course called "Scratch Programming" with 45-min per week. One researcher was the primary facilitator to lead the course. Under the guidance of knowledge building principles of "real idea, authentic problem" and "idea diversity" (Scardamalia, 2002), students were asked to work in small group and to work on guiding examples via Google Form. They then solved the assigned programming tasks while guiding by the principle of "real idea, authentic problem: Then they exercised the CT by translating group-generated and -shared ideas (as guide by the principle of "idea diversity") into practice to test out their programming ideas on the Scratch platform. Afterwards, they documented group results in Google sheet. Specifically, students were in homogenized grouping of 3 to 4 people in a group based on the pre-test results of Bebras Challenge.

Data

Bebras Challenge was the instrument to evaluate CT performance. We conducted it at the beginning and the end of the course to collect pre- and post- test for quantitative analysis. Paired-sample t-test was performed to examine whether there was any significant difference between the pre-test and post-test. There were 10 single-choice questions to evaluate students' the core competences of computational thinking and problem-solving skill, such as the ability to break down complex task into simpler components, algorithm design, pattern recognition, pattern generalization and abstraction. The scoring rubrics including 3 points for correct answers, with 1 point being deducted for wrong answers, zero points for unanswered questions, and the maximum score was 30 points.

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Result

Table 1 shows the overall results. It was found that after engaging in group-based collaborative knowledge building for 6 weeks, regardless of the grades, all the participants' understanding of computational thinking significantly improved from pre-test to post-test (t=-5.018, p<.01). Table 2 further shows that there is a significant difference between 7th and 8th grade students, with 8th graders significantly outperforming the 7th graders in the pre-test scores (t=-3.830, p<.001). This is due to the fact that 8th graders were more knowledgeable with one more year of schooling ahead. But there is no significant difference in the post-test (t=-1.157, p<.243), indicating that the 7th graders were able to benefit more from knowledge building guidance than the 8th graders. In brief, after this course, all participants demonstrated a more informed understanding of computational thinking.

Table1

Understanding of Computational Thinking (Paired-Sample T test)

Grade	N	Pre-test		Post-test		t-value	Sig. (2-tailed)
		Mean	Std. Deviation	Mean	Std. Deviation		
7th and 8th	101	10.25	6.128	14.74	9.056	-5.018	.000***

*p<.05 **p<.01 ***p<.001

Table2

Understanding of Computational Thinking (Independent-Sample T test)

Grade	N	Pre-test		t-value	Sig. (2-tailed)	Post-test		t-value	Sig. (2-tailed)
		Mean	Std. Deviation			Mean	Std. Deviation		
7th	46	7.87	5.463	-3.830	.000***	13.59	9.872	-- 1.157	.243
8th	55	12.24	5.984			15.71	8.281		

*p<.05 **p<.01***p<.001

Conclusion

In summary, the findings indicate that students improve their understanding the concepts of computational thinking after the study. Prior to the course began, 7th grade students have not learned the method of computational thinking to solve problems while 8th grade students have already had a year of learning. Therefore, there was a significant difference between 7th and 8th grade students in the beginning. However, after the six weeks course, students have improved their core competences of computational thinking. Finally, there is no significant difference in the post-test. In conclusion, after engaging in knowledge building pedagogy for six weeks, students demonstrated a significant improvement in the core competences of computational thinking. In future research, we will focus on "how" students changed and further analyze their collaborative learning process during this course.

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International Society of the Learning Sciences

Reading Minds: Exploring Relationships between Sensor-Data and Self-Reported Cognitive-Affective States of Learners

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Abstract: Cognitive-affective states (CASs) strongly affect learning outcomes. Therefore, learning systems need to be CAS-aware to truly cater to learners' needs. In this study, we explore the possibility of multimodal sensor data as reliable indicators of learner CASs. Data collected will include skin conductance, heart rate, skin temperature and global gaze properties, which will be compared with self-reported CASs of learners. Linear mixed models will be applied and results will be presented at the conference.

Introduction

In this paper, we submit a multimodal approach to detect cognitive-affective states (CASs) in learning environments. This is crucial because learning outcomes are greatly influenced by the cognitive affective state (CAS) of the learner (Pekrun, 2006). Specifically, positive emotions such as enjoyment and pride are associated with high levels of engagement and high learning outcomes, whereas persistent negative emotions such as anxiety and boredom are strongly related to low learning outcomes (Pekrun, 2017). Therefore it is pertinent that today's intelligent learning systems take into account a learner's CAS while providing support or feedback. For this to be possible, there must be a way for a system to actually perceive a learner's CAS. This is the need our study aims to address.

One obvious way of ascertaining CASs is to always ask the learner. Naturally this is obtrusive to the learning experience. Ideally an intelligent learning system would, by employing discreet means to collect information from various modalities, build a reliable impression of a learner's CAS. In other words, the key to a highly perceptive learning system is unobtrusive multimodal data collection. Our research project explores precisely this with a focus on sensor technology that can be deployed in real-world classrooms. Therefore we work with data that can be collected via pervasive computing technology – portable computers, unobtrusive sensors and wearables. In this study, we focus on skin conductance, heart rate, skin temperature and global gaze features. This is because past studies have found strong relationships between stress during difficult tasks (Brouwer et al., 2018), emotional arousal (Jindrová et al., 2020) and skin conductance. Research also finds that changes in heart rate and skin temperature may indicate cognitive-load (Larmuseau et al., 2020). Moreover, gaze features such as fixations, saccades have previously been used to determine attentional or mind-wandering states (Hutt et al., 2017). In this study, we investigate whether (a combination of) these measures can give us a reliable (and fuller) picture of a learner's state. The possibility of discriminating between sustained positive and negative learner CASs is of particular interest to us. For example, low skin conductance accompanied by a large number of fixations could indicate an attentive low arousal state whereas the same accompanied by a low number of fixations could indicate an inattentive low arousal state such as boredom which in turn negatively affects learning outcomes (Pekrun, 2006). In essence, this is an exploratory study of the relationship between (combinations of) sensor data and CASs as described by self-reports.

Methods

Participants will comprise of 30 BSc Psychology students from the University of Twente. Participation will be voluntary and active consent will be obtained from all participants before the start of the experiment. Data will be collected via self-reports (described below), the Empatica E4 biosensing wristband (https://www.empatica.com/research/e4), Tobii Pro Fusion (https://www.tobiipro.com/fusion/), a screen based eye-tracker and a generic webcam. All participants will spend an equal amount of time doing three tasks. The first task will be to play Tetris (www.tetris.com). Tetris has been selected because it is an extremely popular and widely studied (Mayer, 2014) game that can bring players into a positive CAS of effortless attention (Harmat et al., 2015). The second task will be to repeatedly match pairs of two-dimensional shapes. The third task will be to "solve" a coordinate geometry puzzle. This will be a wild goose chase because the researcher will never accept an answer as correct. Based on pilot testing it is expected that participants will experience CASs that are positive high-

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arousal (Tetris), negative low-arousal (shape-matching) and negative high-arousal (coordinate geometry puzzle). It is also expected that the baseline (a relaxing music video) will induce a positive low-arousal CAS. The study will use a counterbalanced design for the three tasks to mitigate order-effects. A multiple baseline approach will be employed with 1 minute cooling off periods between tasks. At regular intervals during the study, participants will complete 4 self-report items:

1. The Affect Grid (Russel et al., 1989), a 1-item scale of CASs along two dimensions, arousal and valence,
2. a five-scale item, "This task is: 1) Too easy 2) Easy 3) Just right 4) Difficult 5) Too difficult",
3. a 7-scale item, "I am actively engaged in what I am doing. 1 (not at all) to 7 (very much)" (Kirtley et al., 2019), and
4. An open-ended fill-in-the-blank statement: "I am feeling __".

Results

Within-subject relationship between self-reports and physiological signals will be explored using linear mixed models while controlling for demographic data. Pairwise comparisons will be computed after having applied Bonferroni correction. Results will be presented at the conference.

Practical and ethical considerations

Detection of CASs is highly relevant because it allows us to consequently design intelligent learning systems that are tailored to the needs of each individual learner. A sensor based approach to CAS detection means that this 'tailoring' is informed by a user model that is updated dynamically during a lesson as opposed to the traditional approach of user profiling based on information known before a lesson (for example, sex, age, prior knowledge, race etc). We believe that this increases fairness in the artificial intelligence by mitigating human bias.

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Student Reflections on Data Investigations of Local and Extreme Weather: A Cultural Historical Activity Theory Perspective

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Abstract: This study analyzes middle-school students' reflections on working with large-scale scientific data to investigate local extreme weather using the digital tool CODAP. Drawing from student focus group interviews and Cultural Historical Activity Theory, we examine factors that appeared to impede or facilitate data science learning in a sample of rural middle schools.

Introduction

There is increasing demand for data science skills in modern science (e.g., developing climate data models). Data science requires the use of digital tools to manage, visualize, analyze, and communicate findings from extensive amounts of data (Hey, Tansley, & Tolle, 2009). Many argue that learning data science can lead to enhanced scientific literacy among the public (Ceccucci, Tamarkin, & Jones, 2015). Middle school students currently have limited exposure, however, to working with authentic large-scale data (Wilkerson & Polman, 2020). Our project has been collaborating with rural science teachers in northern New England to design and implement two curriculum units in which students investigate local extreme weather phenomena using large-scale weather data and the data analysis tool CODAP. Drawing on student focus group interview data, this study examines challenges and opportunities for integrating data science into rural middle-school science classrooms.

Theoretical Framework

We use Engstrom's (1987) Cultural-Historical Activity Theory (CHAT) to analyze students' science classroom contexts and factors that may impede or facilitate data science learning. CHAT suggests identifying the following activity components: *Subjects,* or the histories and characteristics of major participants; the *object,* or the activity's goals; *tools* or *mediated artifacts*, or the socially shared cognitive or physical resources; *rules and norms*, which govern social interactions; the *community,* or the group context; the *division of labor,* how responsibilities are shared; and the *outcome,* or the product of the activity. CHAT attends to the contradictions (i.e., conflicting ideas or experiences at the time of change or reform) and affordances of activity components to understand why activities may succeed or fail. Previous studies have used CHAT to understand how subjects' backgrounds and interests may shape scientific norms, rules, and practices and affect classroom activities (e.g., Saka, Southerland, & Brooks, 2009). Others have looked at contradictions in science teaching activities to gain insight into the culture and outcomes of specific programs (Roth and Tobin, 2002). Using CHAT, this study addresses the following question: What contradictions and affordances for learning data science are present in rural middle-school science classrooms when investigating local extreme weather?

Methods

Study participants were middle-school students (ages 12-14) from four U.S. rural schools in northern New England. Study data are from five student focus group interviews conducted in winter/spring 2021, each lasting 45-60 minutes with 2-4 students per group. All interviews were conducted through Zoom, recorded, and transcribed. Initial coding categories were based on CHAT components. Coded excerpts were analyzed using micro-level discourse analysis (Gee, 2010). For instance, microanalysis led to the following subcategories for Subjects: a) student academic background in data and b) student experiences with local weather phenomena. Themes were organized around contradictions and affordances.

Findings

Preliminary findings suggest that contradictions and affordances fall under four major themes: 1) building a local classroom data source, 2) digital tools for conceptual and epistemic learning, 3) prior student experiences/interests, and 4) shifting scientific and pedagogical norms. Below we provide an example of two of these themes—the first a contradiction, and the second an affordance.

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Building a local classroom data source

Students suggested that a challenge they faced in one activity was assembling a classroom data table with 14 days of weather measurements from each student. In each participating classroom there were students who did not complete their measurements (and therefore did not do their part in the class division of labor). A student lamented that incomplete data from his friends prevented them from achieving their goal of making data comparisons:

Researcher: What did you like about this activity, and what did you not like?

Student 1: One thing that most of us didn't really like is that when we were doing a class discussion about the day-before weather, some kids didn't actually write down the data, so we didn't have as much to compare.

Digital tools for conceptual and epistemic learning

Students suggested that CODAP is a tool that supports conceptual sensemaking and the norms of scientists and statisticians. The excerpt below illustrates how students used authentic scientific data and CODAP to make sense of data patterns, and how they draw on scientific and statistical norms to make a claim if weather is extreme.

Researcher: How would you say you decide if a weather event is extreme or not?

Student 1: Yeah, if you compare it to like the average temperature, and it's like what is low and what is above the temperature. So like yeah, it'd be extreme.

Student 2: Yeah. Just comparing like the average temperature with the wind speed to the typical weather. That would tell if it's extreme or not.

Researcher: Was that helpful when looking at the thirty-year averages versus the storm?

Student 1: Yeah, I think the CODAP really helped with the thirty-year graph.

Discussions and Conclusions

Integrating authentic data practices in science classrooms goes beyond "cognitive skills and statistical algorithms" (Radinsky, Tabak, & Adach, 2021, p. 1072). It requires attention to social-cultural dynamics within classroom cultures and the histories students bring to their learning activity. Because daily-life decisions and future careers are becoming more data dependent, learning scientists are exploring effective ways to integrate data in school curricula. Building innovative, digital tools and meaningfully designed educational activities are crucial steps. However, researchers need to understand how students engage with these tools and view the importance of data for their lives and communities. We contribute to these efforts by offering a CHAT perspective for analyzing students' reflections, which can help reveal unseen social, cultural, and historical factors when learning data science skills in a weather science context.

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Opportunities and Challenges for Enacting Equity and Justice-centered CS Learning In "Drag vs. AI" Workshops

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Abstract: We present initial reflections from a study investigating how learning materials and moment-to-moment interactions can enact equity and justice-centered learning in youth STEAM programming. We explore these questions in the context of *Drag vs. AI*, a library workshop in which a professional drag queen leads teens in an exploration of facial recognition technologies (FRTs) and drag makeup as a tool to subvert, fool, and refuse recognition. We are examining ethnographic data from workshops at two sites and plan to conduct follow-up interviews. We will share insights and reflections from our in-progress data analysis around the affordances and limitations of materials and interactions for justice-centered computing education.

Introduction and theoretical background

STEM and STEAM education that attends to power is an urgent and widely felt priority in the learning sciences. Scholars are designing and theorizing at this intersection with a variety of analytic approaches and learning contexts. Considering the growing role of big data in educational, housing, and employment opportunities, several studies have focused on critical data literacies, which allow people to understand, use, and produce data with critical orientations. This scholarship has established bias, exclusion, and discrimination in data representations as a generative topic for advancing critical data literacies among youth. However, there is a lack of queer, trans, and intersectional approaches to research around carceral technologies and algorithmic bias (Paré, 2021, pp. 12-16).

We build on justice-centered computing education research by exploring learning in a drag queen-led STEAM workshop that engages teens hands-on with makeup as a medium to fool FRTs, framed in critical discussions of FRT systems. In *Drag vs. AI* (Algorithmic Justice League, n.d.-a) participants learn about FRTs and use drag makeup techniques to camouflage themselves and refuse classification. The website where participants can test how AI guesses their age, emotion, and gender is a platform for embodied experimentation with AI, where teens can build on and refine existing, intuitive youth practices for reverse-engineering algorithmic literacies (Algorithmic Justice League, n.d.-b). We modified the workshop to include local connections (e.g. a new statewide digital ID app) relevant to participants.

Research questions

With curiosity about how *Drag vs. AI* workshops might support critical, justice-centered CS learning at the intersection of technology and power, we explore the following questions: (1) How were equity and justice-centered theories and pedagogical approaches to CS learning enacted through materials and moment-to-moment interactions in *Drag vs. AI* workshops? (2) How can queer values, epistemologies, and pedagogies emerge and support justice-centered CS learning? (3) How can the design and facilitation of *Drag vs. AI* support transformative sociotechnical knowledge production and identity development?

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Figure 1

Workshop host Cardi Acarrest presenting on facial analysis.

Data collection and analysis

Ours is the first empirical study of *Drag vs. AI* over two workshop enactments, one at a public library and one at a queer youth resource center in the Western US (see Figure 1). We recorded audio, video, and fieldnotes during workshops. After each workshop, we recorded memos and audio of debrief sessions with facilitators, including community partners. In our data analysis, we are applying inductive ethnographic approaches and qualitative coding to better understand how justice-centered CS education was supported in workshops.

In-progress analysis has yielded insights into how participants developed critical algorithmic and data literacies while manifesting queer values and epistemologies through their interactions with the AI platform and moment-to-moment interactions. In our next steps, we plan to investigate how drag pedagogy (Keenan & Hot Mess, 2020) can support theoretical elaborations and practical learning design considerations of justice-centered CS learning.

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CT for All?
Computational Thinking in Danish Language Arts

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Abstract: This poster presentation discusses ongoing, design-based research that investigates how middle school pupils use computational thinking strategies as part of their collaborative effort to write interactive stories, using the online tool Twine within the school subject of Danish (L1). A tool, specifically designed to support pupils' processual text production is introduced, and its affordances and constraints as a structuring resource, supporting the pupil's computational participation and literacy skills, are discussed.

Introduction: the basic challenge

This poster serves to 1) foster a conversation in the learning sciences community around materiality as a design constraint regarding pupils' computational thinking strategies, 2) document a design for learning computational thinking beyond a STEM context in primary school. 3) initiate a discussion of the reach and applicability, beyond computer science, of computational thinking. A key motivation for utilizing tangible things in designs for learning CT is the need to negotiate two ideas: That CT is an abstract mode of reasoning that can be applied in a wide array of settings beyond computer science (Denning & Tedre, 2019) and the idea that learning is situated (Lave, 1988; Dohn et al, 2020). The use of tangibles supports the latter point; the integration of tangibles with use of software supports CT as a more abstract form of knowledge. The use of CT beyond computer science can be framed as a matter of a new form of literacy that is fostered and exercised in different avenues (Kafai & Proctor, 2021), or as a matter of designing for transfer or transformation of knowledge and skills (Dohn et al, 2020).

Theoretical foundations: Computation, transfer and situativity

"Computation" can be understood as a mechanical process being performed on symbols for concepts as well as symbols for numbers. The manipulation of symbols for concepts has its roots in Ramon Llull's *Ars*, the numerical in Leibniz's thinking, and they were synthesized in Boolean algebra (Hansson, 2018). The conceptions share the notion that computation is a certain "mindless", "mechanical" or "procedural" feature of thinking (Hansson 2018). Being mechanical, the task of thinking is transferred from a human to an external, physical piece of equipment or agent. Two aspects of computation are emphasised in this design experiment: The manipulation of concept-words rather than numerals, and the externalisation of thinking to something physical. This, in turn, is intended to facilitate pupils' computational literacy.

Both traditional approaches to transfer (Gentner et al., 2003) as well as traditional conceptions of information emphasise the abstract character of transfer and information, respectively. In contrast, recent developments, both in learning (Levi, 2009) and understandings of information (Dourish, 2017) have emphasised the importance of the material aspects of learning and information. As Dourish suggests, materials produce interesting constraints in computer science, and we follow Levi and others in proposing that they are equally of relevance to learning. The close integration of physical manipulation of concept-representations with use of software is motivated by these more recent developments.

The empirical study

The Design-Based Research (Amiel & Reeves, 2008) reported on here takes place in two Danish middle schools with pupils aged 10-12 (grade 4 and 5). A pedagogical design and a specifically designed tool were tested. At this point in time the 1st iteration is completed, and 12 groups (2-3 pupils) were followed and studied. 6 groups were videorecorded and materials that were produced have been collected and preliminary analysis of recordings have been conducted.

First, the pupils were introduced to the beginning of a fictional text, *The Horrible Hand*. The story was read aloud in class as a starting point for the pupils to continue developing their own stories. To aid the pupils in this task, a tool (fig. 1) was developed consisting of 19 wooden pieces (5 large and 14 small), with different motives engraved into them. On the backside of the 5 large pieces, the pupils could access small excerpts of the original story (via a QR code to a homepage) picked by the designers. The pupils could use these as inspiration

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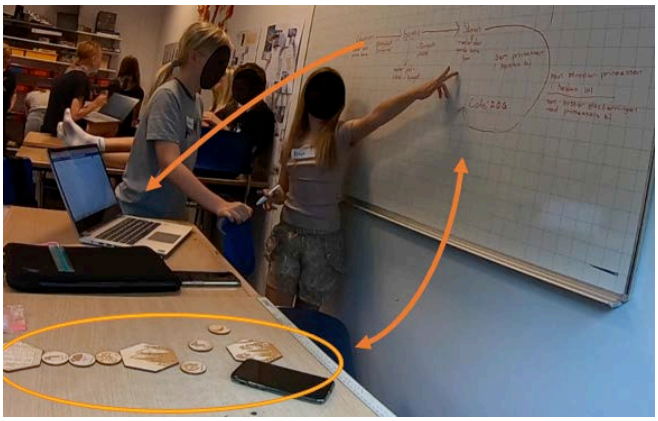
but were not forced to do so. Lastly, the pupils were asked to produce an interactive story in the open-source application called Twine (twinery.org).

Figure 1: Figure 1: The wooden pieces are organized on the table, where they mediate the pupils' structuring and negotiation. They use the whiteboard as further support before writing in Twine.



Preliminary findings and discussion points

Finding 1: The tangible materiality of the wooden pieces (fig. 1) constrain the pupil's construction of the story to step-by-step sequences, both allowing them to decompose their ideas into smaller parts as well as arrange and re-arrange elements of their story in a meaningful way. Finding 2: Further, the wooden pieces foster opportunities for pupils to develop new strategies for structuring the narrative in their stories. It points to a positive impact on the way pupils can survey and organize their text and adds both concrete and embodied experience and new forms of reifications (Wenger, 1998) to their negotiations of the different elements of their stories. Finding 3: The tools (B) place requirements on the pupils' abstraction and literacy skill. Preliminary findings suggest that although the tools are material representations and constrain the writing process into smaller parts, some pupils need support. The question remains whether design solutions can be made, that to a greater extent guide pupils and scaffold their learning process.

Early indications for the next iteration of the design suggest that less firm scaffolding, carried out by the teacher, in the initial stages of the writing and ideation process increases the pupils' creative use of the wooden tools, resulting in more diverse and well written products.

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International Society of the Learning Sciences

Draw-a-Computer-Scientist-Teacher? Designing for expansive identities in undergraduate Computer Science

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Abstract: This poster investigates integrating teacher identities with disciplinary identities in the domain of computer science. Initial findings from a study analyzing undergraduate perceptions of both computer scientists and teachers are presented. Drawing on socio-cultural theories of learning and identity, we argue, and our findings suggest, that surfacing perceptions of both computer scientists and teachers is a productive exercise to reveal areas of commonality and contradictions to overcome in our designs for learning in both domains.

Introduction

Multiple rationales support increasing access and expanding competencies in computational thinking and literacy across the K-12 curriculum (Blikstein & Moghadam, 2019). Much of the work on teacher learning related to this domain has focused on designing professional development for teachers to better integrate these computer science (CS) skills into their classrooms (e.g., Grover & Pea, 2018; Yadav et al., 2016) with the skills themselves seen as having significant value independent from the CS disciplinary domain in which they originated. While encouraging teachers to include CS skills in their teaching practice is desirable, we also think more CS disciplinary experts ought to recognize how teaching supports an extension of their disciplinary practices (Weidler-Lewis, DuBow, & Kaminsky, 2017.) Our research is broadly interested in how to best support the integration of disciplinary identities with teacher identities and blends Learning Science topics of disciplinary learning, identity, and the fields' nascent focus in teacher learning. We are primarily interested in creating novel entry points into teaching from disciplinary domains both for disciplinary experts and for undergraduate students. We are currently in the process of designing complementary undergraduate learning opportunities to support students' pathways into disciplinary practices, such as CS, and into teaching in K-12 settings.

An impetus for the current work-in-progress study we are reporting here, came from the findings of data collected in introductory undergraduate CS courses from the "draw-a-computer-scientist" activity (Manzo, Doore, & Harmon, 2019). Building on the popular draw-a-scientist task (Chambers, 1983), the computer scientist version helps educators better understand student stereotypes of who they think becomes a computer scientist, and then shape curriculum and instruction to combat problematic stereotypes and increase representations of who is and can be a computer scientist. Our data included student responses to the task to list three words that come to mind when thinking of a computer scientist. Given our interest in developing supports for undergraduates to identify with and pursue both teaching certification and CS degrees, an open question emerged that we are now seeking to answer: *What are the similarities and differences between how undergraduate CS students describe computer scientists and how they describe teachers?* We argue answering this question will help us see opportunities to strengthen CS majors' pathways into teaching as well as the potential contradictions that may need to be overcome in students' perceptions of these disparate identities.

Theoretical Perspectives

We take a broadly sociocultural approach to learning, acknowledging identities play a significant role in our ability to learn and act in the world and in disciplinary ways (e.g., Gee, 2000). We see our role as undergraduate educators to create possibilities for students to see themselves as future teachers and CS professionals by providing them with "trajectories of identification" (Polman, 2010) into these domains. While we recognize the relationship between a teachers' disciplinary identity and how they engage pedagogically as a teacher (Luehmann, 2016), we prioritize expansiveness insofar as we do not prescribe any one way of being a disciplinary or teaching expert, but rather embrace a multiplicity of identities in and across domains. We believe such a perspective is necessary if we are to increase representation and access into disciplines that have historic patterns of identity association (e.g., computer science is often characterized as white and male.)

Methods

This study is a work-in-progress that builds on our prior work (Manzo, Doore, & Harmon, 2019). In our current iteration, we are administering the modified draw-a-computer scientist test used in our previous study that now adds the questions: *what adjectives best describe a teacher* and *what adjectives best describes a computer scientist teacher* in addition to the questions on the original draw-a-computer scientist test (Martin, 2004). We will have

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data from four introductory computer science classes at a college in the American northeast with an expected participant count of 100. For our purposes here, we have analyzed data from two classes (participant $n = 39$). We will conduct a more thorough analysis of the complete data, including word associations and pairs across the participants. Here we are presenting frequency percentages of terms to look for similarities, patterns, and contradictions across the terms.

Findings

Initial examination of our current data provides compelling evidence that this is a generative activity to think about the ways in which our students perceive both teaching and computer science as well as their intersection. Table 1 shows the top three terms for how students perceived computer scientists, teachers, and computer scientist teachers with the percentages of students using the term.

Table 1 *Top terms for computer scientists, teachers, and computer scientist teachers with percentages reporting*

Computer Scientist Terms	Percentage of Students	Teacher Terms	Percentage of Students	Computer Scientist Teacher Terms	Percentage of Students
Smart	25.6 %	Caring	30.8 %	Knowledgeable	23.1 %
Intelligent	20.5 %	Knowledgeable	28.2 %	Intelligent	17.9 %
Knowledgeable	17.9 %	Intelligent/compassionate	12.8 %	Patient	12.8 %

These finding are similar to our prior work in which CS students' highest reported term at 18.8% was "smart". Note that being "knowledgeable" is reported at a greater percentage for a teacher than "smart" is for a computer scientist, and being "smart" drops off the top three list for how students perceive computer scientist teachers with "patient" moving into the top three terms. For non-CS-teachers, "patient" was report 10.2% and "smart" at 5.1%.

Discussion and Conclusion

The shared terms across the different domains provide compelling evidence for what characteristics we ought to foster while designing expansively for learning across these domains. A significant finding for us is the lack of any explicit contradiction in students' perceptions across domains (i.e., being "smart" is not inherently contradictory with being "caring"). This will help us in our designs for learning, however, equally important are the terms not in the top three. For example, "white" and "male" were reported for computer scientists, while "white" and "female" were reported for teachers, suggesting we still have to work at combatting gendered and racial perceptions of these fields. As our findings demonstrate, and the Learning Sciences advocates, surfacing perceptions about identities in the domains we are designing for is an important step toward designing for greater access and equity.

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International Society of the Learning Sciences

'Bridging the Distance': Developing Entrepreneurial Thinking in an International and Interdisciplinary Learning Environment

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Abstract: The Covid19 pandemic presented challenges and opportunities for students' learning worldwide. An international interdisciplinary learning environment was designed to bridge the distance, address students' socio-emotional needs and to develop entrepreneurial thinking, a skill needed in times of uncertainty. Twenty-four education students from two countries took part in six online sessions. Initial results support the contribution of the project to developing the participants' entrepreneurial thinking and to the role socio-emotional aspects play in it.

Introduction

The continuation of the Covid19 pandemic confronts higher education with challenges and opportunities such as finding ways to address the quality of distance learning instruction and addressing social and emotional needs of those who partake in teaching and learning. The importance of understanding both challenges and opportunities are significant for orchestrating future learning, dealing with crisis situations and for improving aspects of teaching and learning in the higher education systems (Engeström & Käyhkö, 2021). Elias (2003) suggested that to conduct life successfully, students need to learn how to understand and manage their emotions as well as how to resolve unexpected problems. Teaching pre-service teacher by looking at self-answering such questions may provide them with socio-emotional competences that lead to personal well-being and employment success (Price et al. 2020).

Developing Entrepreneurship thinking is considered an individual's ability to turn ideas into action and involve creativity, innovation and risk-taking (EU Skills Panorama, 2014). Thus, Entrepreneurial thinking might be an asset for students at this very time of accelerated ambiguity.

In this study we seek to promote entrepreneurial thinking and skills through the design of an online, international, interdisciplinary learning environment that is attentive to studying during the Covid19 era. The program was named "Bridging the Distance" project to signify overcoming forced distancing caused by the pandemic in the local communities; Yet it sought to enable, closeness within the international community, by exploring commonalities and characterizing modes of progression – similar and different in each county.

Our study objectives aim to examine: 1. How does participation in an international and interdisciplinary learning environment contribute to the development of entrepreneurial thinking? 2. What are the characteristics of learning design in an academic course that support developing entrepreneurial thinking among the participants? Our initial findings point to the potential development of entrepreneurial thinking for the students. It also points to the place that socio-emotional aspects play among students during the Covid19 period. Furthermore, it emphasises the importance of the projects' tasks design, which relate directly to the need for socio-emotional support.

Method

To address these research questions, we designed a learning environment that spans across six synchronous sessions, between Education students in Israel and Poland. The Israeli students enrolled in the *Pedagogical Entrepreneurship* course conducted as part of the *Regev* Excellence program for pre-service teachers at Kibbutzim College of Education and students who study pedagogy at the University of Gdansk University in Poland. The design was led by the Center for Innovation at the Kibbutzim College in collaboration with academic and professional contributors.

Apart from the introduction and summary (meetings 1&6), the learning design included two main teaching units. The first, invites 'inward looking' on challenges of studying during the pandemic using a design task to collaboratively design a t-shirt using a composition of images and text; The second, 'outwards looking' at the challenges and opportunities of this time, creating a proposal for a social, business and/or pedagogical project presented to potential investors (Figure 1). These activities were held during online meetings in mixed international groups and under the guidance of instructors from both institutions.

We use design-based research (Barab & Squire, 2004) aiming for both theoretical and practical contribution in the context of designing an innovative learning environment. Research tools included two questionnaires for the students (n=24); Video documentation of the six synchronously learning sessions; Student

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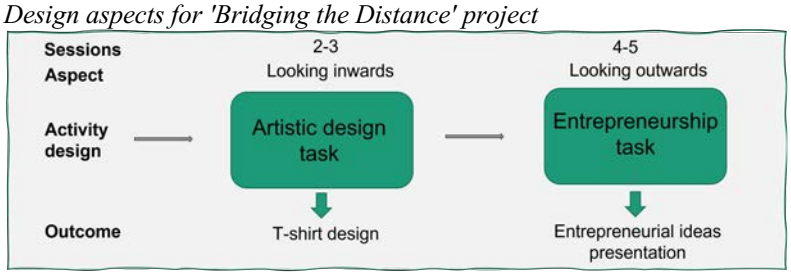
Figure 1
Design aspects for 'Bridging the Distance' project



written reflections; Interviews with six students; Students' outcome analysis and team design notes. We report on early finding from thematic analysis conducted on the interviews and outcome analysis (iteration 1, 2021).

Results

Our findings point to the contribution of the unique learning environment to motivating participants to collaborate through discussion, design, and entrepreneurial ideas to meaningful learning outcomes. It also points to the incorporation of social interactions that were developed during the study sessions in small groups (3-4 participants) as well as identifying cross-cultural shared challenges among participants to do with studying during the Covid19 pandemic.

The six groups' t-shirt design reflected socio-emotional aspects such as loneliness, the need to look forward in a positive way, and the desire to be together. The entrepreneurial initiatives related to topics such as facilitating anonymous expression of mental health issues, creatively resolving international library book lending and assistive traveling - during quarantine and/or amidst covid19.

The incorporation of social-emotional aspects into the learning design and into the design of tasks of the international project turned to be crucial. From the interviews, several social-emotional aspects were identified as contributors/supporters to the development of students entrepreneurial thinking among them: (1) Instructors' respectful teamwork, acting as role model for collaboration and management. (2) International Students' personal connection and meaningful interaction in small groups. These aspects together with the task design, seemed to assist in facilitating students' Entrepreneurial skills: personal, technical & management (OECD, 2014).

For example, S2 reflected on the connection between people: "I think the first course took place in a zoom where the atmosphere was really really really good socially and also among the lecturers. [..] it was important for everyone to talk and get to know." S3 related the T-shirt task design to bridging the distance: "I believe that it was a very adequate task because it made me think about the pandemic, about what I have lost, so primarily the aspect of interpersonal relations, or rather lack of them." Another student (S5), related to life improvement and innovation: "The second task was also great because it showed me that the knowledge about pedagogy/ education/ psychology, which is what we are studying can be used to improve life, to improve the quality of life… Such knowledge can be translated into actual actions and innovations."

Results from this study contribute to the design of international collaborative learning environments that promote interdisciplinary entrepreneurial thinking enabled by socio-emotional support. Such environment that are built upon students needs in the Covid19 era might help them discuss their challenges together, as well as enable them to suggest innovative ideas to social/educational problems. Further analysis of the data is needed for more precise findings to contribute theoretical and practical insights for an emergent design patterns for international collaboration around theses study aims.

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Designing for youth-centered experiences in informal STEM-rich making with minoritized youth during the Pandemic: Conjectures & Considerations.

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Abstract: The pandemic has brought an abrupt shift from in-person community-based programming at an informal weekly STEM-rich making club with minoritized youth, to one of socially-distanced, solo-work only, virtually-facilitated experience. We explore what such an abrupt pivot from in-person to virtual programming meant, including the challenges and tensions, for the design of pedagogical materials and virtual facilitation practices, when facilitators aim to maintain an asset-based, relational engagement where youth can make in agentic ways, pandemic notwithstanding.

Purpose

The Covid-19 pandemic has surfaced many inequities in STEM education, especially for youth of color. Learning environments as youth have come to know them remain unstable, exacerbated by the sudden and necessary pivot to virtual platforms that youth and STEM educators have had to learn to navigate very quickly. While pandemic-related discussions around learning environments in formal classrooms have been robust (McKinney de Royston & Vossoughi, 2021), how, for whom, and to what ends informal STEM settings might pivot during the pandemic have been largely left out of the conversation. This proposal investigates the *virtual* pedagogical practices of informal educators in a community-based makerspace (Make Club) at a local Boys and Girls Club (BGC) that, prior to the pandemic, had operated as a sustained, weekly in-person program for youth. Our overarching research question is: What are the design features built into the virtual pedagogical practices aimed at supporting and maintaining youth maker agency and everyday concerns amidst the pandemic? As STEM education researchers and informal STEM facilitators, we are interested in how youth and informal STEM educators, suddenly limited to virtual programming engage, pivot to continue engaging in rigorous STEM-rich making as a result of the Pandemic, including the challenges, insights, tensions and unanticipated possibilities.

Theoretical Framework

We draw on Cultural-Historical Activity Theory (CHAT) (Engeström, 2001; Gutiérrez & Arzubiaga, 2012) and youth identity (Holland et al., 2001) in learning as guiding frameworks. Youth bring in other identities into the community youth makerspace and there is a plurality and fluidity between their identities-in-practice as youth engage in any particular figured world, either in-person or virtual. CHAT as a framework helps us probe youth engagement on two levels: 1) It allows us to unpack how youth are utilizing what particular pedagogical tools made available in the virtual programming to result in what kinds of STEM-rich making engagement; 2) it makes visible how particular dynamics within an activity system (e.g., different combinations of tool-rule-community) impact youth engagement. Overlaying CHAT with youth identity is helpful in gaining insights into what germane identities-in-practice youth are bringing to bear when negotiating the virtually facilitated Make club activity system.

Methods, Data Sources & Data Analysis

Context: At this BGC Make Club, youth have fostered a community where they have a strong bond and sense of ownership (Calabrese Barton & Tan, 2018). Group collaboration and iterative design are core features of Make Club, for example, youth surveyed club-mates for community concerns that resulted in a semester of building toys such as race cars and coding games on scratch, that Make club youth shared with all BCG children for feedback and further refinement. However, since the pandemic, Make Club has been drastically reconfigured. As a result, by the time virtual Make Club begins at 3:45pm on a Tuesday, Make Club youth participants would have already spent an entire school-day worth of time physically at the BGC, 6 ft socially distanced, with a chrome book. This was due to youth attending school virtually while physically at the BGC. Pandemic rules also dictated only solo work and virtual facilitation by Make Club facilitators. A BGC club staff distributes Make Club materials, individually bagged, from a sanitized table.

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We engaged in participatory design (Bang & Vossoughi, 2016) in our dual roles as long-time Make Club facilitators and researchers. Data includes fieldnotes, zoom videos of Make Club sessions, 18 check in/exit surveys with youth, and educator (Worsley) made artifacts (powerpoints) that surface the pedagogical patterns related to the learning experiences of each youth, analyzed in the grounded theory (Glaser, 1992) for 7 months of 45-minute weekly programming (13.5 total programming hours). The making activity was to create a pop-up book with light-up elements that document significant stories of youths' experiences during the pandemic. While the pop-up cards were the primary project, youth also worked with snap circuits.

For data analysis, we are mapping the trajectory of pedagogical design decisions as informed by, a) pre-pandemic Make Club norms to, b) specific features of pedagogical materials meant for virtual programming, to, c) how youth took up, changed or resisted the making activities planned for. An example of a core analytical thread centers on considering the nature of in-person to virtual pivot of one of the core features of pre-pandemic Make Club --intentionally twinning social design features with technical ones rather than "front-loading" technical know-how as most school STEM activities are wont to do.

Initial Conjectures & Next Steps

Through mapping CHAT triangles for various virtual sessions layered with identity analysis a recurring theme emerged –the imbricated nature of relational representation with pedagogical content modeling and with community building during an isolating pandemic. Even though youth were physically together in a room at the BGC, they were isolated from one another. We mapped the ways in which relational representation were made manifest in the weekly powerpoint slides. First, video representation of an established, embodied presence was helpful in creating short videos (boomerangs) featuring Worsley, the primary Make Club facilitator who shares identifiers with the youth. These videos were used as a direct result of the shift to virtual facilitation. It was important and meaningful for the youth to "see Ms. T show us". Short videos featuring Ms. T's hands "making" included doing particular pop-up folds, showing the trickiness of working with flimsy copper tape, explaining her social reasons for designing a particular pop card. This way, we were "there" with the youth demonstrating and modeling the technical steps as we engage in dialogue with them in real-time, through zoom. In our years of experience as STEM facilitators, youth have also consistently remarked of the lack of representation of Black people in making videos or STEM videos one could locate online. To exemplify relational representation we intentionally populated the slides with Black people, characters, and cultural references as well as pictures of BGC staff and ourselves. We are analyzing how these representations impacted how various tools (including physical materials like copper tape, scaffolding activity sheets showing different types of circuitry from simple to parallel, other art-based materials) were taken up by youth as they navigate the activity system, in connection with which salient identities. For example, many youth were experiencing personal loss in their families to Covid-19, which brought somber designs to the cards. We are further investigating how youth-centered design for virtual programming could facilitate needed caring during stressful times as such.

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Supporting Elementary School Teachers in Their Learning of Programming and Robotics: A Case Study

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Abstract: We examined elementary school teachers' learning of block-based programming and robotics under the guidance of an instructor in a professional learning (PL) course. Data consisted of teacher artifacts and videos recorded in the PL course. Data analysis revealed that the type of guidance and support the instructor provided helped teachers develop their programming skills and shaped their attitudes toward programming integration in elementary schools. The instructor's guidance also posed a few barriers to teachers' learning.

Introduction and background

Many scholars recognize the importance of teaching programming in elementary schools to develop students' computational thinking skills and increase their interests toward computer science and programming starting from early ages (e.g., Lye & Koh, 2018). The literature has some preliminary answers that propose ways to prepare current elementary school teachers to teach programming. These answers generally come from end of program or training teacher evaluations (Cooper et al., 2011), teacher artifacts such as lesson plans (Savard & Highfield, 2015) or programs/scripts of programs (Gabriele et al., 2019). However, more studies are necessary to reflect the complex processes of teacher learning. As Cochran-Smith et al. (2014) claimed, teacher education research should "resist simplification, and account more fully for teacher education's contexts and processes" (p. 105). Therefore, we undertook a case study of how to support teachers in their learning of block-based programming and robotics. We pursued this research to reflect the complexities involved in teachers' learning of programming and robotics and to present ways to support teachers closely in professional learning (PL) contexts. In this qualitative case study, our research question is: How do instructors facilitate K-5 teachers' learning of programming and robotics or pose learning barriers to their learning in a professional learning course?

Context and methods

As a part of a nationally funded research project, a rural school district and a university in the southeastern United States collaborated and organized a professional learning (PL) course, *Robotics for Teachers*, for third through fifth grade elementary school teachers. Nineteen teachers participated in the PL course in the spring semester of 2019. The course composed of four face-to-face class meetings (approximately fourteen hours of training in total) and weekly assignments. Two robotics kits and their programming platforms were used in the course: Ozobot/OzoBlockly and RoboRobo/Rogic. When the teachers worked on in-class tasks in these four face-face-face class sessions, the instructors supported these teachers' learning during their engagement with in-class group or individual tasks. In this paper, we focused on the case of one instructor, Dr Z (not one of the authors of this paper) as he worked with the same group of four teachers from the beginning of the course to the end. We could track these teachers' progress under Dr Z's guidance throughout the course. The teachers he worked with were Isabel, Malia, Neal, and Hope *(all names are pseudonyms)*. Data consisted of the videos recorded in the PL course during which Dr Z worked with this group of four teachers and teacher artifacts (teachers' Rogic and OzoBlockly programs/weekly assignments). We used the systematic whole-to-part inductive approach and part-to-whole narrative evolving in sampling and analyzing video data (Erickson, 1982). The patterns in the phases of interests, facilitators and barriers in Dr Z's guidance, were revealed and reported.

Findings

We observed that Dr Z supported teachers' learning of programming and shaped their attitudes toward programming integration in elementary schools. He also posed a few barriers to teachers' learning.

Dr Z helped the four teachers develop their programming skills and debug their programs through providing support and direct instruction on the essential blocks to have RoboRobo robots move and turn. For example, when Malia encountered a problem with her program, in which her robot completed half the task and stopped, Dr Z guided her and explained the logic behind setting the delay (*duration*) blocks in her program. Although the PL course instructor earlier instructed teachers in using the delay blocks to move their RoboRobo robots, teachers still needed further guidance when they were actively working with their robots to complete class activities.

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Furthermore, Dr Z shaped teachers' attitudes about programming instruction through giving examples from real life elementary classrooms. In the first face-to-face meeting after the course instructor directed teachers to use level 4 out of 5 levels on OzoBlockly, Isabel and Olivia told Dr Z that their students would not be able to use level 4 (manipulating the wheel speeds to have robots turn: one wheel goes faster/slower than the other to make the turn) rather than level 2. Isabel then asked Dr Z why they had been asked to use level 4 instead of level 2 (using degrees in turns: turn 45 degrees). Dr Z replied, "With one of the teachers I was working with last semester, she was using the routing with the wheel speed function (in level 4). This was fourth grade, ESOL (English for Speakers of Other Languages) class. And they were able to do it." The teachers looked surprised to hear it; however, Isabel still remained skeptical of using wheel speeds with elementary school students. She said: "Maybe it was a different task." She also asked whether that teacher was from their school district. Dr Z confirmed she was from their school district and added that the teacher initially set the wheel speeds and then let her students reset them to figure out the rotations. At the end of the discussion, Isabel and Olivia were more receptive of the idea of using wheel speeds on level 4. Olivia added that she would use whatever level her students wanted to use with Ozobots.

Dr Z also posed a few learning barriers with his guidance. The barriers occurred when Dr Z directly told the teachers which blocks to use without providing much context. For example, during the second face-to-face meeting, Dr Z assisted Olivia with debugging her program. She was working on the third task. She needed to use *if then* block with this task, but she was not aware. Dr Z directly told her to use *if then* block and Olivia just followed whatever block he asked her to use. They did not discuss what those blocks meant. Although Olivia's programs worked on her robot, it was observed that she generalized the use of the *if then* block to every program she developed possibly thinking that *if then* block was essential in every program.

Discussion and Conclusion

Our study showed that Dr Z's systematic guidance and direct instruction helped the teachers with their learning of programming. However, when he directly told which blocks to use without providing much context for the use of those blocks, teachers developed misconceptions around the use of those blocks. Teachers' attitudes toward using a particular task and level with their students changed when Dr Z shared that students in another teacher's classroom was able to work on the same task and the level. We concluded that it is important to support and closely guide teachers in many aspects of learning programming and robotics such as in debugging, developing understandings of key programming concepts and ideas. Teacher educators need to provide real life classroom examples on programming integration in elementary classrooms. Additional research can be performed to advance our understanding of how to effectively support teachers' or students' needs in learning about programming.

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International Society of the Learning Sciences

Online Instructional Coaching During the COVID-19 Pandemic

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Abstract: With COVID-19 necessitating a shift to online teaching and professional development, a unique opportunity to study online instructional coaching emerged. With prior evidence that the provision of a STEM curriculum unit and online coaching supported a first-year science teacher in improving his instructional practices, this study utilized interaction analysis to explore the coaching moves that were implemented by three STEM instructional coaches and identify the online coaching moves that prompted teacher reflection. Findings highlight the distinct coaching styles of the individual coaches and the range of moves that preceded teacher reflection. Implications for online instructional coaching are considered.

Introduction and rationale

The COVID-19 pandemic caused many aspects of teaching, including professional development (PD) to shift to online modalities. Researchers have called for more studies of online PD programs (e.g., Dede et al., 2009) and have raised concerns about the quality and effectiveness of online PD (Lynch et al., 2019). The present study is grounded in distributed cognition theory, which emphasizes the social and collective nature of knowledge construction (Hutchins, 1995; Zhang & Patel, 2006), and recognizes the central role of reflection in instructional coaching (Knight & Cornett, 2009). In our previous study of teaching practices, we found that the provision of a STEM curriculum unit and online coaching supported a first-year science teacher in utilizing research-based best practices for teaching within the COVID context (Wieselmann et al., in review). The present study sought to better understand the nature of virtual coaching that supported this teacher and addressed the research questions:

1. What coaching moves do STEM instructional coaches implement in an online coaching environment?
2. What coaching moves prompt a first-year teacher to reflect on his instructional practices?

Research methods

We utilized a multiple embedded case study design (Yin, 2014) to explore the phenomenon of online instructional coaching. Each of three instructional coaches represents a case, and turns of speech served as the units of analysis. The coaches, two of whom are the authors of this paper, worked with a first-year science teacher to support his implementation of an integrated STEM unit focused on physics concepts of force and motion in his seventh-grade classroom. All three coaches had prior science teaching experience in a range of contexts.

The unit was taught over the course of five class periods, each of which was 90 minutes long. Prior to each class period, the coaches and teacher met on Zoom to discuss the day's lesson plan. The coaches observed the teacher's implementation of the lesson and again met with the teacher on Zoom following the lesson, utilizing these debrief meetings to promote reflection and consider any modifications that needed to be made to the subsequent lessons. All of the planning and debrief meetings were recorded and transcribed for analysis. Utilizing interaction analysis methods described by Jordan and Henderson (1995) and collaborative viewing of the meeting videos, we developed a codebook and coded the data using inductive process coding (Saldaña, 2016) to capture the coaching moves evident in each speech turn. This inductive and collaborative approach to coding helped reduce bias (Jordan & Henderson, 1995). As disagreements among coders emerged, we refined our codes and their definitions and ensured that we were calibrated in their use (Wasser & Bresler, 1996). The final codebook included 24 codes. Once coding was complete, we conducted code frequency counts for each coach. We also examined the temporal relationship to determine which coaching moves preceded the teacher's reflective practice.

Findings

Our interaction analysis revealed that Coach 1 performed a total of 165 coaching moves, drawing upon her prior knowledge and expertise to provide an affirmation-rich approach to coaching that focused attention on student learning, revising lesson plans, and prompting reflection. Coach 2 performed a total of 138 coaching moves and used her expertise surrounding the subject content and the state standards to focus on pedagogical knowledge, how students learn, and sharing her personal teaching experiences. Coach 3 performed a total of 69 coaching moves and employed his expertise surrounding integrated STEM curriculum design and the learning sciences to promote a focus on integrating technology and pedagogical knowledge.

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The teacher reflected on his practice and student thinking on 28 distinct occasions. Because of the unit of analysis focusing on speech turns, it was possible for more than one coaching move to be used in the turn preceding teacher reflection. As expected, reflection was often preceded by a coach prompting this reflection (13 occasions). However, even in the absence of explicit prompting, the teacher reflected on 15 occasions. In analyzing the coaching moves that preceded these occasions of reflection that were not explicitly prompted, several moves were most frequent. In descending order of frequency, these coaching moves included affirming (9 occasions), focusing on pedagogical knowledge (6 occasions), focusing on science content (5 occasions), focusing attention on how students learn (4 occasions), and developing or revising lesson plans (4 occasions). Providing the teacher with feedback on his instructional practices only prompted reflection on one occasion.

Discussion and implications

While there was overlap in the coaching moves used by the three coaches, each coach also adopted a distinct coaching style in the online environment. Coach 1, who was the most senior, adopted a coaching approach that emphasized the positive aspects of the teacher's practices through affirmations. This may have served to make the teacher more comfortable with being observed and open to discussing his teaching practices. Coach 2 drew heavily upon her knowledge of general pedagogical strategies, offering suggestions for everything from classroom management to ensuring equitable participation by using a random name generator. Coach 3 had extensive experience with technology integration and was able to share specific advice related to the hybrid format of instruction with both online and in-person learners. Each coach leveraged their position and distinct set of experiences in unique ways in developing the coaching relationships.

With reflection being one of the key elements of instructional coaching (Knight & Cornett, 2009), it is critical to consider how teacher reflection was prompted and supported in the online coaching setting. While explicit prompts for reflection were effective in eliciting reflection, the teacher also reflected in the absence of such prompts. Interestingly, the coaching move of affirming the teacher was the most frequent prompt that led to reflection. It is possible that the teacher felt more comfortable critiquing his own instructional practices when he had already been affirmed by the coaches.

This study of instructional coaching was grounded in the notion that knowledge was distributed across the three coaches as well as the teacher. While limited in scope, it provides a practical codebook for use in future studies. It also reveals promising opportunities for online instructional coaching. Given the evidence of improved teaching practices (Wieselmann et al., in review) and the range of coaching moves that prompted teacher reflection, findings from this study can be used to inform instructional coaching decisions.

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Reframing Design for Transformative Change: Supporting Pre-Service Teachers in Adopting Designerly Stances Towards Inquiry

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Abstract: We need transformative change in K-12 education to address the myriad challenges and inequities facing the world today. Traditional approaches to design in education as taught to pre-service teachers, however, support incremental improvements to efficacy and efficiency rather than transformative change. Guided by contemporary theory and research from design fields, we propose a framework for conceptualizing K-12 educators' stances towards design organized along a continuum from technical rational to designerly. We use this framework as a lens to analyze data drawn from a case study examining 28 pre-service teachers' conceptualization and engagement in design within the context of a design course taken by over 400 pre-service teachers. Our analysis of a range of data sources demonstrated that most participants adopted either a technical rational or exploratory stance towards design by the end of the course. We conclude by explicating why certain shifts took place and proposing ways pre-service teachers could be supported in adopting more human-centered approaches to design.

Theoretical framework

Insights from design fields suggest that a designerly stance towards design for K-12 educators focused on problem finding and framing – in contrast to the more traditional focus on solution finding – would emphasize four key themes as follows: (a) view of the problem space (e.g., Buchanan, 1992; Norman, 2013; Schön, 1984), (b) approach to stakeholders and inquiry (e.g., Bang & Vossoughi, 2016; Christensen et al., 2016; Krippendorff, 2004), (c) framing and frame creation (e.g., Buchanan, 1992; Dorst, 2011), and (d) conceptualization of the design process (e.g., Norman, 2013; Owen, 2006). These elements overlap and interrelate with one another and share, in many instances, common themes. We created a detailed rubric based on these four areas that we used to guide this study and data analysis. Space precludes including the full rubric here, but we will share the full version at the conference.

Research Questions

1. When viewed through the theoretical framing outlined above, how do pre-service teachers' understandings of design evolve in a course that includes an emphasis on design-based thinking from the perspective of the design fields as well as perspectives on design from the field of education?
2. Which aspects of design as defined in the theoretical framing come most naturally to pre-service teachers and which aspects require more support, revisions, or emphasis?

Building on these two core questions, our discussion also considers how articulating a design framework based in the broader literature from the design fields might provide insight into avenues for improvement in pre-service teacher education to improve these outcomes.

Methods, Data Sources, and Coding Schema

We employed case study research (Stake, 2005; Yin, 2014) to consider how, and the extent to which, pre-service teachers engaged in designerly stance towards design within the context of a mandatory five-week course taken by 400 students at a university in western Canada focused on a range of design processes in the field of education including perspectives from design fields (Design Council, 2007; Norman, 2013) as well as design perspectives in education including design thinking (IDEO, 2012). The bracketing of the boundaries for this case involved limiting the focus of the research to data gained from this course. In total, the team analyzed the work of 28 pre-service teachers across the 18 sections of the course who consented to allow their work to be used as data in this study. Data in this regard were drawn from three course pre and post reflections and design projects.

Findings

In the sections that follow, we analyze the data set in relation to our conceptualization of the four proposed themes for a designerly stance to design. Each theme is presented as a continuum from technical rational through exploratory to a designerly stance (Table 1).

View of the problem space. Findings from this study indicated that conceptualizing the problem space

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was the most challenging area for participants. As shown in Table 1, pre-service teachers demonstrated almost no progress from Pre to Post in terms of Problem Space. Our analysis of the data suggested that most of the pre-service teachers in this study entered and left the course with a largely technical rational view of the problem space, particularly in relation to complexity. The majority of participants continued to view problems as uncomplicated and stable with the goals to be achieved largely fixed and predetermined (Schön, 1984). Participants additionally demonstrated difficulties making well-developed connections concerning how the problems they chose to focus on were implicated in larger macro structures and societal challenges.

Table 1. Summary of Findings by Design Theme

Design	**Problem Space**			**Inquiry**			**Framing**			**Process**		
Sophistication	Pre	Post	DCP	Pre	Post	DCP	Pre	Post	DCP	Pre	Post	DCP
Designerly	0%	0%	0%	5%	4%	11%	0%	4%	11%	0%	4%	0%
Exploratory	32%	30%	63%	50%	78%	74%	73%	74%	68%	55%	78%	63%
Tech Rational	68%	70%	37%	45%	17%	16%	27%	22%	21%	45%	17%	37%

Approach to inquiry. One notable area where the participants demonstrated growth from Pre to Post occurred in the area of inquiry as shown in the table and figure. In particular, we noticed an uptick in attempts to gain empathy for stakeholders, particularly students. Although we noted that more participants began to see the importance of an ongoing empathic consideration of students as stakeholders, the overall trend did not suggest a fully designerly approach to inquiry from the perspective of our theoretical framing.

Framing and frame creation. Our analysis of the data set suggested the pre-service teachers started at a more exploratory stance towards framing and frame creation but made little progress beyond that during the course. They overwhelmingly associated design with the creation of more active and engaging learning environments involving a shift away from traditional approaches to education rooted in teacher-centric pedagogies, passive learning, and content coverage.

Conceptualization of the design process. An area where participants demonstrated substantial growth occurred in relation to process. Pre-service teachers initially displayed a range of technical rational and early exploratory perspectives that shifted towards primarily exploratory stances by the end of the course. In particular, pre-service teachers became much more attuned to the iterative nature of design. Given these shifts, there was little evidence of a fully designerly stance in how participants conceptualized and engaged in the design process.

Scholarly significance

The significance of this study is threefold. Our study offers one of the few fully articulated frameworks for conceptualizing K-12 educators' stances towards design. This framework provides both a lens for pre-service teachers to reflect on how they engage in design, as well as a tool for research, critique, and re-envisioning of pre-service and in-service programs. Insights gained from this study additionally offer ways educators might be more intentionally and purposefully supported in moving towards more designerly stances that could position them as agents of change in service of preferable educational futures. Ultimately, helping educators move toward more designerly stances will support them in becoming more comfortable with the ill-defined nature of problems and their societal and cultural roots as well as the critical role of moving beyond traditional teacher-centered frames in educational discourse that have limited educational possibilities for transformative change.

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Sociopolitical Discourses within Student Farms and Gardens

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Abstract: We identified 46 university-based student farms or gardens' (SFG) mission statements from around the U. S. and used sociosemantic analysis to describe and compare the individuals involved, the actions conducted, and the objects involved. Two discourses emerged from our analysis: (a) a depoliticized framing of SFGs as sites for producing food for higher education communities; and, (b) a politicized framing of SFGs as sites for engaging with issues of social and environmental justice within the broader community.

Introduction

This research is part of a broader project to understand the learning that occurs amongst participants at a university-based student farm/garden (SFG). At many junctures in this project, we noticed tensions between the purposes of student farm workers (e.g., growing food to donate to community members) and the purposes of the university personnel (e.g., selling produce at local markets or using produce in promotional events). We see these tensions as arising from conflicting *discourses* regarding the purposes of university SFGs. Discourses are "particular way(s) of representing some part of the (physical, social, psychological) world" (Fairclough, 2003, p. 17). For example, SFGs can draw on various discourses to inform their daily work (ex. community service, food security, university pride). We see these various discourses and the conflicts between them as important to understand to make sense of day-to-day participation in SFGs. To that end, we have 'zoomed out' from our local context to gather a broader understanding of the various discourses which inform SFGs. In this paper, we collect mission statements from 46 SFGs at land grant universities around the U. S. and ask the following three research questions:

1. Who is involved? (ex. students, professors, 'the community', or others?)
2. What do they do? What actions do participants of these SFGs engage in? Towards what or who?
3. What objects or ideas are involved? (ex. Science learning, skills, tools, produce, etc.?)

Data Analysis

To analyze the 46 SFG's mission statements, we drew on a CDA technique called *sociosemantic analysis* (van Leeuwen, 1993) which involved three steps. First, we read each mission statement and annotated three features: *participants* (people or institutions involved in the SFG), *processes* (actions of the people or institutions in the SFG), and *objects* (materials, ideas, or social relations related to the SFG). Second, we developed a codebook to capture the different themes amongst participants, processes, and objects. Third, we create a frequency count for each theme and reflect on the variation amongst the set of SFG mission statements. In the next sections we summarize the themes among participants, processes, and objects included in SFG mission statements. We close with a discussion about the two discourses we see surrounding the purposes of SFGs.

Who are the Participants?

Participants fell into three primary groups among the 46 SFG mission statements: (a) the garden/farm itself; (b) participants from the university or college; and, (c) participants from beyond the university or college. The most frequently mentioned participant was the student farms or gardens themselves. All 46 of the mission statements referenced the farm or garden as a social actor. 25 of the 46 mission statements *only* include the SFG as a participant, and make no mention of other participants in their mission statement. The second most frequently mentioned participants were social actors from the university or college in which the SFG is situated. Students were included as participants in 14 of the 46 (30.4%) mission statements. Faculty and Staff were included as participants in 2 of the 46 (4.3%) mission statements. Far less frequent, were mentions of social actors outside the boundary of the university or college. Families were included as a participant in 1 of the 46 (2.2%) mission statements. Food banks or non-profits were included as participants in 2 of the 46 (4.3%) mission statements. 'Community' was included as a participant in 10 of the 46 (21.7%) mission statements. And 'Society' was included as a participant in 1 of the 46 (2.2%) mission statements. In these instances, SFGs are positioned as organizations whose purposes extends beyond to social actors who are not directly involved with university or college.

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What are the Processes?

We focus on processes as a way to see how SFGs delegate actions to different participants involved in the SFG. In this poster, we describe the *directionality* of processes. By directionality, we mean which social actor conducts the action of a process. Three directionalities emerged from the data: (a) processes conducted by the SFG towards other participants; (b) processes conducted by other participants; and, (c) processes conducted by the SFG and other participants together. Most process directions were those conducted by the SFG towards other social actors. All 46 SFG mission statements included some processes conducted by the SFG. Far less frequent were instances where social actors other than the SFG conducted processes. Nine SFG mission statements included processes conducted by participants outside the SFG (19.6%). Three SFG mission statements included processes conducted by the SFG together with other participants (6.5%).

What are the objects?

Student farms or gardens provide produce (material), knowledge about sustainable practices (mental and material), and friendship (social). We focus on objects as a way to see what services are rendered available by SFGs. The objects identified from the mission statements can be classified in four categories: (a) nature and food; (b) social objects; (c) education; (d) and justice. The primary objects involved in SFG mission statements were related to nature and food. Nature and food objects are any object that is provided from the natural (as opposed to cultural) realm. 39 of the 46 (84.8%) mission statements include some mention of nature and food. For example, Dilmun Hill at Cornell University "seeks to empower students through active engagement in ecological agriculture". Social objects were also frequently mentioned in SFG mission statements. Social objects were any object related to community, partnerships, collaboration, and students. 30 of the 46 (65.2%) mission statements include some mention of a social object. For example, the Community Gardens at Auburn University "provides access to local produce through community partnership". Educational objects were also frequently mentioned in SFG mission statements. Educational related objects are those related to learning, knowledge, and interest. 31 of the 46 (67.4%) mission statements mention education as an object to be provided by the SFG. For example, The Gardens at Texas A&M University "engage the community in a living teaching environment." Justice related objects were the least frequently mentioned category of objects. Justice objects related to sustainability, environment, sovereignty, and hunger. 22 of the 46 (47.8%) mission statements include justice related objects. It stands to note that the majority of these SFG mission statements (19 of the 22) addressed sustainability and the environment (environmental justice); whereas, only 3 SFG mission statements mentioned made any mention of objects related food sovereignty and hunger (*social* justice). Perhaps most stark, was the complete absence of any discussion of race or racism amongst the 46 SFG mission statements.

Two Emerging Discourses

We have begun to notice the contours of two differing discourses about the purposes of SFGs. One discourse portrays SFGs as politically neutral and bound to the space of the institution. This discourse is characterized by mission statements which: (a) draw a distinct boundary between the SFG and the broader community; (b) ascribe most social actions or processes to the garden itself (and therefore fewer social actions ascribed to other participants); and, (c) focus on delivering objects (whether natural, social, educational, or justice-oriented) to participants in the garden or to community which the garden serves. A second, far less frequent discourse portrays SFGs as politically engaged and embedded within larger communities, regions, and cultures. This discourse is characterized by mission statements which: (a) embed the SFG in broader communities; (b) ascribe social actions to a range of participants; and, (c) discuss objects as being exchanged amongst participants who are both a part of the SFG and a part of the community. Furthermore, this discourse focused more explicitly on justice as a product of SFG (ex. food security, food sovereignty) rather than solely generating produce, social experiences, or educational experiences. Now that we better understand the landscape of discourses which inform SFGs around the U.S., we aim to document the discourses which are employed in our local research context (whether in advertising materials, or in interaction). We do this to examine tensions that arise between participants on the student farm to trace how competing discourses mediate learning and interaction.

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International Society of the Learning Sciences

Exploring Different Facilitator Roles in Maker-based Learning

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Abstract: The purpose of this study is to investigate how different facilitator roles (educator, adult caregiver, peer and self-facilitation) influence children's learning engagement--specifically, the learning practices of seeking and sharing resources (SSR)--in a museum's makerspace. We address two research questions: 1). In what ways do learners' engagement vary when facilitated by different facilitator roles? 2). In what ways do different types of facilitators influence SSR practices across age ranges? The results show that facilitation from caregivers and self-directed facilitation is associated with significantly more SSR practices. Additionally, we found that the influence of different types of facilitators on learning engagement varies across ages. Self-directed learning is associated with an increase of SSR as children grow, while facilitation from caregivers is associated with a decline of SSR as children age. Based on these findings, we discuss implications for facilitation in museum makerspace.

Introduction and background

Facilitated museum makerspaces can function as a nexus for creative learning experiences. However, learning does not come inherently with a museum makerspace. Facilitation is a key element of supporting children's learning and development that can boost satisfaction and create a gateway for equitable access through personalization of a learning experience to learners' needs and interests (Gutwill et al., 2015; White et al, 2021). In successful facilitated making, the educator helps a child progress in the complexity of learning, connects the child to activities at a reasonable challenge level, and encourages interest and engagement (Gutwill et al., 2015).

The focus of prior research on facilitation in museums, more generally, often centers on educators; more research is needed to investigate the influence of different types of facilitators in a museum makerspace (Krange et al., 2019). In this paper, we explore how the facilitator role influences children's learning engagement -- specifically the learning practice of seeking and sharing resources (SSR). In this study, we address two research questions: 1) In what ways do learners' SSR vary when facilitated by educators, adult caregivers, peers, or working independently? 2) In what ways do different types of facilitators influence the SSR practices across age ranges? Through this study, we gain insight about which facilitator role tends to support learners to seek and share resources and how this varies by age. The more we understand how to differentially support learners across developmental stages, the more we can train educators and offer suggestions to caregivers to be meaningful partners in learning. Second, this work builds upon previous research to understand how to conceptualize and study learning through making (e.g. Wardrip & Brahms 2015). In particular, this work can more explicitly articulate learners' engagement in seeking and sharing resources through the lens of the Learning Practices of Making framework and how facilitators are partners in the learning process.

Theoretical and methodological approaches

The perspective of overt learning behaviors guides this work. *Overt* behaviors that learners display in a learning environment can help researchers to understand and analyze learning engagement (Chi, 2009). The Learning Practices of Making framework articulates forms of overt learning behaviors in a museum makerspace. One such behavior is seeking and sharing resources (Wardrip & Brahms, 2015). The practice of seeking applies to tools, information, or other supports. Sharing refers to an individual offering to others material objects, help or support, suggestions, or ideas.

We used the SSR Tool (White et al, 2022) to measure learners' seeking and sharing practices in the makerspace. This study included 51, 3-minute video clips including one focal learner (ages 0-18) engaging in a maker activity. The video included seeking and sharing resources prompted by 4 facilitator roles including educators, caregivers, peers, and children themselves. Two researchers coded the video clips with the SSR tool and yielded a high interrater reliability for SSR practices (alpha=0.94).

Initial findings and implications

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To explore whether different types of facilitators played a role in SSR practices in a museum makerspace (RQ1), we conducted a one-way ANOVA. The result indicated that facilitation from caregivers and self-directed facilitation is associated with significantly higher SSR practices than facilitation from peers or educators. Compared to educators, when facilitation is prompted by caregivers ($p<0.01$), and when learners self prompted ($p<0.05$), they yield a higher amount of SSR practices. This highlights the important role that caregivers and self-directed facilitation can play in a makerspace.

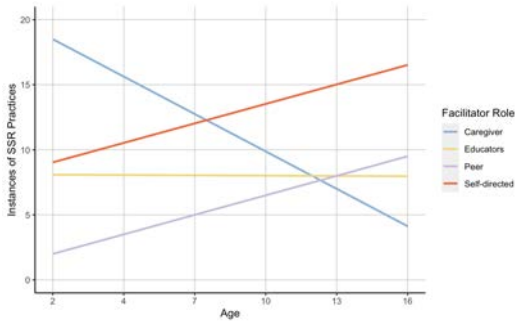
Table 1

*One-way ANOVA & Regression Models (Standard errors in parentheses, ** p<0.01, * p<0.05)*

	Model (1) ANOVA	Model (2) REGRESSION
	SSR Practices	*SSR Practices*
Age		-4.065 (2.514)
Peer	-1.023 (3.061)	-24.92 (27.29)
Self-directed	4.172* (1.581)	-17.88* (7.743)
Caregivers	6.727** (2.054)	Reference group
Teaching artist	Reference group	-17.31* (7.546)
		Interaction Effect
Peer#Age		5.565 (6.561)
Self-directed#Age		5.562* (2.749)
Teaching artist#Age		4.041 (2.649)
Constant	8.023** (1.060)	25.42** (6.827)
Observations	51	51
R-squared	0.240	0.312

Figure 1

Predicted linear regression of each type of facilitators across age



The multivariate regression results (Table 1) suggested an interaction effect between age and facilitation among groups of caregivers and self-directed learning. As children age, we expect to see fewer instances of SSR when facilitated by caregivers and more instances of SSR when engaged in self-directed facilitation. A graph of predicted linear regressions for each type of facilitator illustrates the interaction effect of the caregiver group and self-directed group (Figure 1). In the self-directed facilitation group, SSR practices increase as children grow older. On the contrary, children's SSR practices decline when the facilitation is led by their caregivers as they age. Additionally, we see a slight downward trend in the educators' facilitation as children's age increases. Facilitation from peers also showed a positive correlation with SSR as age increases. Multivariate regression analysis indicated that the influence of different types of facilitators on learning engagement varies across ages.(RQ2) In our analysis, we see an incline in self-directed facilitation in the makerspace as learners get older, with older learners tending to seek and share resources independently. We also observed that peers play an increasingly important role in makerspaces for children in the early adolescent stage.

These findings opened up additional potential approaches to further support and promote engagement in informal learning environments. First, it would also be beneficial to provide support and guidance for caregivers so that they can better facilitate childrens' learning other than just supporting educators. Our study suggested that museums also encourage self-directed learning of young learners. Future design decisions, including the exhibit and facilitation design, should also consider how to further enhance the self-directed learning of young learners.

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International Society of the Learning Sciences

Novice versus Advanced Undergraduate Computing Students' Engagement in Collaboration in an Online Flipped Classroom

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Abstract: This paper explores students' engagement in collaborative learning activities within two data science courses (one introductory and one advanced) taught synchronously online during the 2020-2021 academic year. Here, we draw on a multidimensional perspective of student engagement to understand novice and advanced computing students' collaborative learning practices and propose instructional design elements informed by students' unique needs and the limitations of the virtual format.

Introduction & Rationale

Considering the mass shift to online learning due to the Covid-19 pandemic, instructors of undergraduate students have been tasked with adapting their course material and instructional practice to be appropriate for remote instruction. For disciplines in which peer and instructor interaction are paramount in the development of industry-authentic interpersonal 'soft' skills, the constraints of online learning formats have proven to be a barrier to student engagement. Computing is one such discipline that experiences these tensions.

There is furthermore an increasingly widespread view that flipped classroom approaches engage students in developing these interpersonal skills and practices through active student participation and interaction (e.g., Bishop & Verleger). The flipped classroom model allows students to use class time to engage in iterative problem-solving, collective sense-making, and critical thinking through collaboration with classmates and instructor support. In our prior work, we identified a set of instructional design factors which the literature showed to be effective for flipped classroom implementations (Mithun & Luo, 2020; Mithun et al., 2021).

In this research, we consider how computing students engage in online small group collaborative learning activities in an introductory data science fundamentals course and an advanced database design and management course. We use a multidimensional (Fredericks et al., 2004; Sinatra et al., 2015) and sociocultural (Danish & Gresalfi, 2018) framework of student engagement to understand the behavioral, cognitive, and emotional aspects of students' engagement intersected with their social engagement in collaborative learning settings. We then use these insights in conjunction with instructor observations to identify how the current instructional design for each course can be revised to better suit the unique needs of each group of students. We pose the following questions:

1. How do novice and advanced undergraduate students behaviorally, cognitively, and emotionally engage during peer collaborative activities in an online data science course?
2. How does understanding students' engagement enable instructional design modification?

Methods

A variety of data sources were used to analyze undergraduate students' experiences in the introductory database fundamentals course (n = 21) and the advanced database design and management course (n=12). Students completed an end-of-semester (EoS) survey designed by the authors and a collaborator with expertise in student engagement as multidimensional (see Humburg, 2020). Students also completed university-mandated course/instructor evaluations and participated in an informal focus group facilitated by a third-party evaluator. Novice students additionally responded to weekly exit-ticket check-ins; each week's survey featured a new question about students' experiences within the context of the course, school more broadly, and/or their personal lives.

Quantitative data from the EoS engagement survey was segmented based on the target dimension of engagement, individual versus collaborative setting, and course enrollment. Basic statistical descriptives and comparisons were calculated across all segments in addition to student course/instructor evaluation data. We then ran significance tests across courses for each dimension of engagement and the individual/collective ownership items. We additionally coded all qualitative data (i.e., focus group reports, exit-ticket survey responses, instructor observations, and responses to open-ended text-based survey questions) using two coding schemes.

Findings & Discussion

Our analysis revealed that novice students were confronted with several barriers to engagement in small group collaborative settings which we seek to address in the next implementation of this course. First, we recognize that

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students' lack of behavioral engagement could be attributed to a lack of instructional mechanisms for maintaining individual accountability in group settings. Gaps in cognitive engagement were frequently linked to students not understanding the value of collaborations for their learning and thus, a lack of motivation to participate. Furthermore, novice students struggled to develop meaningful relationships with their peers throughout the semester – a phenomenon students attributed to the inconsistent and random group assignment and lead to a lack of group regulatory interactions.

Thus, we propose the following tweaks to novice students' instruction: (1) negotiating longer-term group assignments during class rather than relying on random weekly assignment, (2) introducing low-stakes 'peer/group evaluations' to more effectively identify and respond to moments of labor imbalance in groups, (3) requiring that in-class work is submitted to the instructor to allow for monitoring of individual students contributions, and (4) increasing transparency around the 'point' and value of collaborative learning activities for each content area.

For seniors, small group collaborative settings enabled the sharing of diverse ideas and perspectives; they recognized that collaborative activities aided in developing interpersonal skills authentic to those they will need after graduation. However, students cited frustrations around the lack of connection between concepts addressed in individual versus group settings. Thus, we take a similar approach as described above and plan to explicitly mention target concepts and practices for each given activity to draw connections between the multiple learning objectives. We also plan to review the current curriculum to better align the core concepts and learning objectives between individual and group activities.

We additionally suggest that student groups could benefit from the integration of mechanisms during large group discussions to make participation be perceived as less 'high stakes.' To do this, we hope to design discussion spaces where contribution is both more accessible and less intimidating for students. We anticipate better incorporating multimodal means of participation (the chat, reactions, polls, asynchronous feedback, collaborative whiteboards etc.) into group discussions to enable students to choose the mode of participation that is most comfortable for them as opposed to not engaging entirely. These approaches to increasing multimodal participation would prove particularly valuable for identifying students' misconceptions as they arise, opening interactional opportunities for group regulation and negotiation, leverage synchronous online tools in instruction as an asset rather than a limitation.

To conclude, we affirm that there is no 'one size fits all' instructional design solution for collaborative learning activities in computing and data science education, but that the students' unique barriers, perceived objectives, and learning preferences be considered in conjunction with affordances of the learning environment to inform theoretically grounded yet context and audience-appropriate instruction.

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International Society of the Learning Sciences

"I Would Rather Argue a Point": How Academic Argument Writing Mediates Civic Cognition and Stifles Democratic Dreaming

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Abstract: This study explores how the forms of writing that young people utilize to discuss civic issues with each other mediate their understandings of the nature and purpose of civic life and open (or close) potential communicative pathways to creative and empathetic forms of civic worldbuilding. Drawing upon a theoretical framework of speculative civic literacies and scholarship in civic cognition, democratic education, and academic argumentation, this study analyzes the discourse practices of 238 high school students from six communities across the United States who participated in a social design-based experiment aimed at fostering democratic dialogue across lines of geographic, social, and cultural difference. Findings from a content analysis of students' digital posts and a qualitative case study of one student's civic literacy repertoires demonstrate that student leveraging of normative academic argument writing structures largely stifles understandings of divergent perspectives and vulnerable civic communication by flattening considerations of identity, affect, and ideology.

Introduction

This study represents one strand of inquiry from the Digital Democratic Dialogue (3D) Project, a social design-based experiment comprised of six high school literacy teachers and their students (n=238) from demographically distinct U.S. communities who leveraged digital media to communicate across time and space in order to excavate their civic histories, analyze their current civic experiences, and dream of collective civic futures. We sought to understand how the forms of writing that young people utilized to discuss (or "argue") civic issues with each other reflected their understandings of the civic and opened (or closed) potential pathways to expansive forms of civic cognition. Specifically, we asked: 1) How do writing structures mediate the nature, tone, and purpose of youth civic communication? Drawing from a theoretical framework of speculative civic literacies, initial findings indicate that the use of normative forms of argument writing largely precluded understandings of divergent perspectives and empathetic civic connections because they invited competitive debate, encouraged the use of civic heuristics, and minimized the role of affect.

Civic Cognition, Democratic Education, and Academic Literacy Instruction

The model of academic argument writing rewarded on standardized literacy exams (and thus taught in an overwhelming plurality of public schools) follows a formula developed by rhetoricians in the 1980s involving the statement of a thesis supported by a collection of claims, evidence, and warrants (Toulmin et al., 1984). When the Common Core policymakers situate this model as effective preparation for deliberation in civic life, they presuppose a utilitarian public sphere in which claims are judged logically on their merits and in which citizens take actions aimed at furthering the collective public good. The underlying assumption is that teaching students how to craft arguments in language approximating objectivity using credible evidence will increase the likelihood that they can successfully advocate for their priorities within U.S. civic institutions (Gutiérrez, 2009). This assumption minimizes what integrative theories tell us about the social and cultural aspects of civic learning that must be attended to in instructional design to disrupt societal inequality (Nasir et al., 2021). Civic cognition is deeply tied to expressions of identity and community membership and decisions often rely upon heuristics and appeal to emotion, which suggests that conventions of academic argumentation do not map well onto the project of successfully advocating for priorities in the world as it actually is (Bougher, 2012).

Speculative Civic Literacies

The speculative civic literacies framework argues that normative practices of literacy and civic engagement are insufficient building blocks for the creation of liberatory social futures; instead, it calls for the cultivation of "expansive, creative forms of meaning-making and communication aimed at radically reorienting the nature and purpose of shared democratic life toward equity, empathy, and justice" (Mirra & Garcia, 2020, pg. 297). The framework takes up Thomas & Stornaiuolo's (2016) approach of "restorying" existing narrative forms by supporting young people to interrogate and innovate the civic narratives that are too often foisted upon them. By supporting the development of new literacy practices that speak to new social potentialities, re-story the existing

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world, and are grounded in the cultural and historical truths that young people possess, this framework evaluates writing practices based on the extent to which they push on the normative and reach toward the speculative.

Methods

We organized the 3D Project as s social design-based experiment that sought to collaboratively reimagine syncretic civic literacy learning experiences for the purposes of social transformation (Bang & Vossoughi, 2016). Six high school teachers representing the states of Alaska, California, Colorado, Michigan, Pennsylvania, and Texas were recruited from the National Writing Project network to participate in the study with one or more of their classes. Our team developed and enacted three design cycles during the 2018-2019 school year that teachers implemented in their ELA classes as part of their core curriculum. For the purposes of the specific inquiry detailed here, we focused on the discursive practices in which students engaged during Design Cycle 2 when they organized themselves into 30 online discussion groups drawing from 14 topics ranging from animal rights and the environment to healthcare and homelessness. We analyzed 372 exchanges across the 30 discussion groups, defining an exchange as a discussion consisting of at least two posts in which students took turns responding to each other about an initial posting (median of 12 exchanges across each of the discussion groups.

Preliminary Findings

When analyzing Design Cycle 2's cross-school civic discussion groups, the 3D Project teacher team found that the great majority of students gravitated initially toward writing that drew upon the academic argumentation paradigm – and that the utilization of this paradigm tended to end exchanges quickly. We found that 83% of the discussion exchanges began with an academic argumentation move. When other students in the discussion group responded with further academic argumentation (which occurred in 74% of cases), the exchange typically ended within three further moves (87% of cases). By contrast, exchanges that began with or transitioned to civic dialogue moves tended to foster lengthier and more complex exchanges. In one example, the writing practices that Cory, a white, male 11th grader living in a small Alaskan town, leveraged during his participation in the 3D Project demonstrated how academic argumentation can serve to both mask the social, cultural, historical, and political nature of civic cognition and forestall vulnerable engagement with different perspectives. During the first design cycle of the project, Cory stated, "I do not enjoy talking about myself [and] would rather argue a point." He attempted to create a dichotomy between himself and the points that he espoused throughout the project by appealing to principles of academic argumentation, yet his claims continually remained subjective and served to reify the very identities he sought to downplay.

Implications and Next Steps

This study's analysis of student civic writing and communication practices raise important questions for the fields of literacy and civic education about the cognitive processes involved in perspective-taking and the effectiveness of current paradigms of academic argumentation to support the development of productive – let alone speculative – civic dialogue. In further analyses of the 3D Project, we seek to explicate the conditions under which the practices of questioning and storytelling led to more generative and imaginative forms of dialogue between students. In future studies, we seek to conceptualize and test alternative writing models that could support new paradigms of stance-taking and civic value-sharing.

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International Society of the Learning Sciences

Key Elements of a Critical Approach to Financial Literacy

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Abstract: Financial Literacy is a topic of recent emergence, still subject of debate about its epistemology and disciplinary background. While Latin American governments are implementing National Strategies for Financial Education under the guidance of multilateral institutions, arguments against these initiatives consider that they perpetuate oppressive practices while displacing the focus of the problem from the financial system to individuals. This poster presents a theoretical proposal for a critical approach to financial literacy to address these concerns.

Introduction

Scholars from disciplines like education, sociology, anthropology, and geography have raised concerns about the dominant paradigm of financial literacy promoted by multilateral organizations (e.g., OECD, the World Bank, AFI, among others) (Blue & Grootenboer, 2019; Hutten et al., 2018; Lucey, 2022; Pinto, 2017; Willis, 2017; Zokaitye, 2017). Financial literacy initiatives have been focusing on increasing individuals' involvement with financial system (Prabhakar, 2019), aiming to foster economic growth and reduce economic inequality. However, these expectations remain unmet and, in most countries, the gap between the richest and the poorest is increasing.

In this context, several Latin American governments, supported by multilateral organizations are developing and implementing *Estrategias Nacionales de Educación Financiera – ENEF*. 'National strategies for financial education' provide the guidelines for deploying financial education, defining common goals, identifying relevant challenges and obstacles, and establishing priorities and a coordinated plan at the national level (OCDE/CAF, 2020). These strategies are highly relevant considering that they configure power and politics in financial education, thereby influencing the definition of the why, how, with whom, and for whom of financial literacy initiatives.

The purpose of my poster is to discuss the theoretical foundations of a critical approach to financial literacy useful to assess the impact of these national strategies and to direct the attention of these policies to the interests of the most vulnerable populations.

Challenging the dominant paradigm

Different voices within the learning sciences field have been calling on scholars to embody the political context in their research questions in recent years. For example, The Politics of Learning Writing Collective (2017) advocates incorporating issues like culture, identity, gender, race, and power in the discussion about learning. Philip and Sengupta (2021) urged scholars to adopt a contrapuntal approach in their designs and theories for recognizing and challenging the sociopolitical contexts in which learning happens. Finally, Penuel's (2019) idea of infrastructuring acknowledges the need to redesign infrastructural components of policymaking to support learning sciences innovations that otherwise would not be sustainable or scalable. Research on financial literacy would benefit from the adoption of these approaches in their analyses.

Sociocultural perspectives present useful frameworks to study how people learn to manage their finances while paying attention to context and relationships between individuals. For instance, Esmonde's (2016) six distinctive elements from sociocultural theories to analyze power provide a solid base to describe the power asymmetries between people and the financial system. Gutierrez's (2008) sociocritical literacy framework offers an alternative perspective to inspire individuals to find alternatives to the oppressive practices of the financial system, respond to the poverty caused by capitalism, and design their own futures.

Elements of a critical financial literacy framework

This proposal of a critical financial literacy framework elaborates on ideas previously discussed by authors from different disciplines. For this discussion, I will introduce three elements from these discussions that follow the ideas presented in the previous section.

The first element is the importance of offering immediately relevant, age-appropriate, and inclusive content (Pinto, 2017). The design of financial education interventions requires careful consideration of the audience to assess their characteristics, needs, and expectations. One-size-fits-all designs have proven to be ineffective and are considered perpetrators of systemic inequity (Lucey, 2022). The second element problematizes the excessive focus on individual wealth accumulation as the principal purpose of financial education (Blue & Grootenboer, 2019). If the goal is to reduce inequality, a holistic approach that privileges collective well-being

would be more appropriate (Pinto & Coulson, 2011). Finally, the third element relates to financial literacy as a response to the influence of financialization (i.e., the presence of finance in all aspects of everyday lives) (Lucey, 2022). Instead of playing a normative role following the premises of financialization, it is essential to facilitate the critical engagement of individuals with the growing sphere of finance (Hutten et al., 2018) enabling them to think about the economic and financial implications of their decisions (Willis, 2017).

These elements provide important perspectives to be included in the study and design of new strategies and interventions about financial literacy from a critical approach.

Discussion and further steps

Considering financial education as a mere tool for increasing financial inclusion is simplistic and doesn't respond to individuals' needs or welfare. Financial education's potential to help people make better decisions and think critically should be acknowledged and privileged instead of considering that people will do better only because they hold a financial product. Moreover, implementing ENEFs in Latin American countries could provide new opportunities for their citizens if they adopt a critical financial literacy framework.

Understanding what people need and expect from financial education and the financial system in general, is indispensable to designing better programs. At the meso- and micro-levels, design-based research (e.g., social design experiments, DBIR) could be helpful to implement the ideas presented and assess the effectiveness of alternative designs of financial education. Anticolonial frameworks could provide practical elements to consider in alternative designs. Future research projects should focus on groups highly affected by inequality and poverty like women, youth, and rural populations in Latin America.

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Methodological Progress in Co-Regulation and Socially Shared Regulation of Learning Research: A Systematic Review

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Abstract: Self-regulated learning (SRL), co-regulation (CoRL), and socially shared regulation of learning (SSRL) have been essential for successful learning and collaboration. However, it is challenging to objectively capture the "invisible" cognitive and emotional processes at the foundation of learning regulation. To better understand and support SSRL, the study reviewed 118 journals published between 2003 and 2020. Results highlighted the need for methodological development of reliable multilevel analysis methods to analyze multimodal data at different proximal levels.

Introduction

Regulation Learning Theory has moved beyond the scope of cognitive process and outcome, to defining SRL as a social, interactive, dynamic, temporal, and developing process (Malmberg et al., 2017) that require a shift toward new forms of instructional tools, data collection, data analysis that acknowledge social entities and shared tasks. Sequencing data and state-of-the-art data mining algorithms are thus utilized to study and represent this transition. Increasing acknowledgment of the interactive role of motivation and emotion (Järvenoja et al., 2020) likewise leads to the exploration and inclusion of physiological measures such as electrodermal activity data, facial recognition of affective triggers and triangulation of multichannel data as a new approach to capturing critical phases of SRL.

Although recent methodological progress has been made to better examine (S)SRL and extend our understanding of the SRL processes, it is still somewhat unsatisfactory. The methodological progress and related challenges have been subject to considerable discussion, and there is an increasing demand for innovative methods with high reliability to advance the field of study. Accordingly, this systematic review highlights the relevant research gaps in guiding the methodological development in (S)SRL research. This study seeks to address the following questions: (1) how has research methodology in CoRL and SSRL of learning progressed over the period between 2003-2020? and (2) What are the key methodological challenges for CoRL and SSRL?

Research methodology

The content analysis approach was adopted to identify methodological gaps in regulation research and suggest implications for the future research agenda. The search string to retrieve relevant articles from the Scopus database is: TS = (TITLE-ABS-KEY ("co-regulation" OR "co-regulated" OR "shared regulation" OR "socially shared regulated" OR "shared regulated") AND TITLE-ABS-KEY (learning)) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "PSYC") OR LIMIT-TO (SUBJAREA , "ARTS")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (EXCLUDE (PUBYEAR , 2021)).

Result and findings

In total, 118 relevant articles on CoRL and SSRL were screened and selected for the systematic review. Table 1 presents the methodological research gaps, while Figure 1 visualizes the frequency of each data type utilized.

Table 1: *Methodological Research Gaps for CoRL and SSRL*

Method Facets	Research Gaps	#
Design of Study	Need for longitudinal approaches	11
	Lack of group comparability would limit the interpretation of the intervention effect	13
	Experimental versus natural setting of study presents different trade-offs	4
	Lack of holistic methodology in collecting complex, nested, and time-bound data.	5
	Hawthorne effect	3
	Lack of intervention fidelity	2
	Research instruments with arbitrary measures	24

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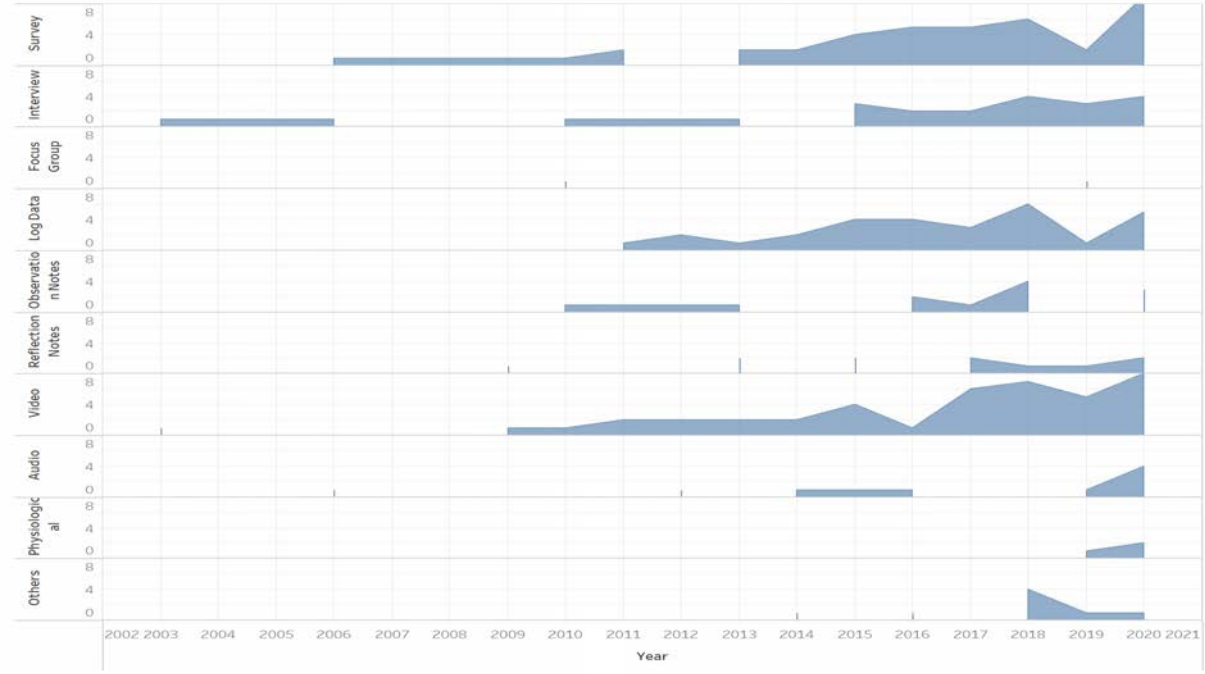
Data Collection	Lack of diverse data collection, need to transition from self-reported data	10
	Sampling bias	5
	Small sample size	29
Data Analysis	Need for integrated multilevel analysis	11

Figure 1: *Types of Data Used for CoRL and SSRL Research*



The Need to Examine (S)SRL at Different Proximal Levels

The majority of SRL studies do not take a longitudinal approach. Since SRL features learners' ability to take ownership of their learning processes, temporal behavioral changes are insufficient to constitute the longitudinal trajectory of change in regulatory efficacy and beliefs. Therefore, we argue there is a need to measure (S)SRL at various proximal levels: capture critical temporal small-scale moments that trigger regulated learning, and longitudinal studies to examine protensive changes of learning behaviors and strategies influenced by these.

The Need for Multimodal Data Collection

Although there are merits concerning the different data collection methods for SRL studies, researchers have noted the limitations of the self-reported data approach, whereby data collected may not be accurately measured as learners overestimated their SRL skills and the lack of domain-based skills measures. The multimodal data approach to CoRL and SSRL research would be a fruitful area for further research.

The Need for Reliable Multi-Level Analysis

By nature, SSRL associated with metacognitive, cognitive, behavioral, and motivational negotiation and adaptation are intertwined with individual, social and environmental conditions that influence and are influenced by regulatory activities. Thus, nested levels of individual data in that group should be explored to determine the reciprocal relationships among different measured variables. Multilevel analysis shows its efficiency in recognizing hierarchical structure and partition of such individual-level and group-level variables.

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International Society of the Learning Sciences

Towards Automated Tracking of Affect: Testing the Use of Continuous Self-Reports and Multimodal Metrics

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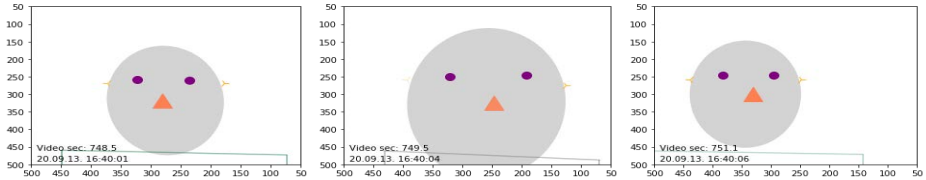
Abstract: The affective states of students while studying outside of class hold rich information about how students are doing in a course and how instruction could be improved. In this paper, we test the co-occurrence of webcam-based nonverbal metrics with self-reported student affective states during an instructional video. Preliminary results suggest that low-level, self-reported affect can be a promising ground truth data for research, and that nonverbal metrics created from webcam streams can be associated with this self-reported affect.

Introduction and setting

The affective states of students while studying outside of class is generally unknown to instructors – However, this information can help instructors better support student needs. With this motivation in mind, we collect two data sources an introductory data science course that could help track student states: continuous self-reports of affective states, and multimodal data via a webcam-based data collection tool, EZ-MMLA. The system does not save video data, and gives students access to their data (see Schneider, Hassan & Sung, 2021, for more details). From the x, y position of the eyes, ears, nose, and upper body joints, four known cues of affect are detected by simple rule-based algorithms: head tilts and nods (e.g., Lee & Marsella, 2006), zoom-ins (e.g., Zhao et al., 2020), and hand over face (e.g., Behera et al., 2020). Figure 1 shows a data sample labeled as "zoom-in".

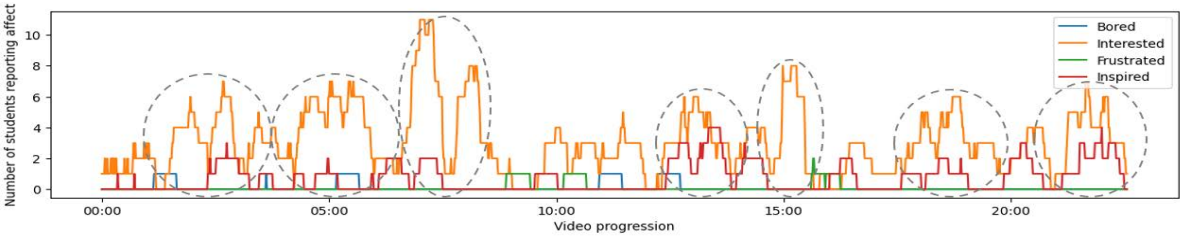
Figure 1
A Student zooming in close to the screen



Results

We first explore affect self-reported with reaction buttons next to the video, to see whether this could serve as ground truth. Then, we perform statistical analysis to check for the existence of links between self-reports and multimodal metrics. Figure 2 illustrates student affect responses throughout the duration of a video. The y-axis shows the number of students reporting an emotion within 30 seconds of a given time. For legibility, we visualize four contrasting emotions (bored/frustrated, interested/inspired), and describe the remaining two (aha, confused).

Figure 2
Self-reported affect for all students: Boredom, interest, frustration and inspiration



Students most frequently reported being 'interested' out of all six possible emotions. Reports tended to congregate around points (circled in dotted lines), indicating moments in the video that students commonly find interesting. While feeling 'inspired' is rarer, the patterns match expectations as they seem to be reported only during times where interest was high. Students rarely reported that they were bored or frustrated. We suspect these emotions may have been underreported, given prior research that documents the prevalence of boredom during learning (Baker et al., 2010). However, we note the few instances of boredom or frustration that exist

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tend to occur in where there are valleys in reported interest. Visual inspection also showed the existence of clusters for "aha" and "confused" reports, and a pattern of confusion preceding "aha" moments.

For the nonverbal metrics, chi-squared tests of independence indicate that all four metrics have significant associations with affective states (nodding: $\chi^2(3, N = 2410) = 37.23$, $p < .001$; tilting: $\chi^2(3, N = 2410) = 13.67$, $p = .003$; hand on face: $\chi^2(3, N = 2410) = 19.56$, $p < .001$; zoom-in: $\chi^2(3, N = 2410) = 69.57$, $p < .001$). Boredom and frustration were excluded due to suspected underrepresentation, and subsequent violation of the size requirement for the chi-squared test. Cramér's V, a measure of effect size that corrects for sample size, indicates that only nodding and zoom-ins are substantially associated with affective states (Cohen, 1988). We summarize the co-occurrence between these four affective states and two metrics of interest in Table 1.

Table 1
Contingency table for the co-occurrence of metrics and affective states

	Nodding	Not nodding	Zooming-in	Not zooming-in
Aha	38 (+9.30)	420 (-9.30)	**20 (-18.39)**	**438 (+18.39)**
Confused	**33 (-18.19)**	**719 (+18.19)**	**105 (+41.97)**	**647 (-41.97)**
Inspired	0 (-15.66)	230 (+15.66)	31 (+11.72)	199 (-11.72)
Interested	**93 (+27.03)**	**876 (-27.03)**	**46 (-35.30)**	**924 (+35.30)**

Each cell shows how long in seconds a behavior was observed during an affective state, and deviance from chance (in parenthesis). For instance, during 'aha' states, zooming in was observed for 20 seconds, which is 18.39 seconds less than expected by chance. As expected, we observe nodding much more than chance when students felt interested, and less so than chance during confusion. Students also zoomed in much more than chance during states of confusion, and less than chance with reported interest and 'aha' moments. We understand this as students moving closer to the screen only while they need to scrutinize the material to resolve their confusion, moving away prior to reporting aha moments or higher levels of interest.

Conclusion

We investigated the use of continuously self-reported affective states and nonverbal multimodal metrics for tracking the affective state of learners outside of the classroom. Coherent patterns within and between emotions indicate students are using the button as intended, and that continuous self-reports could be a promising way to collect ground truth data for research. However, further investigation is needed to ensure that students are reliably reporting states, particularly for negative emotions. Additionally, based on these self-reports, we were able to discern two promising non-verbal metrics for automatic tracking of student affect, nodding and zooming in. These metrics were most consistently tied with two emotions: interest and confusion. These prevalent affective states are noteworthy for their relevance in supporting students, e.g., knowing when students are interested and bored to update the learning material. In future investigations, we plan to expand and refine nonverbal metrics to gain more accurate proxies of student affect. Ultimately, our goal is to track previously invisible student states outside the classroom with the help of automatic, non-intrusive multimodal metrics.

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Developing a boundary practice for collaborative task design in a design-centric research–practice partnership

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Abstract: Collaborative learning needs tasks suitable for collaboration. As part of a project to study the design of collaborative environments, we describe how a partnership with an undergraduate mathematics professor led to the development of a boundary practice for collaborative task design. Initially there was a tension between the researchers' preference for ill-structured tasks and the professor's priority of conceptual over computational problems. We discuss how focus on a single task resolved the tension and gave both researchers and the professor useful design tools for meeting their respective goals in subsequent task revisions.

Introduction

The design of a collaborative task is critical to the success of collaborative learning. Here we explore the role of the partnership with a professor in the development of task design conjectures (Sandoval, 2013) and the iterations on task design for collaborative tasks in an undergraduate mathematics class. Design-centric research–practice partnerships (RPPs) are characterized by tacit, conflicting motives (Kali et al., 2018). Developing a shared vision by surfacing contradictions is essential to create new practices for the collaborators (i.e., "Boundary Practices," Akkerman and Bakker, 2011). We describe how the task design iterations allowed for engagement within the boundary space to create an understanding of the learning goals for this course and the collaborative tasks.

Setting, design, and methods

We developed five collaborative tasks to be used for remote learning in an undergraduate applied linear algebra course. The team began work 5 months before the semester began. After 2 months, we began meeting weekly with the professor to discuss task iterations. A significant shift (henceforth "breakthrough") occurred in our thinking 1 month before the start of the semester while discussing revisions to the Week 5 task, leading to revisions of the three existing tasks and a streamlined design process for the remaining two that continued into the semester.

Data were notes from meetings and our task iterations. We constructed descriptions of our design conjectures for collaborative task design before, during, and after the breakthrough. Then we connected them in a narrative of the significant elements of our process that contributed to the occurrence of the breakthrough.

Findings

Initial designs

Our initial work was based on prior work on engineering tasks (Shehab & Mercier, 2017), in which ill-structured problems played a central role. Accordingly, we initially designed activities around an authentic, ill-structured task. We conjectured that many solution pathways would encourage the group to take up members' proposals, while the need to agree on a solution would incentivize moves to find agreement (Fernández et al., 2001). A scenario and visualization were used to create authenticity and offer multiple layers of meaning to be used to come up with solution ideas. Each task had structured subparts that were intended to prepare students to engage with the central task. The task concluded with reflection questions that we conjectured would reframe the shared experience of problem solving as an opportunity for discussion, rather than in terms of getting the right answer.

The Week 5 task was unusual in that there were no scenarios or visualizations. Students had to prove a symbolic mathematical statement about matrices, with general guidance on how to devise solution ideas. The task was authentic in that engineers may need to abstract proofs to characterize the behavior of a modeled system.

RPP negotiation

We first identified the purpose of the tasks: to teach students to solve conceptual problems, as contrasted with computational problems. The researchers initially understood the ill-structured tasks they had designed as achieving this goal: students would have to construct conceptual heuristics to simplify the complex problem enough to communicate about it and make progress. However, the professor maintained that the problems were too computational, other than Week 5, which seemed promising.

This tension resulted in a breakthrough in the RPP. The researchers realized that when using the phrase "conceptual problem" the professor was referring to a specific genre of mathematical problems, a distinction which did not exist in the STEM fields in which the researchers were trained. Week 5, which asked students to prove a mathematical statement, was a good example; other weeks, which involved constructing a design followed by significant calculational work, were not—except for the structured subparts intended to prepare students for the ill-structured problem. Subsequently, the researchers realized that in pilot tests of the tasks, the preparatory subparts themselves afforded collaborative work. We tabled the conjecture that ill-structured problems could afford collaboration and revised the existing tasks to focus on the structured, conceptual-problem subparts.

Without the conjecture about ill-structured tasks, the researchers decided to revise Week 5 to give it more structure: a walkthrough in six parts of how a mathematician might approach thinking about the proof, including explicit quotations of what the mathematician might be thinking at each step. The professor found this structure in line with his pedagogical goals. Whereas previous worksheets that he had written consisted of isolated problems for students to *practice* solving in groups, he would go on to use the "mathematician's walkthrough" in future tasks to turn the problems into opportunities for students to *learn* a mathematician's perspective.

Modified designs

Subsequent revisions to the design conjectures were minor. Without the ill-structured problem, the structured problems took priority and could be refined. We realized that the multiple layers of meaning offered not only a source of ideas for the group, but also a means to communicate those ideas, such as by drawing on or pointing to the visualization. We also had more time to devote to reflection questions, which during pilot tests were effective at prompting conceptual discussion. We placed reflection questions at different points in the worksheet to reflect on smaller key ideas that were critical to understanding and solving the overall task.

The final structure for all tasks except Week 5 consisted of an easy introductory problem to help students begin confidently, two problems divided into subparts, each followed by a reflection, and a final "challenge problem" without any scaffolding to further engage groups who finished the first three parts.

Discussion

We began developing task iterations five months before the start of the course. The early development of tasks gave us a boundary object to use to align our visions and substantively revise our design conjectures. The professor's learning goal priorities led the researchers to focus on a relatively neglected aspect of the task design, which improved the design and our theorizing about affordances for collaboration for this context. In turn, the researchers' new ideas for collaborative task design offered the professor an idea for how to design tasks that would better meet his learning objectives. Viewing the task iterations as boundary objects allowed them to become joint representations of the collaboration, and a malleable tool for fostering understanding and knowledge growth within the team, rather than static objects provided by the researchers to the professor to use.

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Acknowledgments

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Designing to Support Teacher Mediated Strategies for Student Learning in a Remote Kindergarten Music Class

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Abstract: Using a single-setting, iterative DBR approach to program design, along with the multimodal affordances of music learning, I consider resource design to support teacher mediated student learning in remote contexts. Throughout the KinderMus program, teachers adapted their teaching in remote spaces, finding ways to mediate learning through language, social interaction, and active learning, and considering limitations around access to externally oriented artifacts. Findings have implications for design in both remote and in-person settings.

Introduction

As K-12 education moved almost entirely online in the 2020-2021 school year, many of the strategies regularly employed by teachers to scaffold teaching had to be modified for the unique context of remote learning. This move was especially challenging for early childhood teachers. The change in environment physically separated learners from their peers, reducing opportunity for collaboration, and challenging teachers to rethink active teaching strategies for students seated in front of a computer monitor at home. Many of the strategies like group and partner work, games and movement-based activities regularly employed by teachers required modification. While challenging, this new context offered an exciting opportunity for designing to support teacher development around teaching in remote learning contexts for kindergarten students while simultaneously supporting student learning. Using design principles rooted in design based research (DBR) (Design-Based Research Collective, 2003) along with the multimodal affordances of making music, I consider how teachers adapted and codesigned resources to develop new strategies for mediating learning in remote kindergarten classrooms, with implications for design of both remote and in-person learning environments beyond the present context.

KinderMus Program Design

The objective of the KinderMus program was to both support teacher development around mediating learning in remote contexts and provide opportunity for student learning in music. The design is based on understanding that students learn best when they are actively engaged, when instruction is multimodal, and within a social context along with their peers (e.g., Vygotsky, 1978) and I chose music as a disciplinary focus because it engages students in listening, singing, moving, and playing. As both researcher and music teacher, I grounded the program in general music theory with opportunities for teachers to practice music teaching techniques and engage with students in their music learning, and for students to engage actively with the songs and activities. Lessons were responsive to weekly teacher feedback and reflection. The design of the resource-driven program is based on principles of DBR (Design-Based Research Collective, 2003) and elements of effective teacher PD (Darling-Hammond et al., 2017; Desimone & Garet, 2015).

The program is based on four main design elements. First, KinderMus is content focused on music, incorporating singing, playing, moving, modelling, and peer interaction. Multimodal teaching strategies engage students through active learning and can also be applied in other academic areas. Second, the program is centered on resources and artifacts (Kazemi & Hubbard, 2008). Components include prerecorded, interactive video lessons, written lesson plans, weekly student assessment rubrics, and weekly teacher reflections. Teachers used video lessons during synchronous instruction, directly delivering music content and vocabulary and modelling movements and games. Third, KinderMus is designed in and for real world settings, as interactive resources allow for practice in the classroom context with students (Design-Based Research Collective, 2003; Desimone & Garet, 2015). Students learn both directly from the video resource and from their teacher's interactions with the videos. Fourth, the program employs responsive design strategies (Design-Based Research Collective, 2003). Teachers inform the initial design by providing weekly assessments and reflections. Feedback is directly applied to lessons and resources are constantly updated for student interests, engagement, and learning pace.

Methods

For this exploratory study, I took a single-setting, iterative DBR approach to program design. The study was conducted from fall of 2020 through winter of 2021 at an elementary school site in south Los Angeles County that delivered synchronous lessons remotely during the COVID-19 pandemic. I analyzed weekly teacher survey responses to open-ended questions asking how teachers were using the lessons and their perceptions of student learning as the program progressed, as well as three semi-structured post program interviews conducted with each

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teacher participant. With an iterative approach to data analysis, themes around mediated learning emerged, with descriptive codes emphasizing the verbal, social, and instructional moves individual teachers made to interact with the videos and their students in support of student learning.

Findings

Even in the remote context, teachers were able to adapt many typical classroom teaching strategies to mediate student learning. Responsive design increased teacher and student engagement in music activities. Teachers described mediating learning through language, social interaction, and active learning, and considered limitations around access to externally oriented artifacts (see Table 1).

Table 1

Ways in which teachers adapted to mediate student learning in remote music class

Mediation in music class	Description	Examples from teacher interviews
Language: Verbal scaffolding	Teachers provide verbal guidance, cues, and ideas while students participate in music class; they also make connections to prior knowledge and other student interests	*They liked having their turn so sometimes I would have to give an idea, you know, that was the only one that was hard sometimes. I would have to feed an idea in there.*
Social interaction and imitation	Teachers and peers provide modeling and interaction so students can imitate and participate in group activities	*If I'm dancing to the music. I see them dancing to the music ... I just automatically thought I have to do it. They have to see me model. So I danced and I jumped. I did all that stuff.*
Play: Movement and activity	Learning and meaning-making through active learning activities and play including pantomiming action words in a song, and clapping, stomping, and dancing; lack of opportunity for free play	*The students definitely like to participate. They look forward to me pausing so that they can input their own movement to the songs.* *I really like that everyone can pat and sing and participate so that they don't get bored or lose concentration.*
Artifacts and tools (externally oriented)	Use, adaptation, or lack of books, instruments and other manipulatives to support music learning; home tools are adapted for music making	*...if we were in the classroom, like instruments, you know, like when you are doing the drums ... I have a big box that has cymbals and sticks. So if we all had that ... that would be awesome.*

Conclusion

The Design-Based Research Collective (2003) emphasizes the importance considering how context "can lead to improved theoretical accounts of teaching and learning" (p. 7). Through this DBR project, teachers adapted their teaching in remote spaces, finding ways to mediate learning through language, social interaction, and play-based instructional strategies, and considering limitations around using externally oriented artifacts. While this exploratory study was conducted under somewhat extraordinary circumstances, the idea of designing resources that simultaneously support teacher development and student learning may be adapted for in-person learning and useful in subjects where teachers may have less personal content knowledge and expertise.

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International Society of the Learning Sciences

Adolescents' Interdisciplinary Learning in Self-Driven Learning

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Abstract: Increasingly complex societal and environmental issues demand interdisciplinary solutions. However, there are barriers to implementing interdisciplinary learning, especially in the K-12 context. This study explored whether adolescents (i.e., mainly high-school-age students) chose to pursue interdisciplinary learning topics when they could choose learning topics. Through a content analysis of the application materials of 800 adolescents (M_{age} =16.59) participating *GripTape* – a 10-week self-driven learning program, we found that 44% of learners chose interdisciplinary learning topics. The results suggest that adolescents care about complex societal issues and are willing to tackle them using interdisciplinary knowledge in self-driven learning.

Introduction

Tackling complex real-world issues usually requires interdisciplinary thinking and knowledge. There is a need to foster interdisciplinary learning that is concerned with learners integrating knowledge derived from multiple disciplines to deal with complex problems, situations, and themes (Ivanitskaya et al., 2002). The Next Generation Science Standards suggest that subjects such as science, engineering, and technology are interdependent, mutually supportive, and together affect human society and natural environments (NRC, 2012). However, it is challenging to implement interdisciplinary learning in the school context considering the organization of current curricula, students lacking competencies to navigate across disciplines, and teachers' limited experiences and knowledge in supporting students' interdisciplinary learning. These challenges make us wonder whether self-driven learning, which usually happens outside of school, promotes interdisciplinary learning topics. Self-driven learning emphasizes students' own responsibility, agency, and motivations for pursuing meaningful goals (Ferlazzo, 2015). This study aimed to explore whether youth chose interdisciplinary learning topics in a self-driven learning project, *GripTape*, in which they can determine the learning challenges.

Method

The participants were 800 youth (58.25% female, M_{age}=16.59) accepted by *GripTape* from 2016 to 2020. The project offers youth between 15- and 19-years old opportunities to pursue learning challenges that they are passionate about. Among the participants, 20.75% identified themselves as Hispanic or Latino; 19.63% as Black or African American; 11.88% as White, Non-Hispanic; 7.88% as Asian/Asian American; 2.75% as American Indian or Alaska Native; 0.75% as Native Hawaiian or Other Pacific Islander. The other participants did not report their race information or reported "other". The data source was participants' textual responses to the questions "*What topic or skills are you planning to explore during this Challenge"*. Guided by the common subject classifications and inductively added new categories based on the data, we included the following categories in the final coding book when analyzing participants' determined topics: Arts & Humanities, Business & Economics, Clinical, Pre-Clinical & Health, Computer Science, Engineering & Technology, Life Sciences, Physical Sciences, Social Sciences and Law (Times Higher Education, 2020). Two raters independently coded 258 (31.73%) youth responses and achieved a substantial average agreement in all the categories (Cohen's kappa=0.62, Landis & Koch, 1977). The rest of the data were split and coded by the two raters. The learning topics involving one topic area were labeled as single-subject topics while the ones involving two or more topic areas were labeled as interdisciplinary topics.

Results and Discussion

Figure 1 shows the distribution of youth's learning topics. We can see that Arts & Humanities, Business & Economics, and Social Sciences were the three more prominent topic areas. A similar percentage (around 5%) of youth's learning topics fell into the categories of Clinical, Pre-Clinical & Health, Computer Science, Engineering & Technology, and Life Sciences. Relatively fewer youth chose Physical Sciences and Law relevant topics.

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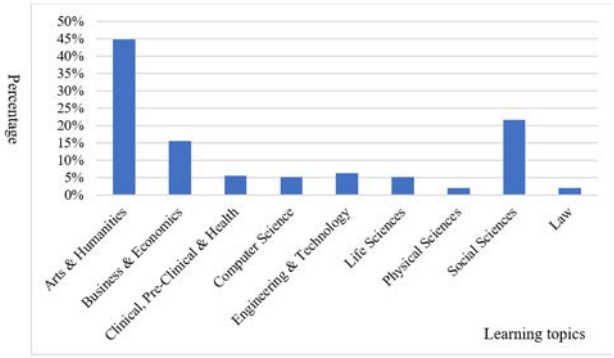

Figure 1. The distribution of learning topics

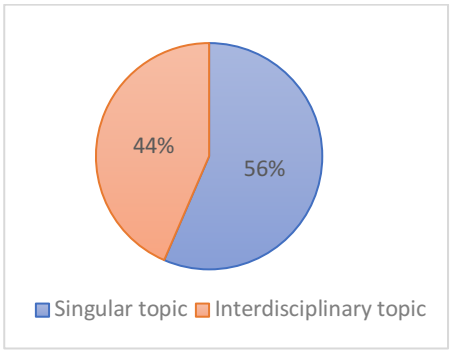

Figure 2. The distribution of singular versus interdisciplinary topics

As Figure 2 shows, 56% of participants chose singular-subject topics in their learning challenges while the other 44% of youth chose interdisciplinary topics. The following is an example of a single-subject topic that was coded as Arts & Humanities because the participant mainly aimed to explore music and singing in the learning challenge.

> *"I plan on exploring music and singing during this challenge. I want to buy music equipment so that I can record the songs that I have written (and hopefully post videos on Youtube). I am passionate about this because music is all that I know. I have been singing and writing songs since I was a little girl, about 6 or 7 years old, I really want to make it into the entertainment field…"*

The following example was coded as both Arts & Humanities and Psychology, and therefore, was identified as an interdisciplinary topic. This participant not only wanted to pursue photography but integrated it with youth self-esteem.

> *"I hope to pursue study in photography and the increase of self-esteem of youth that come from the inner city (using cameras and images), specifically at James Hillhouse school. I'm passionate about this because I was once bullied and didn't have the person in my life besides my mother, (who was alive at the time) to help me build that inner confidence with this project I hope to alleviate some of that pain that students like myself have faced."*

This study found that 44% of youth chose interdisciplinary learning topics when they were not constrained by curriculum structures and were empowered to make decisions. Real community or society issues tend to be authentic and complex and may require the participants to acquire related knowledge, resources, and approaches from several disciplines to make sense of (You, 2017). Interdisciplinary learning benefits learners' deep understanding, positive affect, and creation. It can provide "relevant, challenging, and enjoyable learning experiences" to learners (Scottish Government, 2008, p. 21) and contexts for creativity to arise (Madden et al., 2013). Schools and positive youth development organizations can consider how to enhance youth's self-driven learning by incorporating their agency and voice in learning.

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International Society of the Learning Sciences

The Effects of Affective Feedback on Learners' Emotions in Asynchronous Video-Based Learning

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Abstract: This study examined the effects of affective feedback on learners' boredom, confusion, and frustration in asynchronous video-based learning. Affective feedback messages and writing activity were used to deliver the utility value of learning topics. Facial expression data from 30 adult learners were collected and analyzed to identify changes in affective states. The findings suggested that the utility value message had a significant on reducing learners' boredom.

Introduction

During the COVID-19 pandemic, asynchronous video-based learning was widely adopted in various learning situations to support emergency remote learning. Despite its flexibility, asynchronous video-based learning has been criticized due to the lack of interaction and delivery-centered content presentation. Learners with fewer self-regulation skills tend to experience various emotional states, including confusions, frustration and boredom that negatively influence learning processes and outcomes. In general, feedback approaches to influence online learners' emotions have been cognitively-oriented, such as the provision of question items. While cognitive feedback is essential to help learners better understand learning content, it is equally important for learners to understand why they learn, such as the utility value of learning tasks, to sustain their attention and interest during online learning. Pekrun (2006) argues that achievement emotions are mainly influenced by two appraisals: control and value. Control refers to the perceived causal influence over the learning process and outcomes such as the belief that learning will be completed through one's efforts. Value refers to the perceived valence of action and outcomes, such as the meaning that learners attribute to performing certain learning tasks.

With this backdrop, this study focuses on the role of values on academic emotions, especially utility values' effects on online learners' affective states. Utility value refers to how a task fits one's future plans (Wigfield & Eccles, 2000). This study used two approaches to increase the utility values perceived by learners who took a video lecture about big data: affective feedback message and writing activity. First, we designed affective feedback messages to deliver the utility value of learning content and tasks. Second, we designed writing about the utility value of the lecture topic (i.e., big data) as a pre-learning activity. Writing or reading about the utility value of a learning topic is effective to help learners establish relevance to learning. Among various emotions, this study particularly focuses on boredom, confusion, and frustration that have been reported to have effects on engagement and disengagement in learning situations (D'Mello & Graesser, 2012). In sum, the goal of this study was to investigate the effect of utility value feedback and writing activity on learners' boredom, confusion, and frustration in the situation of asynchronous video-based learning.

Method

The participants were 30 Korean adult learners (20-35 years old) recruited via convenience sampling. The participants were randomly assigned to one of three groups: control group, feedback only group, feedback, and writing group. The feedback only group received feedback messages during watching the video lecture. Based on previous research, we designed four types of utility value messages: (a) utility for daily life (e.g., Data analysis is closely related to our lives. Let's try a little harder!), (b) utility for jobs (e.g., Data analytics is a competency required by various jobs. Let's study hard until the end!), (c) utility for membership groups (e.g., Data analysis can be useful at school or work. Shall we do our best to study?), and (d) social utility (e.g., Data analysis is a good topic for conversations with people from different disciplines. You are doing very well!). In contrast, the feedback and writing group performed an additional task to write about the utility value of big data analysis within 250 words before watching the video lecture. We conducted the Wizard of Oz (WoZ) experiment in a quiet room where the participants interacted with the online learning system controlled by the researchers. The participants were asked to verbally express their emotions (emote aloud protocol). In a separate room, we listened to their verbalizations and send out online feedback messages when verbalizations included words related to boredom, confusion, and frustration (see Figure 1). Corpus grouping respective to each emotion was done before the WoZ experiment (i.e., boredom: I want to quit). For data collection and analysis, we recorded learners' facial expressions and analyzed facial muscle movements called Action Units (AUs) based on the Facial Action Coding System (FACS) to identify learners' emotional states.

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Figure 1
Feedback Message

Results

We extracted 1,671 AUs from the recordings and then AUs less than three seconds were excluded as transitory states. This left 1,123 AUs for final data analysis. Boredom in the control group was the highest (M = 31.00, SD = 14.40), followed by the feedback only group (M = 16.50, SD = 12.78) and the feedback and writing group (M = 11.50, SD = 6.17) (Table 1). As there was a significant correlation between the frequency of frustration and confusion (r = .38, p < .05), MANOVA was conducted to investigate the differences in the frequencies of emotions. There was a significant difference in the frequency of boredom among the groups. Scheffé's test result suggested that the frequencies of boredom between the experiment groups and the control group were statistically significant (p < .05). No significant differences across the groups were found in confusion and frustration.

Table 1
The Frequency of Boredom, Confusion, and Frustration

Type	Frequency			F	η^2
	Feedback only group (n = 10)	Feedback and writing group (n = 10)	Control group (n = 10)		
	M (SD)	M (SD)	M (SD)		
Boredom	16.50 (12.78) [a]	11.50 (6.17) [a]	31.00 (14.40) [b]	7.53*	.36
Confusion	4.50 (4.22)	12.60 (8.58)	6.30 (8.97)	3.16	.19
Frustration	9.20 (7.58)	9.90 (10.05)	10.80 (11.02)	0.07	.01

[a],[b] refers to the values designated with different superscripts within a row differ at α = .05.
* p < .01.

Conclusion and implications

Among three types of emotions, affective feedback had significant effects on learners' boredom while the writing activity had no effect on all three emotional states. As boredom is known to be closely related to disengagement, the feedback assisted learners to remain more engaged. While the existing research suggests that confusion and frustration turn into boredom (D'Mello & Graesser, 2012), the participants tended to experience boredom from the beginning. Follow-up interviews indicated that the participants needed more control over the learning process such as choosing the relevant topic. This finding implies that coupling utility value and control is essential to prevent learners from easily entering the boredom status from the early stage of online learning. We also discovered that the utility messages motivated the participants to remain focused as they emphasized the usefulness of the video. We plan to conduct a follow-up study to further investigate the coupling of control and values and the effects of utility messages.

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Othering: Overcoming a Sociocultural Obstacle to English Proficiency among ESL learners in Malaysia

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Abstract: This study aimed to see how othering affects Malaysian students' English language learning. This article presents insights from data acquired during an interview and examined thematically. It explores three themes that emerged from the interview with Malaysian ESL learners regarding their experiences with othering and how personal growth has helped them overcome the effects of othering.

Introduction

English, being a global language, is a necessary skill for integrating into the real world. Accordingly, English plays a significant role in the Malaysian educational system, where it is viewed as a second language and a language of knowledge that may aid Malaysians in obtaining better work (Kasuma et al., 2021) and hence a higher social position (Zulkefly & Razali, 2019). Learners are encouraged to practice the languages outside of class to improve their skills. However, speaking English outside the classroom is a greater challenge for its users. When learners interact in English, they claim to feel 'othered' by their community members. Othering happens when English language learners are purposely segregated from their ethnic group due to a biased mindset (Lee et al., 2010). This research investigated the impact of othering on Malaysian learners' English language acquisition. The study's findings can provide English learners with an understanding of how to recover from the effects of othering.

Methods

An interview protocol was used to acquire a thorough overview of the participants' experiences with othering when attempting to communicate in English at school or in public areas. The questions were designed to extract information regarding the participants' personal experiences as ESL learners, especially on the problem of othering faced by learners in Malaysia. The interview questions centered on identity, marginalization, motivation, and barriers to learning English. Thematic analysis was conducted by a six-step approach (Braun & Clarke, n.d.; Braun & Clarke, 2006): familiarization, coding, theme generation, theme review, theme definition and naming, and writing up.

Findings

Data from the interview produced three themes: othering belittles one's linguistics ability and cultural identity, being othered compels learners to adjust their viewpoint, and learners experienced personal growth.

Theme 1: Othering belittles one's linguistics ability and cultural identity

Mocking is one of the negative behaviors associated with othering. Many of the incidents include ridiculing the learners' willingness to communicate in English in the presence of non-English users. The mockery made the learners feel embarrassed and upset. In addition, they were mocked for trying to communicate in a foreign language and accused of abandoning their cultural identity.

Student 2: *"Kenapa kamu mau cakap BI sedangkan bahasa kamu tu bahasa Iban sendiri?" Boleh kata sedihlah sebab BI ni universal lah. Semua orang boleh cakap BI. Selalunya saya senyap."* ("Why do you want to speak in English when your language is Iban?" It was sad because English is universal. Everyone can speak English. Usually I just stay silent.)

Student 4: *"I remember the first time my family went to the Iban church. I remember everyone was like, "They talk English. Orang putih." Then they went to ask us, "Orang putih ka?" Then I said, "No, no. I'm Iban."* (I remember the first time my family went to the Iban church. I remember everyone was like, "They talk English. White people." Then they came to ask us, "White person?" Then I said, "No, no. I'm Iban.")

Theme 2: Being 'othered' compels learners to adjust their viewpoint

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Following a firsthand encounter with othering, the participants reflected on the experience. As a result, they came to understand the point of view of people who mocked them. This thoughtfulness is a critical adjustment - seeing through the mockers' eyes may assist learners in moving beyond their pain and continue learning and using English.

Student 7: *"Mereka rasa jijik; mcm pelik. Orang ini dia Iban atau Melayu. Lepas tu dia cakap BI macam dia cakap BM tu. Pelik lah. Lepas tu mereka rasa terancam sebab mereka tak boleh bercakap BI. Jadi mereka rasa pelik atau cemburu, jadi mereka mula ejek."* (They felt disgusted; it was weird. This person is Iban or Malay. Then he speaks English the way he speaks Malay. Odd. Then they feel threatened because they can't speak English. They feel strange or jealous, so they start mocking.)

Theme 3: Learners experienced personal growth

Surprisingly, personal growth develops as a result of the encounter. Despite the unpleasant experience, the learners chose to rise above it by refusing to let incidences of othering impede their language acquisition.

Student 1: *"Kena jadikan itu sebagai galakan untuk cakap BI, lepas tu jangan fikir apa yang orang lain fikir. Just do whatever you want."* (You have to use that as an encouragement to talk in English, and then don't think about what other people think. Just do whatever you want.)

Student 4: *"Beri saya semangat untuk lebih belajar BI ni supaya dapat buktikan bahawa saya ni boleh, dan mereka akan hormat."* (Encourages me to learn more English so that I can prove that I can, and they will respect me.)

Discussion and Conclusion

Attacks on English learners' cultural identities show that they have lost their cultural identity and become outsiders in their ethnic community when they speak English. This is an example of sophisticated othering, as defined by Brons (2015), in which the person committing othering expects the othered to communicate in their native language. This odd method of preventing people from speaking English may be related to the mockers' lack of linguistic abilities and feelings of insignificance when they encounter someone who speaks or attempts to speak English well (Ibrahim et al., 2018). However, language acquisition is crucial to a learner's personal growth (Schmidt, 2014); therefore, the participants chose to improve their English skills instead. Furthermore, they did not appear resentful or conflicted, as they knew that not everyone would support them. Instead, they believed that learning English would benefit them in educational, social, and professional aspects.

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International Society of the Learning Sciences

Creating Comics about COVID-19 to understand the intersections between Science, Community, and Equity

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Abstract:. The COVID-19 pandemic is a complex socio-scientific problem that needs to be understood and addressed at local and global levels. The problem has illuminated inequities among and within communities around the world. Given the importance and complexities of this concern, we targeted COVID-19 to examine student understanding of the interconnectedness between the science (What is COVID-19?), the local context (How does COVID-19 impact community?) and equity (How does COVID-19 impact different members of the community?).

Introduction:

The COVID-19 pandemic is a complex socio-scientific problem in that the virus (science) impacts communities in several different ways and requires people living in those communities to alter their behavior and lifestyles in order to address the problem. In this presentation we describe and present evidence for how storytelling can be a powerful approach that can be used for teaching and learning complex socio-scientific problems. Teaching and Learning about complex socio-scientific problems such as COVID -19 and climate change requires educators and learners to use many non-traditional pedagogical tools and approaches (Shepardson, et al 2012; Authors 2014; Lenzen, Day & Murray, 2002) where in individuals would: (a) teach and learn how to make decisions/take actions that are local, keeping in mind global impacts (Ostrom, et al. 1999); (b) address inequities caused by the problem (Schlosberg & Collins, 2014); (c) teach and learn in ways that are grounded in local epistemologies (Bang & Medin, 2010); (d) teach and learn how to use data that is available to understand future scenarios (Resnick & Welinsky, 1998); (e) learn about and apply knowledge from both formal and informal learning environments (Bell et a., 2009) (f) teach and learn how to collaborate across local and global communities while addressing the power dynamics between and within those communities (Esmonde & Booker, 2017). Storytelling is an approach that can allow individuals to embed scientific content and data in their stories and also discuss how science problems can impact their communities. For centuries people from many different cultures and societies have taught principles of how to solve moral and ethical problems through storytelling (Wilson, 2008, Iseke 2013). Storytelling is a globally practiced approach to teaching and learning that is shared across all cultures and can be used an avenue that allows learners to leverage funds of knowledge (Moll et al.,1992) from their communities. Stories and storytelling provides a pathway for learners to make deep connections between funds of knowledge and learned knowledge in order to see complex socio-scientific problems more comprehensively. Further, research and practice on storytelling pedagogy advances educational equity generally, as centering and affirming the lived experiences of diverse student populations challenges both dominant educational narratives (Ladson-Billings, 2016; Solorzano and Yosso, 2016) and colorblind educational policies which have been found to maintain white supremacy (Bradbury, 2020; Gillborn, 2013, 2016).

Learning Environment Design

The COVID-19 pandemic is a complex socio-scientific problem. It is also a global challenge that impacts all everyday aspects of human life and has altered the social fabric of nations and local communities. This pandemic has illuminated inequities among and within communities with marginalized communities, in particular, having been impacted most acutely (Katamneni, 2020). The complexity of this problem requires nations to work together with local communities on issues of science, economics, socio-cultural norms and equity (Pirouz et al., 2020). Given the importance and complexities of this concern, we targeted COVID-19 to examine student understanding of the interconnectedness between the science (What is COVID-19?), the local context (How does COVID-19 impact community?) and equity (How does COVID-19 impact different members of the community?). We used the authoring of comic books as an approach to engage the youth from three different nations (United States, India and Mexico) in understanding the three questions mentioned above. The youth (13-18 years old) conceptualized stories about how the virus impacts their local communities. This presentation describes the design of a program to help students understand the intersections between science, community and equity. We also take this opportunity to describe how the students approached their work and presented their stories/comic books, which illustrated their understanding of how a complex science problem (COVID-19) impacted their community and different socio-cultural groups within their community. Given COVID-19 restrictions, we designed a virtual

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program on Zoom that would take place three days a week, two hours each day over the course of three weeks. The program was voluntary and one of the measures of engagement was the extent to which students were punctual and actively engaged through the Zoom platform (video and chat) during the two-hour sessions.

Program Activities

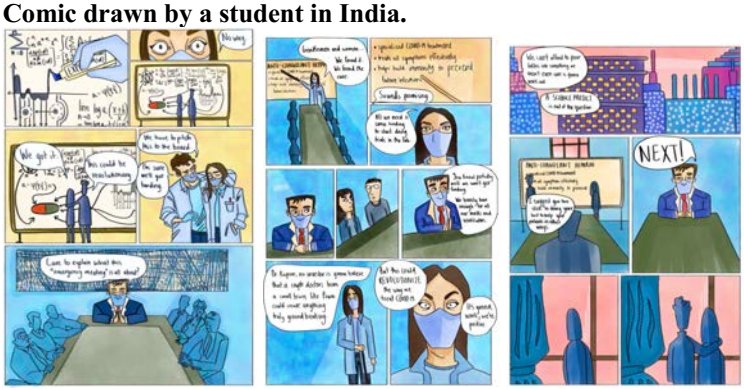
We devised and utilized three main goals, each with an associated question in student friendly terminology, to frame our program design and learning content, such that students were constantly thinking about one or more of the following: Goal 1. Complex systems thinking: How can I make sense of, and address, complex problems? Goal 2. Community based science: How do scientific phenomena impact different communities, and in what actions can/do communities take in order to respond to scientific phenomena? Goal 3. Equity: How does inequity further complicate a complex problem, and what can be done to address inequity in order to better address the complex problem? During week one we focused on getting to know each other in terms of identity, sharing and discussing perceptions of COVID-19, thinking about communities that are being impacted inequitably due to COVID-19, and identifying student-generated topics for graphic novels. During week two we focused on the elements of story-telling and graphic novel design, which included creating storyboards, giving and receiving feedback on storyboards, learning about the various design features comic artists use to tell a story visually, and beginning to design comics using Pixton software or hand-drawing to create graphic novels. During week three we focused on providing students with feedback on storylines and graphics, and learning more about how graphic novels can impact sociopolitical agendas. And on the final day of programming, students presented their completed graphic novels to invited guests, including parents, students' school administrators, and faculty from SUNY at Buffalo. Students were organized into three teams, such that there were students from different countries in each team and discussion in the teams were led by a member of our research team.

Analysis and Findings

Students presented various stories as a part of their graphic novels. The stories included how students thought about the intersections between science (what is COVID-19?), community (how does COVID-19 impact their community?) and equity (How does COVID-19 impact different members of the community?).

Figure 1

Comic drawn by a student in India.



For example, in a story created by student A (Figure 1), the student highlights dilemmas the scientific community is facing in India. In the hand drawn comic below, the student shows as a part of the story how since drug trials cost money and Indian medical scientists have less funding than western medical scientists, it is difficult for Indian scientists to try out new treatments for COVID-19. The student also shows the everyday life challenges faced by medical practitioners in India to treat COVID-19 patients.

Developing comics in a learning environment not only fosters student engagement, but also offers an alternative method for assessing student comprehension of concepts and systems. Creating a comic offers students an avenue for applying systems thinking to a scientific concept in a creative and personally relevant way, as students can use graphic elements and a storyline of their own choosing to articulate learned themes and academic content. Comics additionally enable students to express and connect their identities to what they know, what they have learned, and what is important to them in artistic form.

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International Society of the Learning Sciences

Constructionist Design for Sustainable Development

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Abstract: This poster introduces "Constructionist Design for Sustainable Development" as a design principle to engage students in a constructionist learning experience while addressing environmental and social challenges. To this end, we conducted a two-year qualitative design-based research project that engaged undergraduate and graduate-level students, lecturers, and community members from two universities in Thailand and Japan to design and build innovations that solve environmental and social problems in their communities.

By 2030, the United Nations' Sustainable Development Goals (SDGs) hope to ensure all learners acquire knowledge and skills needed to promote sustainable development. Yet, many countries' roads to education for sustainable development (ESD) remain a challenge. While many universities are cultivating partnerships to promote sustainability on campuses and offer ESD courses, little attention has been put on immersing students in environmental and community-based problems through hands-on learning experiences. This research develops a design principle for creating a constructionist community-based approach to ESD that empowers students to tackle problems and provides the foundation for sustainable development.

The learning processes for ESD should empower students with transformative actions for sustainability (UNESCO Executive Board, 2019). ESD is not just adding sustainability as an extra topic to the curriculum but rather enabling learners to contribute to sustainable societies through critical thinking and active problem solving (Lambrechts & Hindson, 2016). Students should engage in analysis, reflection, and action for local and global citizenship and active participation while acknowledging the rapidly changing and interdependent world (Honan, 2005). Scholars in environmental education believe that knowledge and values on the environment shouldn't operate in isolation; learners should have the opportunities to connect with nature, environmental stewardship, and interest in learning and discovery (Cutter-Mackenzie &Edwards, 2013; Stern et al., 2008). Thus, cultivating active participants requires teaching methods that go beyond lecturing. *ESD for 2030* suggests that learners must first step outside of their safety status quo and become critically aware of the world's existing problems and conditions. Finding opportunities to launch critical inquiries about society and being empathetic with others allows young learners to activate values and a lifestyle corresponding to their sense of identity.

The constructionist design paradigm shares many similarities with literature on the ESD learning process. Constructionists believe that learners learn best when designing and making personally and socially meaningful (Papert, 1993). Learning should be experiential and connected to the real world (Ackermann, 2001). It is also influenced by Dewey's progressive education, which focuses on experiential learning and building connections to the real world (Blikstein, 2013). Through constructionist learning, learners can take an active role in their learning by creatively designing, building, and exploring their projects based on their personal and social interests. It liberates learners from being taught when they are empowered to connect everything they wonder, know, and feel about expanding themselves into learning new things (Blikstein, 2013). To bring constructionism and ESD into higher education, the instruction should allow students to see themselves as a part of the community. They believe that they can succeed and then make connections between their community and global communities. Ladson-Billings' (1994) work on culturally relevant teaching emphasizes the importance of creating relevant cultural connections to students' learning experience. By doing things personally and socially meaningful to their communities, students can reflect on their achievements.

This poster presents a design principle to better support authentic making in higher education by engaging students from various disciplines and the broader community. We situate this research in two universities located in Bangkok and Tokyo. We argue that the principle could be a model for other university-based ESD courses. The Constructionist Design for Sustainable Development (CRSD) should design: (1) For the learners to make connections with their peers and community members by working toward solving social and environmental problems of their interests; (2) to explore and experiment with novel ideas in working on personally and socially meaningful projects; (3) with high expectations of all students while supporting the integration of their prior knowledge and experiences; and (4) for the students to be reflective of their achievement and ability concerning the environment, their community, and beyond.

To provide empirical evidence supporting CRSD, we conducted a qualitative design-based research project with over 60 undergraduate and graduate-level students, lecturers, and community members from Thailand and Japan. The study employs qualitative research methods across three locations (in-person and online). Each implementation is one semester-long. The course's learning goal is to empower the students to be designers and create inventions to solve social and environmental challenges. Students' projects covered but weren't limited to

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sustainable lifestyles, human rights, gender equality, and global citizenship. They followed the design thinking process by empathizing with community problems, constructing problem statements, and brainstorming to achieve the goal. Then they will create a prototype to help them think, learn, and gain feedback from the community and iterate on their designs. Students were encouraged to use digital fabrication equipment such as 3D printers and laser engravers to make their innovations. Towards the end of each course, the students presented their projects and shared knowledge with community members.

The preliminary results show how Constructionist Design for Sustainable Development takes shape as a (1) way of establishing making as a part of connecting students, environment, and community, (2) space for students to work together and collaborate with peers, and (3) form for the students to connect with the problem that they once thought couldn't be solved by themselves. Students showcased their creative and innovative nature in tackling everyday environmental and social problems. For example, a group of pharmaceutical science and economics students made "BraceMed"—a handmade bracelet with a 3D printed pillbox—for a member's grandmother to remember to take medication. The team came up with the idea after learning about the grandmother's high blood pressure due to missing medicine (See Figure 1). Making and designing a bracelet together also serves as a joyous family activity. Another group experimented with different methods to create the most durable shopping bag using zero-waste and 100% degradable materials (See Figure 2). They even went to a local print shop to help recycle their paper waste. Finally, students reflect on their accomplishments and their parts to achieve the Sustainable Development Goals- doing useful solutions with a creative spirit and drive for innovation. We believe that Constructionist Design for Sustainable Development is possible when students develop connections to the problems and people within their community. Additionally, the learning environment must encourage the students to design and experiment with new ideas. Students can be empowered by collaboratively designing solutions that impact their community and themselves.

Figure 1

A student and her mother made "BraceMed" for the grandmother (left) and Students' bio-gradable paper making process(right).

Engaging in a hands-on constructionist class that addresses ESD challenges, students propose and design solutions for the betterment of the community as a tool for engendering change for the environment. The research contributes to the global intellectual community by creating design principles supported by empirical evidence, especially designing environmental education by innovating for their community and environment.

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International Society of the Learning Sciences

Creating Space for Formative Peer Feedback in a Community-oriented MOOC

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Abstract: To advance community-oriented instructional approaches within MOOCs, we examine the impact of creating space for formative peer feedback using a digital workbook in a Resilient Teaching MOOC. We use a coding scheme for classifying peer feedback to analyze responses to shared workbook entries. Findings revealed the presence of five attributes in the feedback: content, explanations, advice, questions, and community connections. Our study elaborates approaches for creating productive forms of knowledge exchange among peers.

Introduction

Massive open online courses (MOOCs) generally embody *individualistic* approaches to instruction (i.e., valuing independence), which could hinder opportunities to engage in significant learning with peers. We investigate how MOOCs can become more *collectivist* (i.e., valuing communities), exploring ways that instructors can pragmatically advance forms of social interaction that connect learners, their coursework, and their peers' ideas.

This study investigates peer feedback exchanged in a custom digital workbook and gallery space situated in a MOOC on Resilient Teaching. Our overarching aim is to advance community-oriented approaches in open, online learning environments. The following research questions guide our inquiry:

- What can we observe about the ways in which learners "take up" opportunities to give formative peer feedback in a MOOC on Resilient Teaching?
- What are the characteristics of the feedback offered?
- In what ways might opportunities for formative peer feedback allow instructors to advance collectivist approaches within open, online learning environments?

Relevant literature

Shute (2008) defines formative feedback as "information communicated to the learner to modify their thinking or behavior to improve learning" and asserts that the aim of formative feedback is to "increase student knowledge, skills, and understanding of content areas and general skills" (p. 154).

To understand the quality of peer feedback (formative or summative), scholars have developed various frameworks to assess it. Prins et al. (2006) advanced a framework that included the following categories: content-related remarks, explanations of remarks, suggestions for improvement, questions to foster reflection, and formulation and structure of feedback. The Prins et al. (2006) framework is the basis of the coding scheme we used to understand the characteristics of formative feedback given and received by learners in our study.

Research context

The Resilient Teaching MOOC launched on the Coursera platform in June 2020. A stated goal of this community-oriented MOOC was to foster a sense of connection and community amongst learners in the course. The course culminated in a resilient teaching plan, a final project that learners could apply in their respective instructional contexts. Throughout the course, a digital workbook developed by the authors' home unit incrementally supported learners' development of their resilient teaching plans through a series of reflection prompts indexed to course topics. The digital workbook included 12 total prompts distributed throughout the course. The digital workbook included a gallery space that allowed learners to share portions of their teaching plans and receive formative feedback from peers that could inform their final assignments. Learners could browse shared entries, ask questions, and offer feedback on their peers' submissions. For this unstructured task, learners were encouraged to review gallery submissions and leave open-ended comments on peers' entries.

Method

Data sources

We collected data from the Resilient Teaching MOOC from the time of course launch in June 2020 to October 2021. During this time, 2,247 learners were "active" participants in the course, meaning that they engaged with

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at least one course item (e.g., watching a video). 1503 workbook entries were shared, 72 of which received peer feedback. We restricted our analysis to initial conversation thread responses (n=72).

Coding scheme and coding approach

We simplified Prins et al.'s (2006) coding scheme to develop our codebook for classifying feedback: content, explanations, advice, and questions. Two coders collaborated to code peer feedback responses using a directed content analysis approach (Hsieh & Shannon, 2005). They applied all relevant codes in the codebook to peer feedback responses (i.e., simultaneous coding). Coders did not apply any code to responses that could not be considered "feedback" (i.e., one word or off-topic responses) (n=22). Coders evaluated the remaining viable responses that did not fit the coding scheme and developed a new code to describe these responses—community connections—and updated their codebook to include the new code and re-coded all viable responses (n=50).

Findings and discussion

Analysis revealed the following distribution of codes: content (n=17), community connections (n=12), questions (n=9), advice (n=5), and explanation (n=3). We structure our findings according to our three research questions:

The ways in which learners "take up" opportunities to give formative peer feedback. The majority of shared entries did not engender peer feedback, with only 5% of entries receiving a response. Of these, roughly two-thirds were "viable" feedback, available for coding. We discovered two unanticipated behaviors: *self-responders* (20.8% of total analyzed responses) and *super-posters* (55% of total analyzed responses) (Huang et al. 2014). Self-responders provided context for their original post, shared additional connections to course content, and requested others to review their work (i.e., community connections).

The characteristics of the peer feedback provided. The majority of responses drew connections between course *content* and their peers' ideas. Our analysis also revealed instances where a peer offered specific pedagogical suggestions, indicating that the peer likely shared a similar instructional background and thus felt comfortable offering advice. These types of comments were less frequent, however, as evidenced by the lower occurrences of the *explanation* and *advice* codes. When guiding *questions* were posed, they aimed to direct peers to useful alternative instructional approaches or encouraged peers to refine their initial teaching plan. Responses coded as *community connections* included elements such as the sharing of personal experiences and instructional approaches, expressions of appreciation for peers' efforts, and requests for feedback.

Opportunities to advance collectivist approaches within open, online learning environments. The responses we analyzed demonstrated that many learners embraced the ethos of a community-oriented learning environment. Learners elaborated on their peers' ideas and critiqued peers' applications of course themes as they pertained to their final resilient teaching plans. These behaviors embody the collectivist mindset advocated by Ladson-Billings (1995), necessary to achieve deeper understanding and higher levels of academic success.

Limitations and future work

Despite a sizable pool of shared digital workbook entries (n=1503), only 50 of these received substantive responses worthy of analysis. This low rate of interaction between peers severely limited our investigation of formative peer feedback in a MOOC. Future work will explore how providing more structure and guidance around formative feedback tasks in community-oriented MOOCs could influence the way that learners take up the practice and shape the characteristics of feedback exchanged.

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Physical Microcosms: Potentials for Enriching Classroom Investigations in Ecology

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Abstract: Ecologists construct physical microcosms that exemplify mechanisms and relations in ecosystems. This poster describes how a 7th-grade classroom complemented field study of an intertidal ecosystem with design of classroom microcosms. Initial designs appeared constrained by literal resemblance. As students' inquiry increasingly focused on interactions among organisms, they configured microcosms to facilitate observation of these interactions. Microcosms became sites for studying processes that could be inferred from field data but rarely observed directly.

Introduction

Physical microcosms are often employed by scientists to investigate more closely how components of a system interact (e.g., Strayer et al., 2006; Tyrrell et al., 2006). When scientists construct microcosms, they do not merely copy a system but instead deliberately select and arrange for conditions in the microcosm that make more salient relations and mechanisms of interest in a natural system. Designing and employing microcosms as investigative tools introduces students to crucial considerations about the status of models as approximations of the world, their utility as investigative tools, and their status as explanations of system structure and function (Lehrer et al., 2008). Because microcosms resemble the target system in some critical ways, they offer students an entrée to modeling, partly because the analogical distance between model and system is visible (Lehrer & Schauble, 2002). However, previous research indicates that for students to perceive the microcosm as a model, and not simply a copy, they must have agency in its construction, especially in decisions about what to amplify and what to suppress, and in articulation of how the microcosm will help answer one or more research questions (Lehrer & Schauble, 2012). Having a hand in some aspects of microcosm construction and use also helps students understand that modeling is performative, and not only a matter of representing objects and relations symbolically.

Research Design & Context

This work provides an account of one seventh grade classroom's use of physical microcosms to exemplify aspects of an intertidal ecosystem for the purpose of investigation. This work takes place within a larger, multi-year design-based research study investigating how students' conceptions of and practices for representing variability inform their construction and revision of models of ecosystems. The context of this work is a statewide middle school citizen science curriculum focused on understanding how the relative abundance and distribution of native and invasive species of crabs are changing due to climate-driven factors. In designing and investigating classroom microcosms, our goal was to consider how physical microcosms might enrich classroom investigations of the target system and to investigate learning opportunities as well as conceptual and material challenges students might encounter as they used microcosms to investigate intertidal ecology. Our design privileged giving students time to observe the microcosm; to "get-to-know" the organisms of the intertidal, and how they relate to each other and the larger system. As thinking progressed, we invited students to "stretch" the components of their microcosms into forms that lend themselves to quantification and investigation of relations among quantities (Lehrer & Schauble, 2006), a process still ongoing in our focal classroom.

Findings & Implications

Although work on the project is still ongoing, consistent with previous work (e.g., Lehrer et al., 2000) we have found that although students initial microcosm designs privileged overt resemblance with the system, over time those commitments to resemblance created a material impasse which forced students to reconsider the purpose of the microcosm and its relation to the intertidal. Moving forward, they prioritized microcosm arrangements that facilitated observations of processes of interest—such as animals' refuge seeking—and that supported the collection of measures (Figure 1). After a period of open observation where students cultivated close looking, considered the purpose of microcosms in science, and posed questions, students completed two rearrangements of conditions to answer the question: *Do the amount of hiding spaces impact green crabs' behavior?* Students investigated this question by designing microcosms with two different hiding conditions: hiding and no-hiding.

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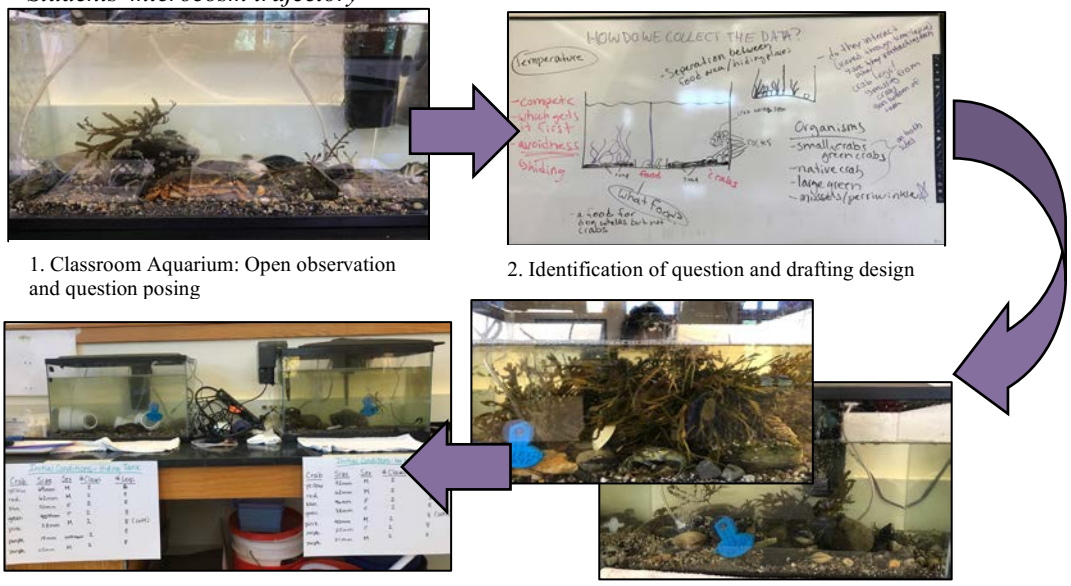
After a lively debate on whether the animals in the tank should be fed (one contingent of students insisted not feeding the animals would ensure "natural" behavior while another argued the environment was already artificial and therefore required providing food), the students settled on providing food in a central location ("hunger games style") to instigate foraging behavior and promote interactions between organisms. During this round of investigation students noted that their reliance on natural materials to create shelter for the animals prevented their own observations of behavior in the "hiding" tank. A second rearrangement of the microcosms using artificial materials was then undertaken to support seeing more of the processes and behaviors the students were interested in (e.g., "Maybe we should change it so that we can see them better."). With inquiry now stabilized, microcosms were now sites of study for processes, such as foraging and refuge-seeking strategies, that could be inferred but rarely directly observed in the field.

Figure 1:
Students' microcosm trajectory



1. Classroom Aquarium: Open observation and question posing

2. Identification of question and drafting design

3. First rearrangement: Hiding (top) and No-Hiding (bottom) Conditions using natural materials

4. Second rearrangement: Hiding (left) and No-Hiding (right) Conditions using artificial materials

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Computational Thinking into K-12 Classrooms: Experiences and Challenges from Professional Learning Experiences

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Abstract: Teachers often find it challenging to learn computational thinking (CT) and integrate it with classroom learning. In this systematic review, we focus on how professional learning experiences have supported K-12 teachers to integrate CT into their classrooms. The findings suggest some effective strategies for building professional learning experiences but highlight the need for more agreement about the nature of CT.

Introduction

Computational thinking (CT), defined as problem solving processes, skills, and dispositions needed to develop software (e.g., ISTE & CSTA, 2011), has garnered national attention as important skills and processes required for all students. While CT is tied to CS, it can be developed as a problem-solving approach. Despite the importance of CT for 21st-century education, opportunities to engage in CT are often present only in informal learning settings such as after-school clubs and limited to coding skills (Sengupta et al., 2018). Teachers often find it challenging to learn about CT and integrate it with classroom learning (Ketelhut et al., 2020). To this end, we sought to understand what kinds of learning experiences teachers had related to CT. To this end, we conducted a systematic review of the literature synthesizing research on how CT-focused PLEs have supported K-12 teachers to integrate CT into their classrooms. Specifically, we pursued two research questions:

- What are the learning goals and conceptualizations of the existing CT PLEs?
- How did prior studies support teachers to integrate CT into classrooms?

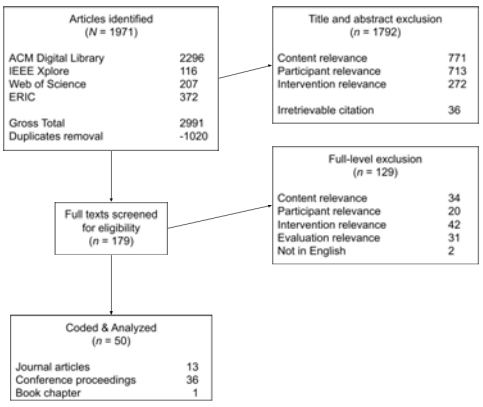
Method

We conducted a systematic literature review based on PRISMA protocol of recent research on CT PLEs across four bibliographic databases: ERIC, Web of Science, IEEE Xplore, and ACM digital library. The search terms combined CT + professional-development-related terms or CT + outcome-related terms. In total, we screened 1,792 articles with pre-established eligibility criteria. After reviewing all articles at the title and abstract level, 179 were determined to have met our initial criteria. Three reviewers examined those articles at the full-text level. Full-text screening resulted in 50 articles that reported CT-related PLEs with K-12 teachers and 27 of which reported PLEs with component(s) on CT integration (see Figure 1 for the literature review process).

For each of the 50 articles, we recorded basic study and participant information. Then, we coded the details of the PLE and the outcomes. All the articles were discussed and coded collaboratively by three reviewers. The consensus was established through iterative discussion, and discrepancies were resolved at group meetings.

Figure 1

The PRISMA Flowchart



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RQ1: Goals and conceptualizations

Overall, the goals of the PLEs focused on teachers' understanding of CT-related concepts, tools, and pedagogies. The goals included advancement of knowledge, change of perception or awareness, and improvement of skills. We saw a wide range of conceptualizations of CT and CT integration. The most prevalent goals included CT principles (c.f., ISTE & CSTA, 2011), which were viewed as problem-solving processes involving skills such as pattern recognition, problem decomposition, algorithmic thinking, abstraction, etc. Other goals focused on specific knowledge and skills in Computer Science (n = 5), computing concepts or practices (n = 4), and robotics (n = 2). The wide spectrum of foci reflects CT education in the K-12 world. On the one hand, CT can be viewed as a development of higher-order thinking skills that support problem solving (e.g., ISTE & CSTA, 2011). On the other hand, CT can be operationalized as specific content knowledge associated with different computing tools.

RQ2: Supporting CT integration

We identified two themes in terms of supporting teachers to integrate CT into teaching practices. First, certain supports were reported to be effective. Studies that involve prolonged engagement with teachers often report positive reactions and substantial change at a behavioral level (e.g., Hestness et al., 2018; Ketelhut et al., 2020). Additionally, personalized mentoring has been reported to support teachers' professional growth. Such support can take various forms (e.g., coach in Hamner et al., 2016). Aside from the technical supports, teachers also need pedagogical supports to actively integrate CT into their classrooms (Dong et al., 2019). CT integration has often resulted from supports from a community of practice (e.g., Hestness et al., 2018). Second, we identified the specific experiences, provided through the supports, that are beneficial to teachers. For example, many studies addressed the role of feedback and reflection in PLE in supporting teachers' CT integration (e.g., Ouyang et al., 2018). Teachers need to develop conceptual understanding and have opportunities for practice to support CT integration. Thus, teachers need to actively plan and teach in CT-integrated classes.

Discussion and Conclusion

Overall, CT integration can be challenging because supporting teachers in changing their attitude, knowledge, beliefs, and practices take time (Ketelhut et al., 2020). Although CT is closely related to coding, we need to incorporate broader theoretical perspectives. Further, more research is needed on computational literacy in K-12 contexts (Kafai & Proctor, 2021). While the field is beginning to understand how to create PLEs that support teachers in teaching certain aspects of CT, more work is needed to understand what should be taught in K-12 CT and how best to support teachers in that endeavor.

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Rotating Bodies Bulge Outward: A Novel Intuitive Resource for Rotational Motion

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Abstract: Physics students routinely struggle to understand the Coriolis force and the centrifugal force. While investigating students' prior knowledge resources in these domains, we observed the use of an intuitive element regarding the "bulging" demonstrated by rotating bodies. This element exhibits similar characteristics to a previously described class of intuitive knowledge resources for making sense of physics phenomena: phenomenological primitives (p-prims). We document the attributes of the "bulging" resource and compare them to the expected traits of p-prims.

Introduction

Inertial forces, such as the Coriolis force and the centrifugal force, are notoriously difficult to teach. Numerous errors about both can be found in the thinking of physicists and lay people alike (Grof et al., 2020). Our team has been working on a novel conceptual approach to teaching the Coriolis force which utilizes the wealth of knowledge that students have amassed about the physical world prior to their formal education (Minstrell, 1992). While cataloging the knowledge resources shared by our participants, we observed a pattern of responses which shared attributes with a previously documented class of intuitive knowledge elements. Here, we describe the observed properties of this potential intuitive resource and make a case for its classification.

Theoretical framework

Knowledge in Pieces (KiP) is a constructivist theory of knowledge and learning. It views knowledge as a network of individual elements, which are connected and activated through recognition. Naïve learners acquire elements to describe natural phenomena through their interactions with the physical world. These foundational resources are called phenomenological primitives, or "p-prims" (diSessa, 1993). P-prims provide "common sense" explanations for the causal mechanisms in the natural world. They are activated when relevant features of a problem-solving context are recognized by the learner, or when a closely related neighbor element is activated. At times, learners may unwittingly create erroneous connections by missing relevant information or over-applying concepts. These faults can be the root of difficult-to-dispel "misconceptions" and can interfere with the learner's construction of new understanding (Smith et al., 1993). As they advance from novice to expert, learners reorganize existing connections to better align with physics precepts and construct higher-order knowledge structures to create interdisciplinary cohesion (diSessa, 1993; Minstrell, 1992). This refinement repurposes p-prims into a supportive role for the larger knowledge structures. By understanding the productive and counterproductive connections in their students' knowledge, educators can improve their strategies to better address the incongruities and support the development of robust, reliable knowledge structures (Brown & Clement, 1992).

Methodology

Eleven undergraduate physics students at a large university in the Intermountain West participated in 1-on-1 Zoom interviews, during which they thought out loud about phenomena influenced by the Coriolis force. Five students had not yet taken the upper-division course in which the Coriolis force is formally taught, while six students had completed this upper-division course. The participants were asked background questions before being guided through a set of thought experiments which visualized the earth as rotating and non-rotating, spherical and oblate, and from inertial and rotating reference frames. The students made predictions about the motion of an object moving across the surface of the earth in each scenario. The audio recording of the interviews was transcribed and student responses were analyzed to uncover the knowledge elements underlying their reasoning.

Results

One element of knowledge, which emerged when the students discussed rotating objects, shared many similarities with p-prims. Nine of the eleven participants were aware that the earth's shape deviated slightly from spherical. Most students explained that this is a consequence of the earth's rotation. Throughout the interviews, the students continuously displayed an intuitive expectation that rotating bodies are "supposed to" be pulled outward,

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regardless of the context. The ubiquity of this assertion prompted closer inspection. We named this element "*bulging*" and compared it to the expected attributes and identifying principles of p-prims (diSessa, 1993).

There was a noticeable difference in the way the two groups of students spoke when explaining the phenomenon. The students who had only taken Introductory Physics tended to offer rotation as a de facto mechanism that needed no further dissection, which is an example of the "principle of impenetrability," by which p-prims are self-sufficient for naïve explanations. In comparison, the students who had taken the upper-division course used more advanced terminology like "inertia" and "centrifugal force" to describe the mechanism. This shift matches the predictions made by KiP: advanced physics instruction co-opts intuitive knowledge within larger frameworks to act as a supporting tenet to higher-order schema. The advanced students reorganized their thinking and used broader topics to explain *bulging* in a way the more naïve students had not yet discovered.

The students mentioned *bulging* in multiple contexts which had little in common beyond the topic of rotation, such as pizza dough, pottery wheels, and carnival rides. This shows that the *bulging* primitive was not associated with any particular object or material property, but rather with the rotation itself. This method of connection via an easy-to-observe abstraction demonstrates the "principle of ready availability." It also supports the "principle of functionality," as having an intuitive explanation for *bulging* would be useful to naïve learners. Students also utilized *bulging* to describe the common experience of feeling pushed to the outside edge of a turn while driving in a vehicle. This exemplifies the "principle of body," which predicts that p-prims will likely have strong roots in physiological experience and will be described by novices using their bodily sensations, as well as the "principle of obviousness," which expects p-prims to form around familiar or universal experiences.

Finally, when asked to predict what would happen if the earth were to rotate faster than it currently does, all eleven students (including those who were previously unaware of the oblate shape of the earth or had not understood its connection to the earth's rotation) instantly predicted that it would increase the size of the bulge. This was a consistent, reliable activation of *Ohm's p-prim*, in which a larger input predicts a larger result. This could be evidence that the *bulging* primitive forms a strong syllogism with another well-established knowledge element. Additionally, students sometimes describe orbiting bodies as being trapped in place by the opposing gravitational and centrifugal forces. This explanation could be recontextualized as an interaction between *bulging* and the *supporting* or *clamping* p-prims. These interpretations showcase the "principle of diversity" and the subtlety that exists between primitive knowledge element activations.

Discussion

Overall, it appears that *bulging* is a good candidate for a phenomenological primitive as it displays many of the key characteristics of p-prims and agrees with a wide range of identifying principles. Ultimately, it will require more targeted scrutiny than this study was able to provide to make a definitive conclusion. Future explorations of *bulging* could endeavor to determine the origins of *bulging*, expand the list of contexts in which *bulging* is activated, clarify the interactions between *bulging* and other p-prims, and assess the role that *bulging* could play in physics instruction. Investigating *bulging* could shed light on the difficulties that many educators have experienced when teaching about the centrifugal force and rotational motion. Instead of fighting against this primitive by labeling inertial forces as "imaginary" or "illusory" (which implies that the students are incorrect in their own perception and memory), educators could acknowledge and reinforce the bodily experience of students to situate the *bulging* primitive within a broader context. With careful refinement, the *bulging* primitive could come to serve a unique and powerful role in the knowledge structures of intermediate physics learners.

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Discussion-Oriented Teaching in the Digital Classroom: Teachers' Collaborative Adaptation in the Face of Disruption

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Abstract: We examine how a researcher-practitioner research group collaborated to adapt noticing practices in the face of disruptions brought on by the COVID-19 pandemic. We used a progress monitoring tool and cognitive field notes to support teacher partners' systematic reflection and to gauge teacher learning. Initial findings suggest these tools helped identify tensions around implementing online class discussions. We highlight the process the teacher partners engaged in as they re-conceptualized engagement, participation, and interaction.

Introduction and Theoretical Approach

The COVID-19 pandemic and the move to online teaching and learning disrupted established teaching practices. We analyze how a group of in-service English Language Arts (ELA) teachers who were committed to dialogic teaching (Mercer, 2008) collaboratively adapted their pedagogy in response to two pandemic-related challenges: (1) students' reluctance to offer spoken responses during synchronous online classes, and (2) identifying students' needs without access to typical feedback sources that teachers have during co-present teaching.

We conceptualize teacher learning as an active process (Bakkenes et al., 2010), and we ask: How did a group of ELA teachers collaboratively adapt their noticing practices in the face of disruptions brought on by the COVID-19 pandemic? We define *teacher noticing* as a teacher's capacity to attend to, analyze, and respond to student thinking (Barnhart & van Es, 2015; Hand, 2012). Such noticing is intentional and guided by experiences, pedagogical commitments, and other factors (Patterson et al., 2020). Here, we examine teachers' adaptations in noticing in their remote teaching, as they facilitated through a series of collaborative workshops.

Data Collection and Analysis

In Fall 2020, we conducted seven workshops to support teachers' noticing in this new context, centered on digital tools: a "progress monitoring tool" (PMT) where teachers recorded student behaviors (e.g., unmuted to speak, turned camera on) over time, and a "cognitive field notes" (CFN) tool (Gutierrez & Vossoughi, 2010), where teachers engaged in guided reflective writing on their noticing practices. Each teacher implemented the PMT and/or CFN in their class and reported back to the group. During workshops, teachers discussed teaching challenges, uses of the tools in their classrooms, and data they collected. Additionally, they critically renegotiated meanings of key terms such as engagement, participation, and interaction prompted by our team's focus on classroom discussion. Study data include written teacher reflections, notes on development and implementation of noticing tools, teacher-provided transcripts of classroom discussions, and meeting notes, recordings, and transcripts. Analysis examined how teachers adapted their practice in the digital space. Inductive coding of reflections, notes, and transcripts resulted in identification of several key themes, outlined below.

Findings

Analyses revealed that teacher partners adapted their teaching practices and their conceptualization of what it means for students to engage, participate, and interact in discussions in the digital space. Teachers' interactions with the tools surfaced tensions around what they could observe in a new teaching context. In particular, noticings aligned with teachers' shifting definitions of key constructs: engagement, participation, and interaction. These definitions were sometimes inherited from teachers' in-person interactions with students, and teacher partners worked collectively to make sense of these terms to help them adapt their noticing practices to remote settings. The teacher partners used phrases like, "I'm currently struggling with the right questions to ask," and "what would be best to record/observe" in their CFN reflections.

Collaboratively, the teacher partners worked through these disruptions by co-constructing a collective learning space that supported reevaluation of what it means to participate and engage in classroom learning when going dialogic in the digital space. One salient workshop activity (late 2020), involved (1) defining engagement,

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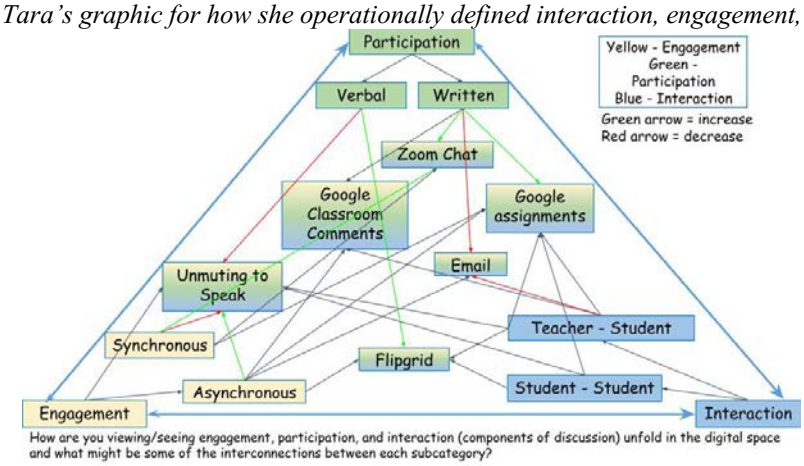
participation, and interaction in writing as well as graphic form; (2) discussing the choices that teachers made in their definitions; and (3) revisiting the definitions at the conclusion of the workshop. Figure 1 (below) is Tara's graphic from this activity, and shows that Tara had begun to complexify her conceptualization of engagement, participation, and interaction, including features from the digital teaching space, after a few months of participating in teacher partner and research team discussions and working with the PMT.

Figure 1

Tara's graphic for how she operationally defined interaction, engagement, and participation.



Tara's view of participation, engagement and interaction broadened over time. Her assessment of student engagement expanded to include asynchronous and synchronous participation, allowed for student-student interactions, and a focus on modes of engagement after participating in collaborative, facilitated efforts to build adaptive expertise in applying the principles of dialogic instruction to online instruction. In a reflection, Tara shared, "It was cool to see discussions unfold that took place half out loud through the speaker and half in the chat … Now that was something I never would have expected" .

Discussion & Next Steps

Our data speak to how teachers adapt their teaching practice by learning to see anew in changed circumstances. These teachers were working within a broad and multifaceted crisis – the COVID-19 pandemic – which disrupted many of their teaching practices. Introduction of new noticing tools (the PMT and CFN) highlighted a particular disruption in their ability to notice student engagement, participation, and interaction, which prompted a collaborative and cascading set of reconsiderations of the definition of engagement and its various instantiations within an online classroom, all facilitated through a variety of reflective activities. Our initial findings point to the power of collaborative sensemaking, particularly around noticing student thinking, facilitated through the introduction of explicit noticing tools and reflective activities.

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Examining Learning Opportunities for Integrating AI Education in English Language Art Classrooms

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Abstract: We conducted a co-design study with high school ELA teachers to investigate their perspectives in the integration of a technology-enhanced AI curriculum. The teachers explored the AI and text mining activities and reflected on them from teaching and learning perspectives. The findings of this study suggest that building models with texts positioned ELA teachers as experts in AI teaching and they were empowered to identify existing learning resources and opportunities in ELA classrooms that could be leveraged in integrating AI learning in their classrooms.

Introduction

Understanding of AI concepts, the ability to use AI knowledge in real-world settings, and analyzing the potential long-term benefits of AI are turning into essential 21st-century skills (Steinbauer et al., 2021). These skills are the basis of future career opportunities. Therefore, providing high-quality AI training to our young generation, especially underrepresented K-12 students, is a critical way to provide equal learning opportunities for these essential skills they need in an AI-empowered society. Following this trend, scholarly attention has turned to examining how to support K-12 AI education with resources, tools, and projects. Many attempts have been made to motivate K-12 students in understanding AI through developing machine learning (ML) models (Yoder et al., 2020). Yet, the field calls for more empirical studies investigating how to support students to learn modeling data in k-12 classrooms (Steinbauer et al.,2021). On the other side, to integrate these technologies into the K-12 curriculum, teachers' perspectives play a critical role in successful implementations (Lindner et al., 2019). Thus, we developed the AI curriculum activities and the StoryQ application, a web-based text-mining and narrative modeling platform, to bring AI education to high school non-computing classes, in this study, ELA classes. This study addresses the following research question: *What are the ELA teachers' perspectives to integrate AI education in their classrooms as they reflected on their interaction with the AI and text mining activities?*

Methods

Two ELA teachers from two public high schools, Martin and Emma (pseudonyms), participated in co-design workshops on the AI unit and technology. Martin has 20 years of teaching experience in ELA while Emma has 10 years of ELA teaching. We focused on ELA teachers in this study as our prior co-design experiences with ELA, mathematics, and computer science teachers indicated a critical need to learn more about the learning opportunities in the ELA classrooms (Tatar, 2021).

Martin attended approximately 10 hours of co-design sessions to test the initial designs of the curriculum from 2020 to 2021. Emma attended the 2021 February workshop for three hours with her colleagues to learn the basics of AI and test the curriculum. After the February workshop, we invited Martin and Emma to attend the 2021 August workshop to test the new design of the curriculum. The August workshop was held on Zoom for two days (seven hours per day). In the workshop, Martin and Emma were guided to complete five lessons related to extracting features from texts, building models, and classifying texts. We collected 27-hour video recordings, including the teachers' interactions in the StoryQ while completing the activities, their responses to the learning tasks, and their discussions. This study draws on the case study approach (Crowe, 2011) regarding thematic analysis methods (Clark et al., 2015). We analyzed the transcript of the recordings using the thematic analysis method. We first closely examined the data to investigate the teachers' experiences, expectancies, and their understandings of how AI works. Then we discussed and finalized the themes and categories in weekly meetings.

Findings and Conclusion

We found that after the teachers analyzed features and built AI models, they started to foresee the opportunities to integrate these lessons into their classrooms. The teachers identified these opportunities as enriching their

students' ELA understanding and raising awareness of the impacts of AI on their future careers. In the workshop, Martin and Emma worked collaboratively to complete the learning tasks. They developed models and then created a confusion matrix (i.e., a visual representation to make comparisons) to investigate where the model made mistakes. With the help of the confusion matrix, they identified specific sentences which the model mislabeled. While reviewing these reviews, they discussed how people use first-person pronouns when they complain about something. Also, they realized that people tend to use third-person pronouns when they like something. Based on their experience with the model, Martin mentioned that "…we tell students to speak from their own experience, speak in the first person, we set these goals and we never explained why". He believed that this activity could be a part of their "norms of communication" unit and illustrate how different statements are used in different contexts. Emma also agreed with him and saw the value of showing different examples to reinforce students' ELA understandings.

Another opportunity that the teachers pointed out was to show students how language arts play out to express feelings. As a part of the learning activity, Emma and Martin trained the model by using the word "love" as a feature. After training the model, they created a visual representation to investigate in which reviews this feature was used and how. They then examined different instances to understand how the selected feature was placed in both positive and negative labels. During this activity, Martin discussed how people expressed their feelings while complaining. Based on the instances, he claimed that when people complain about a restaurant, they use "certain language that's more general appraisals that decrease the weight of the praise". After that, Emma joined the discussion and brought another perspective by thinking of the classroom implementation. She believed that discussing the form and content of the words could help students in the language analysis like "they're trying to access someone's trying to express either a favorable opinion or an unfavorable opinion". Moreover, she further explained that this lesson can be used in the poetry class to analyze emotions. She stated that "…I feel like this lesson would just be set up perfectly for poetry...that's valuable in and of itself, we see words of positive connotations, positive tone…". From these examples, we can clearly see that while engaging with the activities, the teachers developed a basic understanding of how AI models work through exploring features in the text data and examining the visual representations to compare human and AI-predicted labels. After they developed an understanding, they discussed the connections between ELA classrooms and the curriculum lessons. They considered the learning opportunities to enhance their students' ELA understandings by integrating the AI lessons into their classes.

This study contributes to the K-12 AI education on integrating an accessible text mining learning environment into ELA classrooms to engage high school students in developing an understanding of machine learning concepts through building AI models regarding to ELA teachers' perspectives. Taking an ELA perspective to design AI learning activities could potentially broaden access to AI through leveraging students' insights of texts, drawing from their own cultural backgrounds. Future studies could examine different culturally relevant pedagogical strategies to provide widely inclusive AI experiences to engage high school students from underrepresented, diverse backgrounds. In conclusion,

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Do Current Visions of Engineering Literacy Capture Family Engineering Practices? A Microgenetic Analysis of Engineering Learning in a Museum Makerspace

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Abstract: The recent Engineering Learning framework (ASEE, 2020) calls for research on how students can be supported to reach full engineering literacy in PreK-12 education. The current study analyzes a microgenetic engineering moment with a child, parent, and staff member in a museum makerspace. We found evidence of the Engineering Learning framework, but instances where the framework did not fully represent some nuances during making.

Although many states have adopted the Next Generation Science Standards (NGSS Lead States, 2013), which integrate engineering and science practices, engineering education has overwhelming adopted a single vision of engineering, the Engineering Design Process (Carr, Bennett, & Strobel, 2012; Arik & Topçu, 2020). Recently, a new three-dimension framework, called the Engineering Learning framework, has been proposed for formal PreK-12 curriculum that includes Engineering Habits of Mind (EHM), Engineering Practices (EP) including the Engineering Design Process, and Engineering Knowledge (EK). The ASEE (American Society for Engineering Education, 2020) report calls for research to apply the Engineering Learning framework in order to understand how engineering learning is progressing to reach the "end goal" of full engineering literacy for all students. However, the current framework is unclear on how the vision of full engineering literacy is achieved or even visible when still in development. We take up the call to use the Engineering Literacy framework with a preliminary exploration focused on applying the framework to the documentation of microgenetic engineering learning.

Data and Analysis

As a preliminary exploration on the potential of Engineering Learning (ASEE, 2020) as an analytical framework, we utilized data collected as part of a larger project developing a cardboard-focused makerspace at a large Midwestern science museum. Data was collected from May-June 2021 during museum-hosted private events with community partner groups who invited families that are historically and currently underserved by museums to experience and critique the makerspace. Based on a data review with engineering practitioner partners, we selected a single video clip that was consistently identified as an example of engineering. The Engineering Learning framework (ASEE, 2020, p. 25-26) proposes three primary components to engineering education that should be woven throughout curriculum; for the purposes of this analysis, we used the definitions of these components as supplied in the ASEE report as our coding framework. The authors thematically coded (Braun & Clarke, 2006) the transcript based on each of these three components for each major sub-clip of the video clip.

Results and Discussion

Table 1 presents a step-by-step narrative and analysis of the one selected clip where the youth (9 years old) discusses with their parent and a museum educator how to construct a ladder. The clip starts with the child in front of a table that has various materials scattered on it, including scissors, tape, popsicle sticks, string, etc. There was a previously constructed box by the child on the table. A staff member is standing on the opposite side of the table, and the parent comes in the clip later.

Table 1.
Narrative description of segments of one minute and eight second clip with Engineering Literacy coding, specifically Engineering Habits of Mind (EHM), Engineering Practices (EP), and Engineering Knowledge (EK). One-time codes are highlighted in grey.

Seg.	Narrative	Engineering Literacy		
		EHM	EP	EK

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1	The child picks up the box and is describing their desire to build a ladder using a piece of string that she had already attached to the top of the box, and was hanging down. The child, talking to the staff, describes how in scary movies, everybody has to get out somehow, so she would like to build a ladder for that purpose.	Conscientiousness; Collaboration	Engineering Design – Problem Framing	
2	The staff member asks the child if they still wanted to use the popsicle sticks for the ladder, which the child eventually does pick up one popsicle stick and begins wrapping string around the stick, describing "like you know how wigs- you can hold it and gonna make you stay still."	Collaboration	Material Practices	Other
3	The parent then suggests that the child use two popsicle sticks, to which the child responds "how you do that?" The parent takes the popsicle stick and string out of the child's hand and adds a second popsicle stick, which she places down on the table and adds the string on top.	Collaboration	Material Practices; Engineering Design - Ideation	
4	The child is watching while the staff and parent discuss ways of attaching the string and popsicle sticks together. The parent suggests gluing, to which the child replies that there is no glue, so that is why they were going to keep using tape. The child then grabs tape and brings it near where the parent is working on the ladder now.	Collaboration	Material Practices	
5	The staff member then suggest tying the string instead of tape, but the parent struggles to tie it. The staff member says there is a way to tie it, a certain kind of know, but that "you just have to be a little creative there."	Creativity; Collaboration	Material Practices	

The analysis showed that the video clip involved some components of the Engineering Literacy framework. However, in the one instance where the youth explicitly called on her existing knowledge of how wigs are secured in solving the engineering challenge, the Engineering Literacy framework did not have a category to capture this contribution, perhaps because the existing Engineering Knowledge categories are heavily based in professional domains. Thus, we see promise in using the Engineering Literacy framework to understand microgenetic engineering moving forward, but we caution that the existing categories may over privilege professional engineering knowledge. Future plans are to code the rest of the videos in our data set, as well as using data collected from surveys and interviews to understand families' own perspectives of engineering and how that can inform the Engineering Learning framework.

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Fake News Literacy: Intuitive vs. Analytic Processing

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Abstract: Understanding the cognitive processing of fake news is essential when planning to counteract fake news effects, such as through media literacy training. In this study, we aim to provide an insight into how news recipients assess dubious information and how accurate their appraisal of exemplary news is. We conducted interviews with $N = 51$ participants and found evidence for the role of emotions as well as the importance of design and layout when trying to discern true from fake news. Additionally, two particular cases illustrate the different ways of assessing news credibility: through intuition or analytically. In consequence, we suggest a model of online news processing including individual traits such as social influence, attitudes (e.g., political beliefs), and media literacy.

Introduction

Potentially everybody is exposed to huge quantities of information: Fake news, i.e., news content that mimics news articles while neglecting journalistic duties and aiming to mislead recipients (Pennycook & Rand, 2021), play a major role in this regard. Therefore, understanding and fostering fake news literacy has become an important topic of educational research and practice. Developing intentions and forming a cognitive perspective are the results of a decision, for which information needs to be processed (Greifeneder et al., 2021) either intuitively (Schwarz & Jalbert, 2021) or analytically, using methods that discern truth from falsehoods such as fact-checking. However, several factors can bias the processing of information, such as source credibility, social consensus or supporting evidence (Schwarz & Jalbert, 2021). Recent research has further added to the suspicion that failure to identify fake news is often rooted in familiarity and source heuristics (Pennycook & Rand, 2021).

Research Questions

The insight in the cognitive processing of fake news is still insufficiently differentiated. Hence, in this study we aim to explore the cognitive processing routes (mainly intuitive vs. analytic) online news recipients utilize. We examine the following research questions (RQs): *RQ1:* How do online news recipients assess news credibility? *RQ2:* What is the accuracy of their assessment?

Methodology

This exploratory study was built upon a mainly basic, qualitative design with semi-structured interviews for data collection. The interview protocol included 42 questions about demographic data, usage of the internet and online media, specific experiences with dubious news articles, and reactions towards those. In addition, we presented the participants two snippets of news articles, one true and the other fake, and asked them to rate these and describe how they dealt with them. The interviews were conducted in June 2021.The participants were a convenience sample of $N = 51$ German internet users (23 female, 27 male, 1 n/a), from which 40 were 18–30, 4 between 31–49, and 7 between 50–60. The majority of participants (26) were university students, 13 of them had already graduated. When describing their own self-confidence in dealing with online news and its credibility, we found our sample to be very self-confident (43) with only nine accounts of moderate confidence, and one person who described themselves as very insecure on this account. As to whether our participants thought of themselves as intuitive or analytical when dealing with problems, decisions, or information, 25 participants strongly relied on their gut feelings and 27 moderately trusted their intuition. Only 10 participants described themselves as being "head-persons".

For this study we also chose to highlight two special cases. *Participant A* (female, 22 years old) was a communication design student born in Germany and working in an information technology firm. She felt moderately self-confident (4 on a 10-point scale) in handling online news, and reported to seldom question news credibility or check sources. *Participant B* (female, 24) was a media and communication science student, born and grown up in Madrid, and working in Germany. She had already taken part in media literacy training during her studies. She rated herself as highly confident (8 out of 10) when handling online news.

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Findings

RQ1. Many participants (18) explained that they would read an article entirely before passing judgement over its credibility. Some others only read the headline (14) or specific parts of the article (14). However, a deciding factor seemed to be the source of the news content and level of interest in it (32). Throughout the three news examples, the layout and design played the most important role in our participants assessments (11 for participants' own examples, 31 for our real news, 24 for our fake news). In contrast, the source seemed to play a less important role (8, 4, 8). *Participant A* named a majority opinion towards a topic or the comments under the news as the main assessment criterion for news credibility. In absence of such information, she asked other people, friends and family, to share their beliefs and then adopted those of who she thought highly of. *Participant B* mentioned focusing on the content and source of an article when analyzing its credibility, with trusted sources being the established news media formats. She rated our real article as credible because of its content. She rated the fake article as not credible at all, again based on its content.

RQ2. In terms of credibility assessments, we found some disparities between the real and fake news articles. The real article was rated as moderately credible (18), not credible (14), or very credible (12). On the flipside, the fake news article was rated as not credible by a majority (26), moderately credible (14), or very credible (4). Our cases varied substantially in terms of their accurate credibility ratings. *Participant A* gave the real article a 3 out of 10 (not credible). On the other hand, she rated the fake news article as credible (7 out of 10). *Participant B* accurately identified both pieces of news, giving the real article a 10 out of 10 rating, i.e., very credible, and the fake news a 1 out of 10 rating, i.e., not credible at all.

Conclusions

This study was aimed at gaining insight into the cognitive routes utilized by news recipients when dealing with dubious online content. When assessing news credibility, our participants mainly focused on design and visual factors (intuitive route), less on the content itself (analytic route). Furthermore, we found a tendency towards overconfidence in regards to dealing with online news. While the participants in our sample were quite sure of their ability to accurately detect fake news, their results in the two exemplary tasks did not match their self-assessment—this was mainly associated with intuitive online news processing.

The issue of overconfidence when dealing with media effects is not new. It stands to reason that susceptibility to fake news is also rooted in third-person beliefs, i.e., thinking of oneself as not being as vulnerable towards misinformation as the average citizen (Ştefăniţă et al., 2018). Additionally, our two cases can offer some more specific insight into how recipients deal with online news. The great degree of trust *participant A* put into her social circle when assessing truth paints an interesting but worrying picture of recipients who simply do not think for themselves but rely solely on intuitive processing through social cues. Social consensus is a major factor when discerning truth from falsehoods (Schwarz & Jalbert, 2021) and can largely open the door to misinformation. Finally, *participant B* may have shown us the value of prior media literacy education through concise and accurate assessments of our exemplary news articles.

Altogether, this study suggests a classification of online media consumers: critical thinkers, such as *participant B*, with a high degree of media literacy and solid source knowledge who do not bother investigating dubious news but simply ignore them based on their experience, and naïve non-thinkers like *participant A*, who solely follow social cues but not necessarily experts and do not evaluate credibility at all. For future research endeavors, it may be worth investigating the interplay between personal characteristics (e.g., a strong focus on the social environment), prior consolidated attitudes (e.g., political beliefs), and specific media literacy competencies (e.g., high degree of source knowledge) in regards to which factors really help people identify misinformation and how to foster them with targeted educational interventions. These individual traits may be part of a conceptual model of online news processing, which we aim to validate in future research.

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Mental Simulations to Advance Adaptive Teaching Expertise in Reflection-based Instructional Coaching

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Abstract: Reflection on classroom artifacts is a core feature of teacher professional development. Despite its ubiquity, however, reflection as a learning mechanism is often ill-defined and lacking clear connection to a larger theory of teacher learning and change. Here, we present Mental Simulations for Teacher Reflection (MSTR) as one kind of robust teacher learning routine. Our aim is to offer a well-specified routine that embodies core principles for developing adaptive teaching expertise in expert-guided reflection contexts.

Introduction

Education researchers increasingly emphasize adaptive teaching expertise, i.e., the ability to read, interpret, and flexibly respond to students' developing thinking during instruction, as critical for student-centered instruction (van Es & Sherin, 2002). Despite wide consensus that adaptive expertise is an important teacher learning goal, research to understand the nature of its development and cultivating these processes in practice is still relatively thin (Carbonell et al., 2014). Reflection-based instructional coaching is recognized as one promising approach for developing the kind of pedagogical knowledge and skill needed for adaptive teaching expertise. However, significant variation exists in the effectiveness of such programs for transforming teaching practice, both within and across program designs and instantiations. More work is needed to understand what specific mechanisms underlie robust teacher learning in these contexts, and how they can be concretely supported in coaching practices and routines. Here, we present one kind of teacher learning routine—Mental Simulations for Teacher Reflection (MSTR)—that culminated from the work of one interdisciplinary research team focused on this issue. In what follows, we provide a summary of the conceptual backdrop, basic components, and quality dimensions of MSTR, followed by a concept map to illustrate how MSTR connects to larger mechanisms for developing adaptive teaching expertise. We conclude with implications for future work.

Research Background

MSTR primarily draws on adaptive expertise research to define the learning and change processes associated with developing a well-connected base of conceptual and procedural knowledge for student-centered pedagogies. We particularly focus on how to elicit and scaffold teachers' pedagogical reasoning processes in ways that support two key components of adaptive teaching expertise: (1) Recognizing, interpreting, and resolving instructional ambiguities and discrepancies; and (2) Iterative linking between teaching specifics (e.g., teacher moves, lesson contexts) to more generalized representations (e.g., larger pedagogical dilemmas, goals, and principles) to support knowledge building and conceptual change (Walsh, 2021; Kavanagh et al., 2020; Bransford et al., 2005).

Mental simulations for teacher reflection

Mental simulations, as a process for systematically engaging 'what-if' reasoning processes to generate causal inferences in ambiguous and uncertain situations (Markman & Dyczewski, 2013) provides an empirical framework for a coaching routine aligned with these theoretical perspectives. Adapting mental simulations to a teacher learning context, MSTR includes three basic components: (1) **Establishing Ambiguities**: coach and teacher iteratively discuss and refine shared understanding of the problem space, situating the context for the simulation; (2) **Proposing Alternatives**: coach and teacher iteratively propose alternative teaching moves for addressing instructional ambiguities; (3) **Weighing Alternatives**: coach and teacher iteratively hypothesize and weigh the potential of selected alternatives for advancing pedagogical goals and principles.

Table 1 (below) presents the quality dimensions of the interactions within each MSTR component that link to goals for adaptive teaching expertise. Lastly, Figure 1 captures the rationale for MSTR as a robust teacher learning routine. Specifically, it (1) describes the quality dimensions associated with each component of MSTR, and (2) illustrates the links between MSTR components, quality dimensions, and processes involved in knowledge development and conceptual change (i.e., provides an explanatory model).

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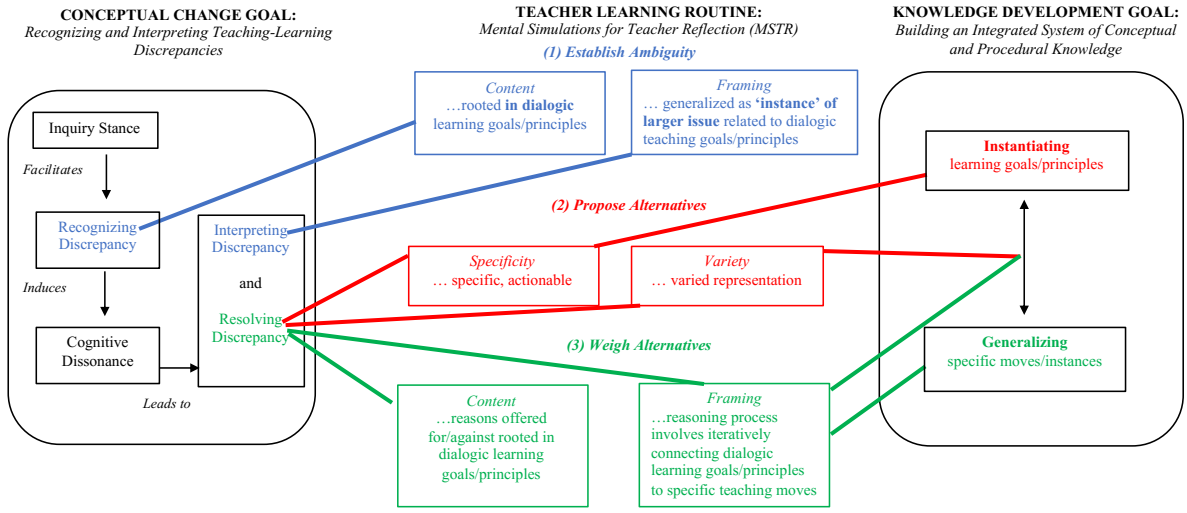
Table 1. *Quality Dimensions and Examples for each MSTR component*

MSTR Component	Quality Dimensions	Example
Establish Ambiguity	**Content**: Ambiguity 'topic' rooted in dialogic goals/principles **Framing**: Specific moment in a lesson or lesson plan is generalized to a pedagogical issue relevant across contexts	Student misconceptions problematized in terms of holding students accountable to rigorous thinking
Propose Alternatives	**Specificity***:* Alternatives are articulated in specific and actionable terms **Varied representation:** Multiple alternatives (2–3) are presented or an alternative is articulated in varied terms	Multiple specific talk moves or phrasings are proposed to address misconception (e.g., "where's your evidence for that claim?" or "what makes you think that?")
Weigh Alternatives	**Content:** Reasons offered for or against different alternatives are rooted in dialogic goals/principles **Framing:** Process of reasoning through alternatives includes both *instantiating* (connecting dialogic goal/principle to a specific move) and *generalizing* (connecting a specific move to dialogic goal/principle)	Relative merits of proposed alternatives are iteratively discussed relative to conceptual learning goals (e.g., students draw sound conclusions about text meanings) and dialogic principles (e.g., supporting students to assume responsibility for their learning)

Figure 1. *MSTR Components and Quality Dimensions to Facilitate Conceptual Knowledge Building and Change*



Discussion and implications

MSTR represents one artifact that emerged from our ongoing efforts to advance more robust, theory-based empirical frameworks for studying teacher learning mechanisms. By explicitly describing the components and quality dimensions within a coaching routine, MSTR can be leveraged to inform more effective coach training and serve as a foundation for future hypothesis testing.

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International Society of the Learning Sciences

Coalescing Knowledge Within Networks of Research Practice Partnerships: The Case of a School-Based Citizen Science Network

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Abstract: Synthesizing valuable insights developed within diverse partnerships that are part of a network is challenging. This study explores implementation stories of school participation in Citizen Science and insights shared by participants as part of two workshops, intended to increase cross-fertilization among participants. Six new abstract design principles were identified as corresponding with learning through Citizen Science. This study illustrates how these principles' identification can support cross-fertilization between partnerships and amalgamation of the dispersed knowledge.

Introduction and theoretical background

The Taking Citizen Science to School (TCSS) center is a network of Design-Centric Research-Practice Partnerships (DC-RPPs, Kali, et al., 2018), that includes members from different organizational, scientific, theoretical, and practical backgrounds. Each partnership within the network, implements a different Citizen Science (CS) project offered by the center in one or more schools, and co-designs or adapts curriculum materials to local contexts. This requires members to cross cultural boundaries of the various expertise. In doing so, members collaboratively advance educational practice, educational-research and the CS-related scientific research. As a result, unique knowledge and insights develop within each partnership, which have the potential to be valuable to other members in the TCSS network (Sagy, et al., 2019). The challenge of TCSS is to amalgamate this dispersed knowledge and make it accessible to all members of the network. This goal is in-line with the educational research challenge to increase and scale the educational innovations' applicability (Law, et al., 2021). The approach we chose is based on identification and abstraction of design principles (DPs, Linn, et al., 2006), within implementation stories of school participation in CS, which were perceived as effective for this challenge (e.g., Kidron & Kali, 2015). DPs connect theories of learning and instruction (know-why) with features of implementation (know-how, portrayed here by the stories) and provide a way to encompass, synthesize and present the knowledge gained in the diverse DC-RPPs, communicating the conceptual design ideas behind the implementations. Members of RPPs can then further adapt these emerging DPs to their RPPs' needs (Kali, et al., 2018). This poster describes how this approach was examined in two workshops, as a first step towards synthesizing the insights developed within the various DC-RPPs.

Method

To provide opportunities to identify, share and discuss cross-project DPs while enriching existing design knowledge and amalgamating the TCSS network's dispersed knowledge, we designed two workshops. In each workshop, participants (N=38, 30) worked in groups (five in the first and four in the second) where they: a) shared implementation stories of CS activities within their schools; b) identified or formulated DPs for school-based CS that may be integrated in these implementations; and c) shared and discussed those DPs in a plenary session. A description of 25 DPs for implementing CS in schools, which stemmed from the Design Principles Database (Kali, 2006) for science education was used as a resource. By integrating practical (know-how) and theoretical (know-why) knowledge, participants developed what Bereiter (2014) calls principled practical knowledge, intended for further use by the TCSS network. Data from both workshops was recorded, transcribed and analyzed deductively and inductively with the aim of identifying references to DPs as well as overarching insights beyond existing principles. The process of developing new DPs based on these insights was validated by the six authors of this research and triangulated with current learning science and educational research literature.

Initial findings

Altogether, 128 statements that related to DPs were identified. These statements were chosen as they included insights that made an abstraction of the practice. 23 of the 25 DPs were referenced in one way or another. Three DPs were not referred to at all (e.g., "Cultivate productive discourse norms"). Overarching insights provided bases

for six DPs that were later on validated and articulated, capitalizing on learning sciences and educational research literature: "Encourage active citizenship", "Freedom of choice", "Multidisciplinary and interdisciplinary learning", "Flexibility and adaptability", "Promote educational leadership" (e.g., Ballard et al., 2017, Iyengar & Lepper 1999, Kidron & Kali, 2015, Bransford et al., 2000, Ado, 2016 and Bandura, 1997, respectively).

To illustrate the process that enabled the articulation of new DPs we focus on the emergent "Encouraging active citizenship" DD. Twelve statements (of 128, three in the first workshop and nine in the second) mentioned the idea of active citizenship, by six groups. One group, for instance, found that what connected between their implementation stories was that CS partnerships can foster empowerment of students, caring, and agency to contribute to their local environment. To add this emergent DP to the pool of DPs available to the network, we used language participants brought to the table and integrated it with learning theory. Within the description of each DP, we included also practical examples and citations of workshop participants, acknowledging their contribution as part of the DP's authorship. For example, the 'Encourage active citizenship' DP's description resulting from this process, which became a resource for use and refinement to networks' members follows:

> Participation in CS involves students in active citizenship and provides them with opportunities to contribute to their communities and wider society. Importantly, encouraging active citizenship tends to provide students with meaning to their activities outside the school's boundaries, connecting them with current issues such as climate change and biodiversity, while fostering students' sense of agency and self-perception as contributing citizens.

Discussion

The initial findings portray the potential of sharing implementation stories and relating them to DPs as a mechanism to support amalgamating of the dispersed DC-RPPs' knowledge. The workshops led to refinements of existing DPs and articulation of six new DPs. It also informed the design of a pilot version of a Web-based platform for supporting networks of DC-RPPs in coalescing principled-practical knowledge.

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International Society of the Learning Sciences

"It's so frustrating!" Understanding Design Dilemmas in Co-Design through Curricular Values

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Abstract: Co-design is an increasingly common process for curriculum development in science education, where teachers and researchers work together to create curricula, drawing on mutual knowledge and expertise. In efforts to understand this process, I looked at design dilemmas that occurred during design meetings and categorized the ideas that emerged in terms of underlying curricular values. I characterize these emerging curricular values and identify ways in which participants work to achieve and balance them.

Introduction

In the last decade, there has been a strong movement to transform science teaching and learning in the United States to be more student-centered, equitable, and meaningful (NRC, 2012). Curricular materials are an important step in achieving these goals—both to provide tools for teachers to use that reflect these reforms, and to help them develop the practices needed to use these tools (NRC, 2015). Curricula developed through cooperative design by teachers and researchers are an important strategy that brings together different kinds of expertise needed to achieve curricula that reflect target reforms and are tailored to the realities of classrooms (Penuel et al., 2022; Reiser et al., 2000). A co-design approach can also provide opportunities for teacher professional development of pedagogical and subject matter knowledge (e.g., Peel et al., 2020), and support teachers' agency (e.g., Severance et al., 2016).

Yet, developing designs for classroom learning involves balancing different priorities that need to be addressed (Penuel et al., 2022). Furthermore, tensions can arise between teachers and researchers working together due to their differing agendas (Couso, 2016). I aim to understand how these design intricacies unfold by examining (a) the curricular values that emerged regularly throughout the design process in one curricular co-design context and (b) how they were balanced in conversation during team meetings.

Project overview and methods

I take an in-depth look at the work of one design team of 3 teachers, 3 researchers, and a district science curriculum specialist who developed a Next Generation Science Standards (NGSS)-designed pilot high school physics wave unit during 25 90-minute weekly Zoom meetings across 7 months. The development work was part of the OpenSciEd project, a collaboration between inquiry Hub at University of Colorado Boulder, Biological Sciences Curriculum Study, Denver Public Schools, and Northwestern University. OpenSciEd is an ongoing partnership which strives in part to lead the development of research-based NGSS-designed classroom materials made available to the public.

All meetings throughout the creation of the unit were recorded and transcribed. I fulfilled the role of a participant-observer in the setting, diving more intimately into the design work to be better familiarized with it. I watched the recordings of meetings and identified *design dilemmas*—times when team members were at a crossroads in the curriculum or were faced with problems that had multiple possible directions. Within these design dilemmas I characterized the *curricular values*—criteria that were used to make design decisions—that were evident in specific utterances. I also identified *tensions*—moments when curricular values were at odds with each other.

Results and discussion

Table 1 presents the range of curricular values I identified, along with indicator questions that operationalize the values being offered. I found that co-designers' utterances fell into seven different categories of curricular values: *coherence, coherence from the students' perspective, student engagement, equity focused science education, alignment with the standards, scientific accuracy,* and *teacher's pedagogical approach* (see Table 1). These curricular values were sometime stated independently from other values; for example, "I'm looking for more fun things to do here" was a concern for the need to reach the value of *student engagement.* More often values were stated as aligned toward achieving a certain goal or at odds with each other. For example, during a deliberation on how to incorporate energy into the lesson, Matt, a teacher participant, stated "There might be a tension between how we are thinking about energy for this application [as a model in which fields carry energy] (*coherence from the students' perspective*) and how we

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are thinking about energy in our whole course (*coherence*) and in the NGSS [as systems carrying energy] (*alignment with the standards*)." Based on preceding utterances, it is evident that the first "we" used here positioned Matt in "student hat"—as if he was a student experiencing the lesson. The value he was naming was *coherence from the students' perspective* which he portrayed as in tension with 2 other values: the coherence of the "whole course" (*coherence*) and "the NGSS" (*alignment with the standards*). For Matt, the "whole course" and "the NGSS" were aligned toward the same goal. Therefore, the underlying values were not in opposition with each other, but both conflicted with the value of *coherence from the students' perspective*. This led to a segment of utterances in which the team deliberated over how to proceed with the lesson using curricular values as criteria for their proposed directions.

Table 1

Curricular values that were found during design team meetings, the indicator questions used to operationalize the values, the definition of each curricular value, and examples of identified corresponding utterances.

Curricular Values	Indicator Question	Definition	Examples of Utterances during meetings
Coherence	How do we—designers—understand this curriculum?	The layout of the lesson and unit makes sense and is logically organized to the design team.	"Alright, so let's see if I understand this correctly. I'm reading it as a little bit of a contradiction within the same paragraph, that we're going to think of it as a photon."
Coherence from the students' perspective	Will this make sense to students?	Designers develop a path that is motivated by anticipated student questions and interests.	"...if I'm a kid, I'd be like 'teacher I want something that compares all those'. And then, bam, here is the spectrum."
Student Engagement	Is this fun and exciting?	Students are excited about and engaged with the lesson or unit.	"I can see that excitement there." "I'm looking for more fun things to do here."
Equity focused education	Is this equitable?	Being mindful of the ways in which science education is culturally and socially responsive and meaningful. Making curricula for all students.	"The history that we know around most of these experiments are white guys from Europe and um that can be really problematic when students are going through the curriculum and every single example looks exactly the same."
Alignment with Standards	What do the standards tell us to do?	The Performance Expectations and Disciplinary Core Ideas outlined in the NGSS are incorporated.	"Do you think that we might get pushback from other people on the fact that it's high school and we're not using terminology from the NGSS?"
Scientific Accuracy	Are we doing good science? What does physics say?	The science present in the lesson and unit needs to be precise and correct.	"Yeah, it's not really accurate to call all particles molecules, but I think you can call all molecules particles. So then let's just use the word 'particle.'"
Teachers' Pedagogical approach	How does this approach to the task reflect our pedagogical commitments?	Ideas expressed by a participant of the design team from teaching experience.	"I am always for never using vocabulary...I just, I hate voca… I don't know, it gives me like PTSD to like pre-teach vocabulary. I just, I don't like it."

This work introduces *curricular values* as useful metrics or evaluation criteria in design work. This study highlights that it is possible to identify these values systematically, and that these values are at the core of design dilemmas. Theoretically, this work deepens the understanding of deliberations within design dilemmas and helps to discern what stakeholders bring into the co-design space. Further understanding underlying curricular values and relationships between them can inform models of how to support co-design as a vehicle for implementing reforms.

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International Society of the Learning Sciences

Science Learning Through Drawing

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Abstract: Engaging students in visualization, especially constructing visual representations has been suggested as fruitful to support science learning. This study explored how elementary students learn astronomy, which is a challenging topic for both teaching and learning, through drawing and communicating with others about their drawings. Data were collected from multiple sources and analyzed qualitatively. Findings indicated that drawing as cognitive and epistemic resource facilitated students' reasoning in both individual and social domains.

Background

Visual representations such as drawing are integral to scientific thinking and reasoning (Prain & Tytler, 2012; Tytler et al., 2020). Scientists use visual representations (e.g., drawings, diagrams, sketches) to make discoveries, test ideas, explain findings, and elaborate knowledge (Gooding, 2006). Researchers in science education broadly agree that students need to learn how to interpret and construct visual representations of science concepts and processes (Prain & Tytler, 2012). In particular, there is an increasing focus on student-generated drawings as research suggests engaging students in the process of visual representation construction supports learning better than simply interpreting experts' visualization (Yoon et al., 2021). Researchers suggest the role of visual representation should be to support learning with representation, instead of learning from representation. This study aimed to explore how elementary students learn astronomy science with and through constructing visual representations and communicating with audience about their visualizations.

Seeing from socio-cultural perspectives, representational work as epistemic practices of science is embedded in and cannot be separated from its social and cultural contexts (Yoon et al., 2021). Drawing to reason is the use of cultural symbolic and semiotic tools to make sense of the phenomena and solve problems (Tytler et al., 2020), thus is mediated by the tools used and constrained by its context and various physical and conventional resources available (Gooding, 2006; Lundin & Jakobson, 2014; Prain & Tytler, 2012).

Constructing and refining representations is a core epistemic activity within science and should therefore be a major emphasis in the science classroom. Rather than "tools for something more fundamental, such as conceptual knowledge," students' representational work such as drawing is "enacting science learning and reasoning" because it is consistent with how knowledge is developed and communicated in the science community (Prain & Tytler, 2012, p. 2757). In constructing and refining drawings, students need to consider the extent to which it is coherent both within component parts of the drawing and across related representations (Tytler et al., 2020). The consideration of coherence is a key feature of model-based reasoning central to the epistemic practices of science (Lehrer et al., 2008). In this way, drawing is constrained by the need to achieve specificity of detail and the requirement of unambiguous communication (Prain & Tytler, 2012).

Curriculum Context

There are many reasons for astronomy to be a part of the education system and culture. Astronomy is deeply rooted in the history of almost every society because of its practical applications and philosophical effects. Astronomy is mainly based on descriptive methodologies, which are different from other science domains, in which scientists conduct experiments to test their hypotheses. Thus, astronomy shows an alternative approach to the "scientific method" in school context (Plummer & Tanis Ozcelik, 2015). Further, engagement with astronomy topics which fosters curiosity and imagination is widely suggested as a method of inspiring students to further study of science. Nevertheless, research indicates that some astronomical phenomena are difficult for students to understand and challenging for teachers to teach (Plummer & Tanis Ozcelik, 2015).

Throughout the four-month research period of this study, a classroom science teacher and her nineteen students from a Grade 5/6 science classroom in a public school in Canada worked on an astronomy science unit. Students were encouraged and supported to learn characteristics of other planets and their moons in the solar system by drawing a design to further current space exploration. Students' drawings were to be based on their experiences, knowledge learned in this unit, and information from online research on their topics. At the end of the unit, each students presented their ideas with drawings to their peers.

Research Methods

This qualitative case study employed multiple methods for data collection, including observing students' drawing processes, interviewing students to learn how they drew from their perspectives, and collecting students' drawings.

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Data from multiple sources were analyzed together for thematization to understand how students learned elementary astronomy by constructing and communicating with others about their visual representations.

Findings

Findings from this study were organized into the following two themes:

(1) In the individual domains, drawing has cognitive and generative functions for interpretation and sense making. Drawing as a cognitive resource can enact students' reasoning within the inquiry process. As a form of representation construction and refining, drawing provided students with opportunities to coordinate, integrate, and synthesize information in a coherent way to interpret the astronomical phenomena under investigation. Students in this study examined the coherence across multiple representations, including their own drawings, texts in books and websites, and online audio and video resources, to form their plausible claims. While achieving the coherence, students negotiated, refined, and advanced their understandings of the astronomy topics. For example, in this study, a student, Nate (pseudonym), explored characteristics of Triton (i.e., Neptune's moon) through drawing his design which is a rover for sample collection. During the interview, he shared how and why he made changes to his rover' wheels in his drawing.

> They were like the wheels of car, then I changed … I know that to have the right wheels, I need to know what the surface [of Triton] looks like, so my rover can move … NASA says it is all ice … wheels have cleats will not fall on the icy surface …

By exploring relevant online resources, Nate collected helpful information based on which he refined his drawing. Through drawing, students coordinated, integrated, and synthesized information to form interpretation.

(2) In the public realm, drawings have social and critical functions for communication. When students' designs and claims were introduced to the classroom community, their drawings were crafted into and functioned as an epistemic resource that could provide pictorial evidence for their claims. The community as audience examined the clarity of the visual representation, as well as the coherence among elements of the representation, to determine whether the visual claim was plausible and acceptable. For the purpose of communication, students always included other representations, such as annotation, images and gestures, together with their drawing to explain their designs. For example, to help his peers to understand how his rover's wheels looked like, Nate also created a 3D physical model with foam balls and toothpicks. In addition, trough social interactions, students' drawings were further refined, as well as their understandings about the astronomical topics.

Conclusions and Discussions

Findings from this study indicated that drawing as cognitive and epistemic resource facilitated student science learning in both individual and social domains. With its cognitive and generative functions, drawing helps students make sense of the phenomena as it enacts student reasoning. In the social context, students' drawings function as epistemic resources for the purpose of communication.

Despite attracting children's interests and affecting their everyday lives, many teachers have found astronomy challenging to teach (Plummer & Tanis Ozcelik, 2015). Finding from this study suggest that it could be fruitful engaging students in visual representation construction such as drawing to learn elementary astronomy.

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Centering Ethics in AI Education: Cutting Through the Controversy

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Abstract: Current efforts teaching the ethical implications of AI neglect current dilemmas rooted in biases. We propose two design considerations for curriculum designers in this area: embedding ethics across the curriculum and foregrounding authentic problems facing the AI field. Our proposals are compared to a responsible AI curriculum we are helping build to explore the implications of each approach to ethics in AI.

Introduction

As encounters with Artificial Intelligence (AI) subside from the surreal and remarkable to the ordinary and mundane, a new literacy is emerging. How are we to make sense of these modern marvels we interact with everyday, that shape our lives in powerful ways? AI technologies answer questions I pronounce in my kitchen, decide if I qualify for a credit card, and scan my face to access my phone. Yet the technology appears impervious to inspection, shielded in a black box, suggesting no questions need be asked. But the consequences of these ubiquitous technologies are not neutral nor fair, but biased and ethically fraught. To prepare a public to contend with the ramifications of our increasingly AI-driven world, education researchers have called for students to learn not only the technical knowledge and skills related to AI, but the societal implications (Zhang et al., 2021; Lao, 2021). In response, lessons on AI have been designed and implemented for children as young as 4 (Ali, Payne, Williams et al., 2020).

However, current efforts addressing the ethical dimensions of AI in education fall short of realizing their promise. These nascent endeavors focus on identifying stakeholders and their values to explain AI as socio-technical systems (DiPaolo et al., 2020), products of design agendas and biased datasets. But learners are presented with scenarios disconnected from real-world dilemmas— cats, dogs, and peanut butter and jelly sandwiches figure prominently (Ali, Payne, Williams et al., 2020)—and neglect how AI design decisions may cause harm. Our project intends to fill the gaps in this freshly poured foundation. As part of a team building a responsible AI curriculum for middle schoolers, we are envisioning a new set of principles centering ethical thinking in the design, teaching, and learning of AI in school. We propose ethics must be embedded, with authentic problems facing the AI field foregrounded. This poster begins to explore why ethical thinking must be woven into and emphasized throughout AI curricula, and how ethical dilemmas should be approached.

Roots of Bias in AI

Ruha Benjamin (2019) explains how "[w]ith emerging technologies we might assume that racial bias will be more scientifically rooted out. Yet, rather than challenging or overcoming the cycles of inequity, technical fixes too often reinforce and even deepen the status quo." Indeed, it is the rising awareness of systemic bias, of unfair decisions made by humans making up an organization, that results in outsourcing organizational processes and practices to AI. In AI we trust, may the logic read. However, outsourcing decision-making that is historically biased to AI simply embeds the social bias into a technical artifact. This can be seen across time, whereby dehumanization caused by AI today echoes a legacy of oppression championed in the sciences.

For example, an AI technology used in the U.S. criminal justice system to predict recidivism rates *incorrectly* flagged black defendants as likely to commit future crimes at rates nearly double that of white defendants (ProPublica, 2016). Bonilla-Silva & Zuberi (2008) remind us "that the founder of statistical analysis also develop[ing] a theory of White supremacy is not an accident. The founders developed statistical analysis to explain the racial inferiority of colonial and second-class citizens in the new imperial era" (p. 5). That is to say, scientific progress and technological innovation often act in tandem with logics of domination, particularly White Supremacy and anti-Black racism (Gould, 1996).

Design Considerations for AI Education

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Our proposal is to center the reality of bias in AI by grounding content in real-world problems. Teaching how image classification works should occur in a context connected to its use by industries and effects on consumers. Datasets using cats and dogs may be effective at teaching the technical aspects of image classification, but essentially ignores the sociological, and presents a problem of transfer for students expected to discuss ethical issues when their hands-on engagement revolves around cute animals.

Our second design consideration, embedding ethical thinking content throughout the curriculum, intends to better reflect the AI-creation pipeline, where decisions with significant ethical consequences occur every step of the way (Suresh & Guttag, 2021). Learners need to be confronted with scenarios that allow them to leverage their prior knowledge to make meaning about how AI impacts their lives, with the goal of helping them understand how they can affect change in their communities.

Currently, little research exists regarding the teaching and learning of AI and its inherent dilemmas. Based on their literature review, Long and Magerko (2020) identify ethics as one of 17 key competencies substantiating AI literacy. Based on their literature review of 150 documents, only two intersected AI with curriculum design for non-technical learners and ethics. Thus, ethics is an imperative component of a robust AI education, while a body of research that could help direct efforts integrating this competency into AI curricula remains almost nonexistent.

Applications: The case of RAICA curriculum

Responsible Artificial Intelligence for Computational Action (RAICA) is a design-based research project to develop and research a project-based AI curriculum for middle school students in the U.S. and Dubai. Our overarching research question asks *how can we transform students from AI consumers to conscientious AI contributors?* A curriculum module spans 20-25 lessons, 50 minutes a piece. Students learn core AI concepts, such as supervised learning and natural language processing, by creating a technical solution (using simple coding tools such as Scratch) that leverage AI technologies (like image and audio classification).

The curriculum designers struggle with the question of controversy—-i.e., How can we include real ethical dilemmas that might be controversial without damaging the sense of safety for teachers and students? For example, we adapted the activity featuring cats and dogs to explain image classification, but noted how detached from real world dilemmas this technology is implicated in: Black people being labeled gorillas or primates by Google and Facebook (Mac, 2021; BBC, 2015); deep neural networks detecting sexual orientation based on a subject's face (Wang & Konsinski, 2018); and military applications, such as Project Maven, which intended to identify people and objects in drone footage (Wakabayashi & Shane, 2018).

The RAICA curriculum bookends ethical questions, sans scaffolds between understanding bias with datasets featuring cats and dogs and what that can mean when applied to humans. We propose for future iterations to embody these two design considerations to present learners first and foremost with scenarios based on real-world dilemmas. We will then investigate the impact these proposed principles have on students' grasp of AI's ethical implications compared to the initial implementation. Considering transfer, we expect students to have a richer understanding of how AI shapes their world and how ethical considerations apply across different AI technologies.

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International Society of the Learning Sciences

Empirically-driven Multiple Choice Response Options

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Abstract: We introduce an empirical method for generating multiple choice (MC) response options for educational assessment. Developing quality response options for MC questions is labor intensive, especially when parallel items are necessary for repeated assessments or multiple test forms. We propose a data-driven, iterative approach for creating an item bank of MC questions by first collecting a sample of open-ended student responses that are subsequently rated by subject-matter experts. Contextual sentence embeddings of the observed student responses as well as the expert ratings are used in conjunction with hierarchical clustering to create MC options that span the desired ground truth rating levels specified by the item creator. We evaluate the quality of the automatically generated response options qualitatively, based on existing research relating to best practices for item writing.

Introduction

Although the grading of multiple choice (MC) items is less time consuming than open-ended (OE) items, constructing quality response options for MC items can be more labor-intensive and difficult (Gierl, 2012). Previous research on item design suggests that response options should include feasible student conceptions about the topic of interest, whether they be correct or incorrect (Haladyna, 2010; Zimmaro 2010). In addition, related research suggests that MC options should be homogeneous in content but different in their level of correctness (Burton, 1990). Finding plausible distractors that reflect common student misconceptions and are contextually related to other options requires considerable effort and can be hindered by expert blindness (Nathan, 2003). We suggest that the application of artificial intelligence (AI) can help mediate such issues and aid in constructing items that exemplify these item writing guidelines.

The motivation for this work is to reduce a common time burden for educators, as well as suggest a more objective, data-driven method for creating quality MC response options for both single item creation, and the creation of a bank of parallel items. We propose an iterative item development method as such: first, desired items are created as OE items and a preliminary data collection is performed to obtain a sample of student responses. Once subject-matter experts rate the observed responses, we create vector embeddings of the responses, and use hierarchical clustering to automatically identify contextually similar response options that reflect real students' conceptions.

Multiple Choice Response Option Generation

The data we used for this project was sourced from a 2019 field test of a critical reasoning in mathematics assessment developed by a team of researchers at the Berkeley Evaluation and Assessment Research (BEAR) center. The data included responses to 30 different mathematics related items. However, for this study, we focus on the 6 items with over 300 responses each. Student responses were each rated from 0 (fully incorrect) to 3 (fully correct) by multiple researchers at the BEAR center.

Our method for automatically generating MC response options is as follows. We first use Sentence-BERT (SBERT; Reimers, 2019) to create sentence embeddings of the collected responses. SBERT is a modified version of BERT that utilizes siamese and triplet network structures to create semantically meaningful sentence embeddings. Next, we reduce the dimension of the often-sparse sentence embeddings from vectors of size 768 to size 50 using truncated singular value decomposition (SVD). With the reduced sentence embeddings, we perform hierarchical clustering with the Ward linkage criteria. Hierarchical clustering consists of a family of algorithms that form clusters by merging or splitting data points in succession, and the Ward linkage method performs merging by minimizing the sum of squares within the clusters. We use the silhouette coefficient to search for the best number of clusters from 3 to 6.

Finally, we filter for clusters that include at least 20 responses to make sure there are enough responses from which to sample. We randomly sample response options from the user specified rating level categories to create an item version. If it is the case that the cluster from which we are sampling does not contain all rating categories needed, we sample from a different cluster. Once the final item responses are created, we recommend that a human intervenes to perform a quick pass of final necessary modifications to the responses such as making sure that all responses either end in a period or do not, removing clear grammar mistakes, etc. Item writing recommendations specify that answers should use similar language, there should not be any grammar issues or misspelled words to prevent obvious incorrect answer elimination (Burton, 1990).

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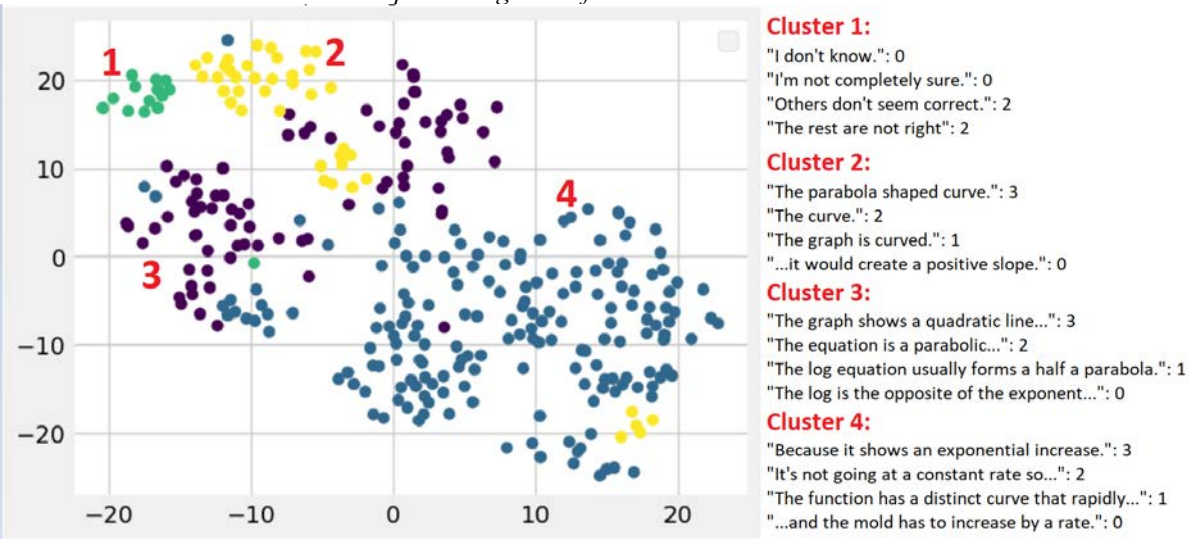
Results and Discussion

As this project is a work-in-progress, we evaluate the goodness of the generated items qualitatively. Figure 1 shows a 2D visualization of the response clusters for an item that references a graph of an exponential function. For each of the four clusters, example responses are included as well as their respective ratings. The examples shown for clusters 2, 3, and 4 may serve as fixed response options for three different parallel items. The options span the 4 ratings levels, but the user can also specify to sample one fully correct answer (rated as 4) and the rest fully incorrect answers (rated as 0). Cluster 1 seems to contain "I don't know" type answers which should be avoided, and only answers rated as 0 or 2. Our method would not sample from this cluster because responses do not span the desired rating levels. Noticeable issues in some of the sampled response bundles include drastically uneven response lengths and the lowest rated responses being nonsense answers such as "I just guessed". However, as previously suggested, human intervention is necessary for final touches and filtering out unusable bundles of response options.

Further evidence is needed to validate the utility of our method. Anticipated future work includes qualitative evaluation of the response clusters from education professionals, as well as psychometric evaluation to ensure that parallel items are of similar empirical difficulty. However, we believe the proposed method for empirically generating of MC response options illustrates how technology can be a practical aid to educators.

Figure 1

2D visualization of hierarchical clusters of student responses. Example responses (some truncated) for each cluster are included as well as the expert rating levels from 0 to 3.



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Predicting Learning Gains in an Educational Game using Feature Engineering and Machine Learning

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Abstract: In this study, we use feature engineering and machine learning (ML) to develop a regression model to predict students' learning gain while playing an educational game. Specifically, this study used the log data from 199 students' gameplay to build a logistic regression model. The model we created includes 14 features with an accuracy of .61.

Introduction

Educational games are complex environments that can assess students' learning process and outcome. As students interact with the game, they produce rich data which provides evidence of learning. Using machine learning (ML) techniques, we can make use of game data to derive models that predict students' experience. By doing so, we can create educational games that will respond—providing supports or adaptive challenges—to student's learning needs. In this study, we use feature engineering and machine learning to develop a regression model to predict students' learning gain (pre to posttest) using gameplay data from *Physics Playground* (*PP*; Shute et al., 2019).

Method

We examined a dataset (n = 199) from 9th to11th-grade students (*Male* = 104, *Female* = 91, *Other* = 4) in a large public school in the southeastern United States (see Shute et al., 2020). Students self-reported a diverse range of ethnicities: White (42%), Black or African American (31%), Other (19%), Hispanic (8%). Collectively, these students generated about 6 million data points in 5 days of gameplay (about 1.5 hrs of gameplay per day). *PP* is a 2D computer-based game (including 81 levels) created to help secondary school students learn Newtonian physics. Using simple physics agents (e.g., ramp, lever) or manipulating physics parameters (e.g., mass of the ball), students hit a red balloon using a green ball in *PP*'s levels. To access the learning supports, students click on the help button, which is always available during gameplay. The game's incentive system includes earning money resources and spending money opportunities (e.g., buying background music, background image, new ball, or a solution video). We collected log data of students' interactions with the game. The log file contains nearly 17,500 events representing each level played by all 199 participants. 13,312 events were used for modeling after removing missing values. A set of features was distilled based on our prior work on developing evidence-based assessments (Shute et al., 2020). We originally considered 45 features that show students' actions in each game level, such as the coins students earned (gold or silver) and how long students played a level. Our refinement and selection of the feature space was guided by the theory of game-based learning (Plass et al., 2015) and literature about predicting learning gain with interactions with technologies (Crossley et al., 2020). After several rounds of feature selection based on training data for reducing overfitting, we selected 14 features (Table 1) for modeling learning gains using a logistic regression model. The learning gains were measured through two isomorphic tests with multiple-choice items (pretest = 18 items, α = .77; posttest = 18 items, α = .82). The higher the absolute value of a feature weight in a regression model, the stronger its influence on learning gains. All features were normalized using z-score normalization. We tuned the regression model to achieve high accuracy in predicting learning gains.

Results

Our final model achieves a cross-validated accuracy of 0.61 and a cross-validated kappa of 0.12. The features explain 5.31% of the variance of those who had learning gains. The confusion matrix shows that the model had the majority error cases in predicting events that should be false but were predicted as true. This indicates that in the future, we still need to revise the feature space so that the model could identify patterns for positive learning gains. As shown in Table 1, game levels with challenging physics concepts (concept difficulty), learning support, game mechanics difficulty (GM), and agents drawn are good predictors for learning gain while not solving the game level (solved), money earned, number of help button usage, game supports viewed, and number of physics animations viewed negatively predicted learning gains.

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Table 1
Definitions of Features and their Weights

Feature	Weight	Definition
Performance		
Time	-0.001	The time, in seconds, a player spends in the level.
Solved[1]	0.720	Whether the player solved the level or not (yes/no).
Money earned	-0.030	The amount of money earned playing the level.
Wallet balance	-0.001	The amount of money in the player's wallet at the end of a level.
Support		
Help button usage	-0.090	The total number of times the help button was used within the level.
Learning support viewed	0.080	The total number of learning supports, of all types, viewed in a level.
Game support viewed	-0.060	The total number of game supports, of all types, viewed in a level.
Physics support viewed	-0.060	The total number of physics supports, viewed in a level.
Physics animations (PA) viewed	-0.010	The total number of physics animations viewed within a level.
Engagement		
Agents drawn	0.020	The number of mechanical agents (e.g., ramp) drawn within a level.
Objects drawn	0.007	The total number of objects (excluding agents) drawn in a level.
Level Traits		
Type[2]	0.003	The type of level. Either manipulation or sketching.
Concept difficulty[3]	0.200	The difficulty of physics concepts included in the level.
Game mechanics (GM) difficulty	0.070	The difficulty of game mechanics included in the level.

[1] Compared to unsolved; [2] Focus is sketching type levels; [3] Focus is hard difficulty

Discussion

Looking at the features contributing to positive learning gain, we can see variables that are related to game performance. Specifically, solving the game levels and drawing agents (simple machines). Other than game performance variables, learning support-related variables are also good predictors of learning gain. That is, the total number of learning supports viewed was a positive predictor of learning gains. Variables that predicted learning loss included variables other than gameplay (e.g., clicking the help button, money earned, game support, and physics animations viewed). These variables indicate that students needed help and showed that students spent time doing tasks which took them out of gameplay. Finally, variables related to a game level's difficulty were also important predictors of learning gains. Specifically, the concept difficulty was a strange predictor compared to game mechanics difficulty. This indicates that difficult concepts and difficult levels in terms of game mechanics contribute more to students' learning. The model we came up with can be used for early detection of learning gain.

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International Society of the Learning Sciences

Mentors' Learning Support Roles and Their Impact On Girls' Identity Imaginations

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Abstract: Mentoring programs have been intentionally designed to support Black and Latina girls in pursuing STEAM. Here, we examine how the support roles mentors play in an OST STEAM program relate to younger girls' imaginings of their own identities. Findings from surveys taken by middle-school girls and mentors indicate that by the end of the program year, girls showed more willingness to imagine themselves in various identities, relating to the support roles mentors most often played.

Introduction and Background

Black and Latina girls are traditionally and still dramatically underrepresented in science, technology, engineering, and mathematics (STEM) fields. Several studies have explored the reasons behind the gap, citing factors such as negative stereotypes, lack of opportunities, and more (e.g., Margolis et al., 2008; Wang, 2013). Out-of-school time (OST) programs have been designed to spark and sustain girls' interest in STEM as early as middle school when their interest starts to decline (e.g., Barron, 2006). Studies have shown that mentoring is a promising means of promoting girls in STEM, and women who have chosen courses, college majors, or careers in STEM emphasize the importance of role models in their decision-making processes (e.g., Stoeger et al., 2016). Our previous work has shown that mentors helped create a counterspace (Ong, Smith, & Ko, 2017) -- a safe place to explore their identities and interests in solidarity with one another and to imagine potential futures for themselves -- during a year of online programming due to the pandemic by adapting quickly to youth needs, highlighting and celebrating the full, authentic selves of the learners, and by remaining mindful of the challenges associated with intentional community building (Thompson et al., 2021). In addition, a number of generative roles have been identified to describe how educators including mentors and caring adults can advance learners' technological knowledge and skills (Nacu et al., 2014; Barron et al., 2009). In this study, we build on those frameworks in an OST STEAM program—adding art and design into STEM—for middle-school girls, asking: How do the support roles that mentors see themselves play relate to the STEAM identities of youth over a year?

Methods

The Digital Youth Divas (DYD) is an OST STEAM program serving primarily Black and Latina girls in middle school. The program is designed to foster community between youth participants and high-school to college-aged mentors who facilitate the STEAM activities. In the 2020-2021 program year, there were 30 girls participating consistently in virtual programming 1-3 times per week. There were 12 mentors working with the youth. Eleven of the twelve identify as women, and all identify as Black, Latina, and/or Asian.

Youth took a survey at the beginning and end of the program year. For this preliminary analysis we looked at the item: "How much would you use the following words to describe yourself?" followed by words such as "reader, student, engineer" etc. Fifteen of the youth answered this question on both the pre- and post-surveys and thus are included in the analysis here. The mentors took part in weekly planning and professional development meetings, including a workshop on support roles for learning. At the end of the program year, mentors took a survey asking questions about their perceptions of how the program went, and what support roles they felt they played. For this paper, we noted changes between youth pre- and post-survey responses. Then, we identified the support roles the mentors said they were most likely to play. Finally, we considered these two sets of data in relation to one another and looked for themes or relationships that emerged.

Findings

Youth responses to question "How much would you use the following words to describe yourself" were generally more positive on the post-survey than on the pre-survey, meaning that youth were more likely to choose "Very Much" or "A little, or sometimes" to each word choice on the post-survey. This demonstrates that the girls showed more willingness to imagine themselves in multiple potential futures in STEAM after participating in the program. Specifically, the descriptors entrepreneur, performer, fashionista, designer, and visual artist showed the most

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positive growth among all the descriptors. The only descriptors that did not show positive gain were computer programmer and athlete. Our poster will display additional details from the data.

On the mentors' post-survey, they most often reported "always" playing the roles of encourager (80%), friend (80%), and monitor (60%). These roles primarily centered around validating youth's ideas (encourager, friend) and supporting the learning processes (monitor). The mentors elaborated in open-response questions on the survey, reflecting on the most meaningful parts of the mentoring experience. They shared that "being able to build relationships with the girls" and "connecting with the girls and learning alongside them" were the most valuable parts of the experience. A mentor shared:

> *I had a strong STEM identity coming in as a Divas Mentor, since I was a declared computer science major by the time I signed up for the position, but being a mentor has allowed me to take that identity and share it proudly with youth girls, at an age where I knew I was also a STEM kid but wasn't sure if I should embrace it.*

This mentor took joy and pride in acting as an encouraging role model for the youth, and knew it was a crucial time to support girls of color in their STEM journeys. The roles played by the mentors are active, highly supportive, and uplift the girls' sense of self, which can in turn impact their openness and imaginations. Although not all the descriptors chosen by the girls are strictly-STEM related, it is likely that the support of the mentors helped the girls feel more confident in embracing all their interests and identities, allowing them to see themselves as complex and unique individuals with many possibilities open to them in the future.

Discussion

We do not seek to imply that the mentors alone caused the changes in the girls' responses. Rather, we expect there are several factors at play, including the program curriculum, parent involvement, other STEAM learning opportunities, or other influential people in the girls' lives. However, we do know that mentors play a crucial role in girls' OST STEAM learning, so it is likely that the mentor roles influence this development in some ways. Correlational analyses in the future could further tease apart this relationship, and also support future work around ongoing training and support for mentors. As a limitation of this study, we acknowledge that we present here tentative findings from a small data set. However, with a relationship between mentor actions and girls' imaginations becoming visible even at this small scale, we are encouraged to more deeply explore how mentors can support and encourage Black and Latina girls in their social dreaming and ideas about the multiple future pathways their lives could take.

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Title: Stories of Impact: Scientific Narratives and Climate Justice

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Abstract: Climate justice involves recognizing the deeply intertwined relationships between people and their environment, along with the recognition and validation of the fact that climate change has a disproportionate effect on the most vulnerable populations on the planet. This poster session shares the design and findings of a Climate Justice Map-mediated Scientific storytelling project designed to support students' learning and action of climate justice by deepening and personalizing their involvement in locally situated climate issues.

Introduction

Climate justice involves recognizing the deeply intertwined relationships between people and their environment, along with the recognition and validation of the fact that climate change has a disproportionate effect on the most vulnerable populations on the planet--historically marginalized communities and other living things. Thus, issues related to climate change need to be addressed by approaches that allow for important conversations of equity (racism, patriarchy, economics) alongside climate change science. Climate Justice Map-mediated Scientific storytelling (CJMAPS) is one such approach that supports student learning and action of climate justice by deepening and personalizing stakeholder involvement in locally situated climate concerns. This poster discusses the design elements that make the CJMAPS approach a way to address issues related to equity alongside science. The poster will also present findings from data collected during Spring 2022, when the first iteration of the approach is implemented.

The CJMAPS learning environment is designed around the driving questions: How do we organize and build relationships with people and natural world in a time when the climate is rapidly changing everything in our immediate and distant environment? Relationship building between and within communities for a cause is not an easy task (Krishner 2015). The related attitudes and behaviors are complex and dynamic, and are likely influenced by personal experience and knowledge as well as cultural and political knowledge and values systems. For example, research has shown that cultural and political values play an important role in how individuals understand climate science (Leiserowitz et al., 2012). Similarly, building connections to the natural world also requires people to reflect and attend to their own identities and positionalities and to the consequences caused by their actions. Through the CJMAPS program, learners use their lived experiences and construct a story using ArcGIS Storymaps software. The learners will: explore an issue related to climate change; research the personal, socio-cultural and political aspects of the issue; and then create a story using the ArcGIS software that will reflect their understanding of how the issue is connected to self, their community members and land. For the first iteration of the study we have asked students to seek out how birds (local and migratory) have been impacted by climate change.

Birds connect people of different racial, ethnic, and socioeconomic communities by virtue of nesting and migrating through several different places. However, birding exists within the racialized context of a society in the U.S. that normalizes whiteness and white identities in the outdoors, the environmental movement, and science. This context was exemplified in the U.S. news in May 2020 when Christian Cooper, a Black man who was birdwatching in Central Park in New York City, asked a white woman to obey park rules and leash her dog. The woman called the police to say he was threatening her. Cooper took a video of the incident, which went viral and prompted increased attention to the racialized experiences of people of color in birding, the outdoors, and STEM fields (see e.g. #BlackBirdersWeek2021). This context highlights the need for climate justice education to attend to the sense of belonging and identities of educators and participants in the learning environment. Bird ecologist J. Drew Lanham (2013) talks about his experience as a Black bird watcher in the United States, satirizing about belonging and identity. Thus, although researching about local and migratory birds might at face value seem a neutral activity, like every scientific endeavor researching birds is also a segregated and racialized activity. We hope that through building stories about birds and birding students will be able to understand the socio-cultural and political dimensions that surround their research on climate change and birds.

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Theoretical background

CJMAPS seeks to use technology mediated tools to create space for racially and ethnically diverse students to explore authentic climate justice issues while also strengthening their relationships with the land and their communities. Students' exploration of their relationships with land and community are central to learning environmental science (Tuck et al., 2014). However, environmental learning is often framed by Western scientific meanings of place (e.g. land ownership versus reciprocity) and ignores the historical and ongoing eradication of Indigenous peoples who inhabit or formerly inhabited lands and the history of forced landlessness among chattel slaves (Engel-Di Mauro & Carroll, 2014). In contrast, CJMAPS draws upon land-based pedagogies and centers students' and community members' voices and perspectives to provide space for multiple epistemological understandings to be incorporated to students' sensemaking. When learners are supported to understand how scientific content interacts with the socio-cultural contexts of their lives and in particular with their relationships with land and communities, science learning and engagement flourish (Bang et al., 2014). Each ethnic group has their own socio-cultural and political history that impacts their interactions with land and community. For example, historically African Americans were denied land ownership. As Smith (2007) discusses, "Forced for generations to work the earth without just reward, without the right to own land, without even the freedom to travel, what meaning could they find in America's pristine wilderness? Locked in a struggle for social justice, what interest could they have in the claims of nature?" (p. 3). African Americans have a long tradition of caring for land in ways that are distinct from other Americans (Finney, 2014). All students need space and time to understand their relationship with lands they inhabit. Map-mediated storytelling fosters students' exploration of their unique relationships with the land and their community. Mapping these relationships supports their visualization and development of their stories within a climate justice and community-driven context.

Prior research that examines participant learning in locally relevant science identifies the following: students draw upon multidisciplinary understandings of science and local communities to develop relationships with selves (identity development), nature, and their local communities (Bang et al., 2010; Schindel Dimick, 2016); and students leverage community-driven science understandings when learning is situated within place (Birmingham & Calabrese Barton, 2014). Incorporating place-based science and structuring science learning for multiple voices to contribute to meaning making provides significant opportunities for students from diverse and historically marginalized backgrounds to engage in science (Bang & Marin, 2015). This work has implications for understanding how map-mediated stories and what aspects of these stories influence how students make sense of place-based climate justice.

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International Society of the Learning Sciences

E-textile Fashion: Designing Maker Activity for Chinese Migrant Girls

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Abstract: We present a low-cost STEAM workshop for twenty-five Chinese migrant girls to learn electronics through making hats. Data sources include video recordings of all classroom activities and post-interviews of students. We analyzed post-interviews of all participants and then narrowed our focus to Meimei, a girl who expressed an interest in art design. We hope this study will inspire future designers and educators to design maker activities for local schools.

Introduction

In the last three decades, China experienced the world's largest rural to urban migration. Because migrant families do not possess an urban household registration, children from these families are excluded from full access to free compulsory education (Goodburn, 2015). Therefore, migrant schools, usually funded by charities, become an option for migrant children. Lacking stable funding for resources and qualified teachers, children in these schools likely do not receive an education as good as their peers in public schools (Lu & Zhou, 2013). Compounding the issue of unequal resource distribution, female students in China experience additional documented inequities based on cultural traditions (Goodburn, 2015). With these inequity issues in mind, our project aims at providing more learning opportunities to those underrepresented students. More specifically, we would like to engage young migrant female students in making activities as a form of STEAM learning.

Design

Our workshop was designed for an internal grant with the goal to empower Asia-Pacific women in STEM education. We focused on the migrant girls in Shenzhen, China, because it has the most migrant population in the country. We expect our making-oriented workshop to offer an entry point for migrant students to join local maker events. The design of our workshop referenced Buchholz's work (2014) that e-textile toolkits offer females expanded access to materials and tools and provide with them opportunities to take leading roles in advanced technical activities. Our workshop consists of five sessions (60 -120 minutes per session). Each session has explicit learning goals to reduce teachers' concern that making activities are not directly connected to curriculum standards. In the first four sessions, students worked in group of two to design hats, sew circuits, and prepare posters in the innovation room. The layout of this classroom naturally encourages group work, as opposed to traditional classrooms that desks were lined up and facing the front. On the last day, they presented their projects to their peers, teachers, and Makers from the local community in an open space.

Method

Context and participants

We implemented the workshop in an elementary school in Shenzhen, China. Twenty-five 5th and 6th graders participated in this workshop. The workshop was led by three researchers, who designed the workshop collaboratively. Students worked in groups of two or three to participate in four sessions of making activities. On the last day, students gave poster presentations to students and teachers in the participating elementary school and makers from the local community.

Data analysis

We analyzed the post-interviews with the purpose to understand students' design goal, and their motivation in the workshop, what difficulties they had and how they solved problems they had during the workshop. With the analysis, we found a girl, Meimei, a fifth-grade student, who explicitly demonstrated interest in design and challenged advanced materials. Meimei's story was the epitome of how 25 migrant girls engaged in our workshop. We applied video analysis on Meimei and her partner Lei's work in classroom. Based on Meimei's interview response, we focused on the difficulty Meimei faced in classroom, and re-watched video of focusing on what Meimei's team has learned through making, their attitudes towards making, and how they collectively work on the project and solve problems.

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Results

In the post-interviews, seventy percent of the groups mentioned the most difficult parts were 1) calculating hat dimensions from measured head circumference and 2) sewing the circuit. And fifty percent of the groups recognized the importance of working with their teammates to solve problems collaboratively. Meimei is one of the girls who explicitly said her dream is to "be a fashion designer" in the future, and she was very interested in fashion and design. Meimei was a member of the Art Club, and she was one of the few students who tried to connect a tri-color LED in her in design. In Meimei's interview, she also mentioned that she faced several problems like other students, such as measuring and sewing the circuit. But her intrinsic motivation to advance her design helped her to explore how to sew the circuit.

Meimei's case: sewing a circuit with her partner

To better understand how Meimei was engaged with workshop, we focus on Day 3, the first day when we introduced circuits to students, with the goal to light up an an LED light on their hat. We found Meimei and her teamate Lei worked collaboratively to solve problems and actively participated in the workshop. Through tinkering with the materials, they recognized the concepts of positive and negative ends in an electronic circuit. In the beginning, Meimei's group had difficulty connecting the circuit. Lei, Meimei's teammate, sought help from teachers and peers, while having Meimei concentrate on tinkering with their toolkit. They both participated and allocated their time wisely. After getting brief facilitation and rounds of tinkering, Meimei started to sew the circuit on their hat, while Lei observed and offered verbal instructions. There was a moment that Lei pointed out that the circuit was in the wrong direction. Then she pointed it out to Meimei. But Meimei was confident of the direction because she identified the negative end of the circuit. Here, Meimei used a formal science term, "negative end," to refer to the direction of conductive thread, a concept she had never learned. Meimei mentioned the lights were in different shapes as she thought, but she seemed comfortable with the new materials. Applying formal science language to unfamiliar materials is a sign that Meimei started to understand the concept. Besides, during the workshop, Meimei and Lei were always collaboratively and actively participating in making. When they were sewing a circuit to their hat, Meimei was in charge of sewing at the beginning. Lei soon nudged Meimei and said, "Let me sew, let me sew, let me sew." Meimei secured the knot for Lei and passed her the needle. Even though only one of them was needed to sew the circuit, Meimei offered Lei help and observed her sewing closely. In their collaboration, they found ways to address each other's feedback and suggestion. They also rotated roles so that they both had almost the same amount of time to try working on the materials. There were also examples of Meimei and Lei working closely together on their project in the video data, we hope to present more data in our final presentation.

Significance

In this study, we designed a low-cost e-textile workshop for migrant girls in Shenzhen, China. Within the one-week workshop, students worked in groups, designed a hat, and sewed simple circuits on their hats. In our post-interview analysis, young girls mentioned the workshop was "a meaningful learning experience for learning electronic circuit, sewing, and design" and "would love to introduce the workshop to our friends." Our focused analysis on a girl named Meimei demonstrated how she took the initiative in her hat design project, overcame difficulties, and collaborated with others. Our workshop provided girls with different learning experiences as they claimed. With our follow-up communications with the participating school in 2021, the participating teachers were able to run another round of e-textile in the school. This also showed the potential to design accessible, meaningful hands-on integrated STEAM learning activities for young girls. We call upon maker educators and curriculum designers in China and other countries who are interested in gender equity to consider learning through making and develop activities relevant to students' local communities.

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International Society of the Learning Sciences

Eliciting Multimodal Strategies: Early CT Assessment by Design

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Abstract: Performance assessments can provide meaningful insights into young children's knowledge; however, documenting assessment responses as incorrect or correct limits our understanding of students' abilities. One method of improving our ability to measure student understanding is by documenting the strategies students use to engage with assessment tasks. In this study, we describe how purposeful assessment design can provide insight into students' thinking by qualitatively examining how students solve performance assessment items using multimodal strategies.

Introduction

Performance assessments allow for documentation of the process used in solving a task and the outcome. For example, the Research-Based Early Math Assessment (REMA; Clements et al., 2019) documents correct and incorrect responses as well as additional student response codes. These additional codes, called strategy codes, provide insight into *why* a student may or may not answer the assessment questions correctly. Accounting for the *strategies* (student performance observables) students use makes it possible to interpret student understanding, not just discrete skills. This paper describes how purposeful assessment design can provide insight into students' thinking by examining how students solve performance assessment tasks using various multimodal strategies. We designed our assessment to measure computational thinking (CT) in early childhood. We begin by describing a design process for building an early childhood CT assessment, then present an analysis of students' strategies in responses to assessment items. Finally, we discuss how students' multimodal strategies allowed us to interpret their CT skill understanding.

Framing perspectives

We used the Evidence Centered Design (ECD) framework to design our assessment, an approach in which designers make explicit the behaviors and evidence associated with specific tasks. ECD is designed around fundamental questions about whom we assess, for what purposes, and under which constraints. The five layers of ECD include: (1) domain analysis, (2) domain modeling, (3) the conceptual assessment framework, (4) assessment implementation, and (5) assessment delivery (Oliveri et al., 2019). In the first two layers, the focus is on the purposes of the assessment, the nature of knowing, and structures for observing and organizing knowledge. In the third layer, the focus is on the student model (the skills being assessed), the evidence model (how do we measure it), and the task model (situations that elicit the behaviors/evidence). In prior work, we have written about the first three layers in our assessment design process (see Clarke-Midura et al., 2021). In the present study, we focus on the conceptual assessment framework (CAF). We designed our assessment to measure early childhood computational thinking (CT), which involves "the conceptual foundation required to solve problems effectively and efficiently…with solutions that are reusable in different contexts" (Shute et al., 2017, p. 151). We view coding as an important context for developing CT and use tangible robot coding toys as a context for promoting CT.

Participants, data, context

Seventy-seven kindergarteners (5–6 yrs.) in two Title 1 schools (n=17, n=60) in the western United States participated in a pilot CT assessment. The interview-based format accounted for kindergarteners' emerging literacy skills and took about 15 minutes to administer. We analyzed video of 77 participants responding to 14 pilot assessment items (approximately 9.5 hours). Students were asked in the assessment to enact, sequence, or debug programs depicted by coding cards in order to move an agent (a small figurine) around a 10"x10" grid. The program codes consisted of four directional arrow commands that instructed the agent to move forward, backward, rotate left, and rotate right. For example, in Algorithmic Thinking item 8 (AT8), children were asked to write a program (FORWARD, FORWARD, ROTATE LEFT, FORWARD, FORWARD) for moving the agent from one point to another as marked on the grid. This current analysis focuses on the *strategies* children used to reach this goal- not the programs or *products* themselves.

Data analysis

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To understand students' strategies, we asked two questions: *What strategies do children demonstrate?*, and *Do students use these strategies to engage in the assessment tasks?* We conducted iterative rounds of qualitative analysis of the assessment events. First, we conducted iterative rounds of open coding to systematically document assessment strategies for sub-sets of items designed to measure specific CT components. Next, we applied focused coding to categorize observable indicators and identified three engagement modalities: *gesture and body movement* (G), *interacting with the assessment materials* (M), and *language/sound use* (L).

We observed G strategy indicators in students' head movements, hand gestures, and body orientations. An example of a G strategy is *gestures along path in various parts,* wherein students trace a path with their finger. When exhibiting M strategies, students moved the agent and/or manipulated coding cards. Students using the M strategy *enacting incremental movement* might move an agent in a hopping motion. L strategies provided insight into students' thinking through students' use of directional language (i.e., forward, turn), number words (i.e., two, one more), sequencing language (i.e., first, then), and nonsense sounds (i.e., onomatopoeia, popping sounds).

Some strategies were multimodal, meaning students demonstrated the strategy using two of the three primary modalities. For example, some students used the *make a sound for each enacted movement* by attaching a nonsense sound to each agent movement, combining M and L modalities. We accounted for multimodal strategies by adding the categories *gesture and movement + material use* (G+M), *material use + language use* (M+L), and *language use + gesture and movement* (L+G) (See Table 1).

Table 1
Number of Strategies Categorized as Each Modality

	G	G+M	M	M+L	L	L+G
Total Strategies (*N=33*)	2	2	18	5	5	1
Observed Strategies (*N=26*)	2	2	13	5	3	1

Results

For AT8, students exhibited 26 of 33 pre-identified strategies. The most common strategies were *visually references the path and program* (G; 47% of students), *enacts/builds program in chunks* (G+M; 37%), *enacts with incremental movements* (M; 35%), *enacts program after writing it* (M; 27%), *puts multiple codes on a program at once* (M; 23%), and *tests the program while building it* (M; 15%). All other strategies were each used by 10% (n=6) or fewer students. We accounted for the different number of strategies per category by averaging the number of students using each strategy with the strategies/category. The average number of students using G were 17, using G+M were 12, using M were 7, using M+L was 4.7, using L were 5.3, and using L+G was 1.

Discussion

Designing early childhood assessments to elicit students' knowledge through multimodal means allows preliterate learners to demonstrate their knowledge, which may otherwise be inaccessible through traditional assessment measures. For example, a student using the *enacting incremental movement* strategy moved an agent in a hopping motion when enacting a program. By using this strategy, the child indicated an understanding that one code equals one discrete movement, a critical skill for programming in early grid-based CT contexts. Applying an understanding of one-to-one relationship is also a key skill in early childhood mathematics. Only examining a student's final answer limits an assessor's inference of student's knowledge to a single point of evidence whereas connecting strategies to a student's performance provides multiple inference points and a more comprehensive perspective of a student's knowledge. Increasing points of inference is important for implementing equitable assessments with preliterate children and for operationalizing computational thinking in early childhood.

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International Society of the Learning Sciences

Strategies towards Designing for Sustained Engagement in Computational Modeling in Science Classrooms

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Abstract: This poster presents emerging strategies for engaging students in extended investigations with computational modeling. Drawing on the literature on modeling and co-design with teachers over a year, we present 3 strategies and describe how they support student sense making and learning: 1. Curricular coherence and consistency; 2. Integrating multiple forms of data and modeling while foregrounding uncertainty; and, 3. Enabling unpacking blocks as a way to balance between ease of use and expressivity in modeling.

Introduction & Background

There is considerable research exploring how, through design and pedagogy, educators can lower the barrier to computational modeling. Modeling environments that make use of accessible media like domain-specific toolkits (e.g., Kahn, 2007; Wilkerson, Wagh & Wilensky, 2017) ease the technical aspects of programming, whilst pedagogical approaches such as bifocal modeling (Blikstein et al., 2016) support conceptual aspects of computational modeling. Thus far, however, much of this work has involved one-time or short exposures to computational modeling through specific projects or activities. Less is known about how to make computational modeling a *sustained* practice in classrooms.

This poster presents a design-based research study that seeks to design for and study the role of sustained engagement in computational modeling in middle school science classrooms. We build on the broader modeling literature in which extended investigations with modeling and iterative refinement are part of what students do (e.g., Lehrer & Schauble, 2012) to identify three strategies: 1. Coherence and consistency: By "coherence", we mean repeatedly revisiting a small set of disciplinary core ideas from multiple perspectives to pursue extended investigations (Lehrer & Schauble, 2012). Prior work has shown that linking multiple units with a core conceptual idea helps by providing a broad range of contexts to make sense of a conceptual idea (Fortus et al., 2015); 2. Integrating data and modeling: Physical experimentation is a common practice in many middle school science classrooms. We leverage this practice by juxtaposing data and modeling to highlight--rather than dismiss--discrepancies between models and data, bringing noise, uncertainty, and intrinsic differences between them (Blikstein et al., 2016; Gouvea & Wagh, 2018), and, 3. "Unpacking" blocks: We propose the construct of *unpacking* blocks to balance between ease of usability and expressiveness in domain-specific modeling environments.

Design methodology

Our aim in this poster is to present design strategies that have emerged as important through teacher co-design for engaging students in extended investigations through computational modeling in science class. We iteratively refined and modified the A2S modeling environment and unit design through monthly co-design sessions with 4 middle school science teachers over 1 year and an additional 4 teachers over 6 months, a 3-day intensive co-design workshop with 8 teachers, and observations and design reflections from 224 students engaging with the units in science class. Out of 4 target units, we have developed and implemented 2 curricular units.

Findings: Design strategies for sustained computational modeling

Below, we present the design manifestation of each of the three design strategies.

Coherence & consistency

Based on teacher feedback, we use diffusion or the movement of particles from high to low concentration as a disciplinary core idea in the first two units. In one unit, students examine how diffusion impacts ink spread in

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hot and cold water, and in a second unit, they examine how it impacts the spread of wildfire smoke. To underscore that the same disciplinary idea relates to both units, the library of blocks for particle behaviors the two units in the modeling environment considerably overlap. For instance, random movement ("move"), particle collisions ("bounce off") and behaviors representing student ideas such as combine ("attach") or disappear ("erase") are present in both block libraries. In the poster, we will present whether and how students attend to, make sense of and link identical behaviors in these two different phenomena.

Integrating data and modeling

We aim to build uncertainty into student investigations through data to create resistances for students to consider, tackle and possibly resolve (Manz, 2015). The A2S modeling environment enables students to link modeling with real-world data. In the first unit, students build and compare their models with a video of an experiment they conduct in class. In the second unit, they build and compare models with satellite videos of smoke spread from California wildfires. In the poster, we will present how students engage in integrated data and modeling practices to make sense of target phenomena.

Unpacking blocks: Balancing ease of use and computational expressivity

The goal of "unpacking" blocks is to enable students to be able to open up a defined block to view and modify its definition. The idea is for students to be able to view and redefine how a domain-specific behavior such as "interact" or "move" is encoded and enacted. For instance, students can define interaction between two particles as them bouncing off of each other or combining together or one particle changing another particle's color. Conceptually, this is a place for students to test their theories about agent level mechanisms, and how they can impact the model. In the poster, we will present whether and how unpacking blocks provides a way for students to computationally express more sophisticated conceptual ideas in code.

Discussion

This poster contributes to the literature on computational modeling by examining design strategies that can support students and teachers in classrooms to engage in extended investigations with computational modeling. In the poster presentation, we will present each of these strategies and how they enable students to engage in sustained modeling investigations of two different phenomena. We will also reflect on some of the challenges in designing for extended investigations in computational modeling.

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Learning health sanitary practices through scaffolded questioning in interactive eBooks for young children

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Abstract: Adult assistance during the usage of digital devices may not always be available for children in certain circumstances. Taking this into account, we seek to study how far young children can learn in a scaffolded environment through interactive eBooks without adult intervention. Using the topic of learning sanitary hand practice concepts, the eBook will use scaffolded questioning methods to guide the child in the self-learning process.

Introduction

Since the pandemic, children's dependency on digital devices has increased with the number of work-at-home parents and quarantine lifestyles (Wong et al., 2021). This adds to the issues where parent/teacher direct supervision in informal learning environments may not always be available, especially for those not as privileged to have that timely and economical benefit. Meanwhile, the significance in health awareness education has also risen, where many digital learning platforms using different instructional methods emerged to help children learn related issues and information during the pandemic (Tiwari, 2020).

The usage of interactive eBooks or mobile apps as a medium between an adult and a child for educational purposes have been examined. Some have looked into the strategies that are used to steer the learning process (e.g. Tiwari, 2021), and some have investigated how scaffolding methods during mobile and science-related learning increased performance and motivation (Callaghan & Reich, 2021; Georgiou & Angeli, 2021). Uscianowski et al. (2018) examined storybook sharing methods, which was effective in easing the cognitive understanding process for young children. Saliminen et al. (2021) studied the usefulness of scaffolded dialogues in toddler classrooms which enhanced learning in academic activities. However, there is a need for further research on scaffolding features that contribute to the success of young learners (Shoukry et al., 2015, as cited in Callaghan & Reich, 2021). Therefore, this study seeks to expand existing theory by identifying how young children can cognitively process and engage in understanding the importance of health practices through eBooks. Our research questions are: 1) What aspects of scaffolded messages through technology are most effective for children during the early learning stages? and 2) How much are they able to foster deeper learning by themselves with the guidance of scaffolded eBooks?

Theoretical background

Scaffolding uses cognitive support methods which are known to be an effective strategy towards young students who especially need help in learning difficult tasks (Georgiou & Angeli, 2021). Diverse scaffolding methods exist, such as feedback using hints to foster motivation and guidance (Callaghan & Reich, 2021). Salminen et al. (2021) mention the importance of dialogue with early child learners as it helps them build “deeper thinking and communication skills through shared meaning making” (p.13). Like feedback and dialogue, questioning approaches help children develop reasoning and reflection of their own thoughts (Uscianowski et al., 2018; Wasik & Jacobi-Vessels, 2016). Since the use of praise with feedback can stimulate learning and connect real life situations (Callaghan & Reich, 2021), we will integrate questions in quiz form with their corresponding feedback into the eBook in lieu of adult questioning methods to probe deeper thinking (Wasik & Jacobi-Vessels, 2016).

Overall layout of the eBook

The design of the eBook will apply a storybook flow using the topic of teaching sanitary health practices in relation to the pandemic era. It aims to use scaffolded questioning and feedback methods in the form of hints and answers to guide preschool and early elementary children towards comprehending new concepts. The story will incorporate structured questions, feedback, and dialogue in the form of hints along the journey for the child. As an example (see Table 1), the first quiz will be presented after the opening narration and will question the actions needed after an outdoor activity. It will be examined if this will help replace the role of an adult questioning the

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child about a certain topic before delving deeper into the contents (Wasik & Jacobi-Vessels, 2016). This narration will guide the reader to reflect on everyday activities until they reach the quiz probing self-thinking towards the topic to be learned throughout the book. Praise and hints will be used to provide encouragement and instruction for the children when they answer the quizzes (Callaghan & Reich, 2021). As an additional function, an audio option will be provided in consideration for children with different needs, such as age-based, or those with dyslexia and the visually impaired (Tiwari, 2021; Chang et al., 2022). This button feature next to the written text will read aloud the sentences for the children, hence, becoming an interactive feature and acting as a role for the need of adult supervision when understanding the writing.

Table 1

Screenshot examples of quizzes and feedback in prototype

Quiz	Answers	Feedback/Hints (incorrect answer)

Future work and implications

With our prototype, we plan to investigate how interactive eBooks can be used as a scaffolding tool to aid young children in understanding health-related concepts. We plan to observe how they navigate through the eBook and how questioning can scaffold their understanding of sanitary practices during pandemics and flu seasons. While previous research examined teacher/parent and child interaction (Chang et al., 2022; Callaghan & Reich, 2021), this study will probe into how far technology can itself play the role of a physical adult, and how far into the learning process should the scaffolding be preserved (Georgiou & Angeli, 2021). In addition, the study hopes to provide information for creating instructional methods directed at young children for diverse needs, including those who cannot always be supervised by an adult during a digital learning process.

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International Society of the Learning Sciences

"Keeping Them with Us": Constructing Equitable Online Spaces for the Theatre Classroom

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Abstract: We draw on notions of space-making as relational and constituted in interaction to explore how teaching artists construct space as power is redistributed in the online theatre classroom. We use case study methods to illustrate how the shift in power has impacted the design of online learning environments. Findings highlight tensions and possibilities for how power is negotiated and the importance of student voice, with implications for the design of more equitable online learning spaces.

Introduction

In the wake of COVID-19, the shift to online instruction has raised new questions, tensions, and possibilities for how power is distributed amongst teachers and students in the classroom. Such a shift in power can be observed through the way space is created within online settings. In the arts, which often involve voluntary activities and tap into learners' inherent interests, it is especially compelling to explore how power has been negotiated within online learning spaces and how that shift has impacted the design of online learning environments. In this poster, we turn to teaching artists who have shown to be adaptive and innovative during the present pandemic times (Dahn et al., 2021) to address the following research question, *How do teaching artists negotiate power relations in the co-construction of online spaces for theatre learning?*

Space-making: New possibilities and tensions for the online theatre classroom

This poster is grounded in notions of space-making as both physical and socio-culturally constituted through interaction (e.g., Massey, 2005). The shift to online learning amidst the COVID-19 pandemic has presented new possibilities and tensions for making space together in classrooms. The theatre/performing arts classroom in particular presents a special case in which power is negotiated, highlighting student voice and positioning students as authors of their own learning. While conventional teacher-student power relations tend to be hierarchical, with the teacher holding authority over the student, some pedagogies disrupt this dynamic by granting students more power in classroom interactions (e.g., Matusov et al., 2019). The shift online presents such an opportunity for reshaping classes as a more equitable and shared space, and positioning students as having voice and agency (Mills & Comber, 2013).

Methods

Chicago Arts Partnerships in Education (CAPE) is a Chicago-based, non-profit arts organization that fosters long-term partnerships between Chicago Public Schools teachers and CAPE teaching artists toward inquiry-driven arts-integrated curriculum in K-12 classrooms and afterschool programs. Our study is part of a larger project, situated in the context of CAPE's initial shift to online arts instruction between March and August 2020 following teaching artists' transition to remote instruction. We focus on a summer theatre class as a case study to understand how teaching artists negotiated power relations in the co-construction of online spaces for theatre learning.

We took an illustrative case study approach (Stake, 1995) to investigate the transformed power relations between teachers and students within the digital space, the resulting tensions, and the impact on the construction of space. Through one CAPE teaching artist's experience, we illuminate key components of the digital space, as impacted by a shift in power. Theatre teaching artist Sonja had been with CAPE for 4 years and for her summer theatre class with elementary school students, she co-constructed with her teacher partner and students a virtual space toward addressing the following inquiry question: *How can theatre help us process our experience of quarantine?* Through an iterative thematic analysis of a semi-structured interview with this CAPE teaching artist and a multimedia reflection post written by the teacher-teaching artist pair, we highlight emergent themes around the construction of online spaces for the theatre classroom during unprecedented circumstances that altered existing power relations.

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Findings

Shifting power relations toward more equitable online learning spaces

The collapse of the physical space to an arguably more restricted, digital one within the theatre classroom prompted teaching artist Sonja to consider the question of what learning is now available when "there is no 'room'," what was once essential for rehearsing and performing in a shared space, and for taking chances. By its very nature, the digital space has the potential to constrict learning opportunities, due to the sizable lack of a shared physical space to support collective inquiry, characteristic of the theatre classroom. As Sonja mused, "without the room uniting us (...) how do we go after things that are individually challenging or difficult?"

Indeed, students in Sonja's summer class were less likely to go outside their comfort zone and engage in the same way they would have in the physical theatre classroom, with some deliberately turning their camera away when approached to participate in a task that made them uncomfortable. As Sonja noted, "You could start talking about democracy. Power, you know, all these other things that have shifted when we all have the same screen, space on the screen and anyone can just click their thing and be gone." The digital space thus embodied a shift in power, with students electing in which activities to participate and becoming authors of their own learning. Though the space for learning may have been restricted by the digital platform, in limiting risk-taking and experimentation, it also allowed students to participate and engage in ways that they see fit, constructing a more equitable learning space.

Foregrounding the relational nature of space-making

Despite the noted challenges and tensions, opportunities emerged in the relational nature of space-making, which necessitated a change in expectations and a prioritization of class structures that honor students' needs. Keeping students engaged and present thus became the highest priority in constructing online spaces for learning, involving the construction of a social space that recognizes the limitations of the present and nurtures an atmosphere that looks to "protect the fragile ecosystem of our collective." What that essentially meant was "meeting kids where they're at," as to "keep them with us." In the case of Sonja's theatre class, the collapse of the physical classroom was mirrored by the collapse of existing power relations, which guided the construction of a space that was predicated on relationships that aimed to build connection as the primary goal in the design of the learning space.

Sonja and her teacher partner supported the relational nature of space-making through embodied activities, foregrounding the social space of the online classroom, by prioritizing routine in the form of regular check-in's with students and theatre games, reminiscent of pre-pandemic times. To preserve the performance aspect of a theatre class, in constructing the digital space, Sonja and her teacher partner centered individual performance through first, having students memorize monologues, and later, having students write and perform their own original monologue around their quarantine experience. In shifting the focus of performance to the level of the individual, individual experiences and student voice were highlighted and honored. Constructing digital spaces for theatre learning in particular, which is highly reliant on establishing a connection, could thus benefit from self-expression in opportune places.

Toward sustaining connection for its own sake

This study explored the shifting power relations within the digital space and the resulting tensions and implications for the construction of online learning spaces. Sonja's case foregrounded that "connection for its own sake" is more than enough, and "may potentially be both the most urgent achievement, and the lowest common denominator," considering that students can opt out at any point. The digital theatre classroom observed a shift in power and a more equitable class structure, which is arguably unique to the theatre classroom, with the arts often elective and voluntary, making it especially pertinent to keep students present. In reshaping expectations and meeting students where they are at, teaching artists could support students in their learning and together turn challenges into opportunities.

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International Society of the Learning Sciences

Promoting Authentic Research Experiences in the High School Classroom: Opportunities and Challenges

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Abstract: This study examines the nature of student experiences conducting open-ended scientific investigations as part of a new high school neuroscience curriculum. Semi-structured interviews with program participants (37 students and 25 teachers) revealed both challenges, mainly reading primary research articles and making sense of data, as well as opportunities for increasing students' self-efficacy and college readiness. These findings can inform future efforts to promote authentic research experiences in K-12 classrooms.

Background

Despite efforts to promote inquiry-based learning, many K-12 science classrooms, especially in underserved schools, still heavily rely on direct transmission of pre-packaged knowledge, and practical work that does take place is often overly orchestrated, not allowing students to experience the open-ended investigative nature of science (Burgin, Sadler, & Koroly, 2012). By engaging students in authentic scientific inquiry, they can gain an understanding of the dynamic nature of science as a process that involves developing theories, testing them empirically, and then revising the theories based on data (Schwartz & Crawford, 2006).

To address this need, our team has developed a semester-long neuroscience curriculum for high school students ("*BrainWaves*") that emphasizes student-led investigations. In this program, students first learn about neurons, brain anatomy, and brain plasticity, and then, with support from science mentors (Ph.D. students and postdocs), develop a research question of personal interest to them (e.g., how does listening to music affect learning), read background literature, design an experiment, collect data from their peers, analyze data, and share their findings at a culminating program symposium (Azeka, Carter, & Davidesco, 2020).

In the current study, we asked how students and teachers experienced the process of conducting open-ended science investigations, what kind of scaffolding students needed, and what kind of challenges and opportunities were encountered in this process. This work is grounded in participatory inquiry learning, a sociocultural perspective on learning that emphasizes rich, authentic problems and co-construction of knowledge and ideas with community members (Barab & Hay, 2001).

Methods

To address our research questions, a phenomenographic methodology was deployed (Larsson & Holmström, 2007). Phenomenography is a research approach used to describe the different perspectives of people (in this case, students and teachers) and to understand a phenomenon (here, open-ended scientific investigations in the classroom). To that aim, semi-structured interviews were conducted with all 25 teachers who implemented the neuroscience program between 2018-2021 as well as with 1-2 students from each classroom (37 students total). All teachers and students were from public high schools in a large northeastern city in the United States. The interview questions were designed to help researchers understand students' past experiences in science classes, their experience in the program, and their outlook on science and college preparedness. Interviews lasted approximately one hour and were audio-recorded with the participants' consent.

Transcribed interviews were coded through a thematic analysis process outlined by Braun and Clark (2006), which suggests a six-step framework of, (1) familiarizing oneself with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report. Two trained researchers conducted the analysis and met frequently to discuss and refine the codes and how they were operationalized. Following preliminary data analysis, the research team grouped codes into broader overarching themes by analyzing the statements associated with each code.

Findings

Four overarching themes emerged from both students' and teachers' perspectives. First, there were reported challenges in conducting background research. Some students struggled with finding relevant literature, while others felt overwhelmed by the amount of literature that emerged from their search. There were also reported challenges in understanding scientific jargon and the basic structure of research articles. For example, one of the students reported: "I have never read that type of scientific literature, it was a new experience… For one it was a

lot harder to read. Some of the ones we read were like stuff you can get from google scholar, but other stuff was like well there is this really obscure thing with words that we do not even know. So we had to search what things meant, like what is the amygdala and the drugs they use to turn it off and other things." This sentiment was shared widely with another student remarking, "It was like I want to say confusing but like brand new it has the abstracts and it is different from other articles that we read in my prior science classes."

Second, interpreting data, especially when it contradicted students' hypotheses, was a challenge. This often resulted in students focusing on aspects of the data that supported their hypotheses. For example, one teacher reported: "I think the idea of being open to whatever your data shows you is important because a lot of times students are looking to prove their hypothesis and so it is difficult for them to first of all understand that they are just supporting their hypothesis and but also the fact that their data might disprove their hypothesis."

Third, findings indicated that support and scaffolding was a key element in shaping students' experiences of conducting research. For example, one of the teachers pointed out that "the science mentors came in and they really helped me when it came to checking the proposals before they started it and checking their research questions and methods, which was all part of their proposal. That was really like the big chunk of like making sure that they were going in the right direction before they actually got started." Similarly, a student commented, "Oh yes the mentor showed us how to identify if a site is credible or not and she helped us to um factor in more variables and factor in things that could help us or affect the experiment that we were doing."

Lastly, despite the challenges, the overall experience of conducting research was highly positive. In particular, it seems that this experience helped increase students' self-efficacy and college readiness. One student told us: "I think it (the program) prepares us for college because if we have that experience and exposure now we won't receive that as a shock in college and say like oh my god what is this it is like no we need to know now so that we are not overwhelmed at college and end up failing the course." Relatedly, one of the teachers reported, "that was fun to see them sort of like kind of be able to become more independent learners and when they were proud of themselves when they came up with something unique."

Significance

These findings suggest that student-led research investigations can provide a rich context for students to develop their science self-efficacy. However, sufficient scaffolding and structure are needed to help students overcome challenges related to reviewing background literature and designing an investigation that can yield interpretable data. This work could help shape questions for further research, such as how to prepare teachers to support students' data practices. This work could also impact how teachers facilitate students' investigations while balancing student autonomy and curriculum requirements. At the conference, we seek to explore how these findings can provide direction for others seeking to bring authentic science research literacy into K-12 classrooms.

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Positioning Self and Others Through Sympathizing, Empathizing, Anthropomorphizing, and Zoomorphizing: A Case Study

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Abstract: We investigate the relationship between learning and identity by analyzing students' positionings and attendant reasoning in the context of a university seminar designed to engage STEM undergraduate and graduate students in examining the broader impacts of their STEM fields and practices. Specifically, we highlight students' discursive use of sympathizing, empathizing, anthropomorphizing, and zoomorphizing as ways of projecting self onto humans and nonhumans, reasoning "as if the other."

Introduction and Theoretical Framework

Sociocultural studies of learning and identity have often highlighted processes of *positioning*—of self, group, and others—as key sites for investigating students' *reasoning*, disciplinary (Bell, van Horne, & Cheng, 2017) and beyond. Here we contribute to these efforts by analyzing how students reason to position themselves and their science in socially and ethically articulate ways. The student discourse and interactions we study played out in a university seminar designed to engage STEM undergraduate and graduate students in examining the broader impacts (societal, cultural, environmental) of their STEM fields and professional practices.

We borrow from sociocultural and critical theories of learning and frame identity as lenses through which one positions oneself (through discursive moves; Gee, 2001) and through which other practice participants position such a person relative to socially and culturally relevant categories, locally or more broadly defined (Azevedo & Mann, 2021). For example, in the context of schooling children develop academic and disciplinary identities—say, as "good," "average" or "bad" students and as "doers" or "non-doers" of mathematics or science—and these processes are seen in the mutual, reflexive positionings of individuals and their interacting parties, both peers and teacher (Bell, Van Horne, & Cheng, 2017; Nasir & Saxe, 2003).

Empirical Context and Methods

Data for this study were drawn from a larger, ongoing project of design-based research (Barab & Squire, 2004) on a three-credit semester-long course taught by the first author on the broader social and ethical impacts and consequentiality of science. While offered via a geosciences program, the course drew students from many STEM disciplines, including geology, environmental sciences, physics, math, computer science, STEM education, and others. A total of 26 students were enrolled in the two semesters it was taught, approximately 42% of whom were female. Our data corpus consisted of 48 whole-class forum discussions, over 66 hours of recorded video of Zoom-based class discussions, three iterative drafts of issue investigations for every student, and the readings and resources that students assembled and cited in framing their issue investigations. The research team systematically examined these as artifacts of student participation in the course, independently logging aspects of their work that revealed the ways they reasoned about their science and identity, and meeting periodically to share and code logged data.

Analysis and Results

We identify four highly visible ways that students positioned self and others in thinking ethically about their discipline.

In mathematics, *homomorphism* refers to a variety of ways that one mathematical structure might be mapped onto another of similar form, and here we have adapted the word as a general term for a number of kinds of *empathetic* and *sympathetic* reasoning where students identify themselves with other humans. In responding to a writing prompt about whether science can be good or bad (as opposed to neutral), Caroline made the rhetorical choice to humanize science, reasoning that science is carried out by scientists, who are, after all, people: "I probably believe in 'good' or 'bad' science to some extent but it's kind of like believing in 'good' or 'bad' people." (written reflection, Jan 20, 2021). This kind of homomorphizing enabled her to *sympathize* with science, and map characteristics, imperfections and accountabilities she knows as a human onto science as a group of humanized others. Students also reasoned empathetically. In response to another student discussing the historical mistreatment of certain groups by scientists, Aiden agreed and posed the rhetorical question: Considering this history of mistreatment, "why would those other groups now start to simply accept scientific discoveries at face

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value?" He did not include himself in "those other groups," but rather *empathized* with them in a way that allowed him to push back on received Western notions of science as objective, neutral and uniformly beneficial.

Anthropomorphizing refers to ways of attributing human characteristics, behavior, and feelings to nonhuman things in the world, be they living or otherwise. One culturally ubiquitous example of anthropomorphizing that clearly permeated the discourse of the students was their reasoning about *mother earth*. Prompted in the first week of class to write about her scientific interests, Rebecca, a geology major, described her research on geothermal energy as the study of "how we can use the heat that comes from Earth's center in a way that doesn't hurt our Earth," revealing anthropomorphic reasoning that positioned her in care of the earth (written response to prompt). Responding to the same prompt, Sylvia, an undergraduate in environmental science, showed signs of anthropomorphic reasoning for similar positioning, writing about "the world" as something she wants to "give back to," in part by figuring out "ways in which humans can join with the world" and better understand the "world's problems" (written response to prompt).

Finally, *zoomorphism* is a type of discursive device where traits of non-human living things are imagined in or ascribed to humans (c.f. anthropomorphizing human traits to non-humans). We use *zoomorphizing* to refer to a type of positioning move through which a person maps or ascribes aspects of non-human *living things* to humans. In the closing passage of Caroline's final paper on anthropocene science, she presented a brief vignette about a neighborhood walk that she frequently took past a patch of cacti, cacti that had been impacted by an extremely deep and long freeze. Previously, Caroline and others had linked this freeze to anthropogenic climate change. In equating the "somewhat messy transition state" of the recovering cacti to her own self, Caroline formed an emotionally articulate relationship to the non-human world, and positioned herself as something of a cactus grappling with anthropocene conditions of climate change: initially "stalwart," then "defeated" by the freeze, now "naive and pliable," still vulnerable, but remembering and growing. Through this reasoning, she drew from the non-human world to pattern a characterization of her own affective state, and in doing so made some sense of her own identity as a scientist living in the Anthropocene.

Discussion and Conclusion

Acts of positioning self and others in the course of practice participation, moment-to-moment and over the long haul, are key events in which a student enacts and/or works out multiple identities relative to school subjects and disciplinary practices. Prior research has helped us understand students' identity work and development, attempting to work out terms for how one positions and is positioned by important *local actors* in the learning process (notably student peers, teacher, and parents) (e.g., Nasir & Saxe, 2003).

Our analysis adds to current understandings by (1) showing how student positioning considers actors more remotely detached from their daily lives and sometimes imagined/idealized (i.e. *distal "others,*" including non-humans), and (2) showing the ways in which students achieved these positionings (i.e., through discursive devices of sympathizing, empathizing, anthropomorphizing and zoomorphizing). Crucially, these various forms of projecting self onto human and nonhuman others (and vice versa) afforded students a means of *pivoting* into a different, imagined "world," much like Vygotsky's (1967) formulation of imaginary play. Here we find students' use of certain discursive devices allowed them to pivot into the imagined perspective of other actors, and to draw insights that would not be possible otherwise.

It is likely that students deploy a wide variety of subtly different strategies for *reasoning "as if the other*." For example, we note that *chremamorphizing* is a common way of writing that is similar to zoomorphizing, except that humans are ascribed aspects of non-living things. All of the discursive strategies of *morphizing* we have examined here appear to be particularly salient to and tractable in student's disciplinary identity work. This is due to both the conceptual *and* affective affordances they provide for knowing and valuing different imagined worlds, worlds that students might ultimately realize as more inclusive, equitable and just.

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International Society of the Learning Sciences

Enabling Self-Regulated Learning in MOOCs Using Community of Practice

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Abstract: One of the main reasons for learners to drop out from Massive Open Online Courses (MOOCs) is the lack of self-regulated learning (SRL) skills necessary to learn effectively in online environments with low levels of support and guidance. Although there is an agreement on the importance of SRL for MOOC learners, little research has examined which SRL strategies learners need help the most, or how to help them practice those strategies to further develop their SRL skills. This study identifies key SRL strategies that are crucial for MOOC learners to develop in order to improve their learning outcomes and increase course completion. Based on results from interviews and a questionnaire, recommendations were presented on using a chat feature embedded on MOOC platforms to enable the community of practice and help learners practice SRL strategies effectively.

Introduction

COVID-19 pandemic has enabled a surge in enrollment across Massive Open Online Courses (MOOCs) on platforms including Udemy and Coursera (Impey & Formanek, 2021). But MOOCs suffer from extremely high dropout rates of 90% or more, and the lack of self-regulated learning (SRL) skills can be an important factor that leads to high dropout in MOOCs (Terras & Ramsay, 2015). Nawrot and Doucet (2014) found that the most common reasons for dropping out from MOOCs can be related to time management and metacognitive strategies such as goal setting and strategic planning, both of which are part of SRL.

Although there is an agreement on the importance of SRL to improve learning outcomes for MOOC learners and reduce course dropout rates, little research has examined which SRL strategies learners need to develop the most, and how to help them practice those strategies to further develop their SRL skills. The purpose of this study is to identify key SRL strategies that are crucial for MOOC learners to improve their learning outcomes and increase course completion, and explore new features MOOC platforms can implement to help learners hone SRL skills. The study aims to answer the following questions: What are key challenges for MOOC learners to self-regulate their learning? Which SRL strategies can help MOOC learners improve learning outcomes the most? How can MOOCs be improved to help learners practice crucial SRL strategies?

Methods and data analysis

In order to understand key challenges for MOOC learners to self-regulate their learning, 15-minute interviews with 31 MOOCs learners were conducted. All were recruited from an email sent to a group of graduate students in a research university in the United States. They all had taken multiple MOOCs before and were in their late 20s to late 30s. 16 (51%) were female and 15 (49%) were male. Questions in the interviews focus on the learners' personal learning experiences, attitudes toward MOOCs, and key challenges learning in MOOCs.

To identify SRL strategies that are most helpful for MOOC learners to practice, a questionnaire aiming to evaluate MOOC learners' level of mastery of six different SRL strategies was sent to the same 31 participants. The questionnaire was adapted from the work of Kizilcec et al. (2017) with 18 statements (3 statements per SRL strategy) that participants can select on a 5-point scale (1=not at all true for me; 5=very true for me) how true each statement is describing them while learning on MOOC platforms. The questionnaire was implemented in Google Forms, allowing participants to make their selections easily on a likert scale.

Findings

Four types of challenges from MOOC learners emerged from the interviews: lack of time, boredom, lack of pressure or urgency, and lack of peer interactions. 74% participants mentioned the lack of time as a key challenge, and 77% participants mentioned boredom as an important reason that they dropped out. The third type of challenge for MOOC learners is the lack of pressure or urgency mentioned by 84% participants. One participant said, "I would love to have more strict deadlines and clear objectives for learning on MOOCs." Lack of peer interactions was named by 90% participants as another key challenge. According to one participant, "I want an accountability buddy to check in regularly on my progress and goals and to ask questions."

Most of these challenges the participants are facing as MOOC learners can be interpreted as needing to learn SRL strategies. For example, the lack of time can be interpreted as needing time management and goal setting strategies, and the lack of pressure or urgency can be interpreted as needing strategic planning strategies.

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The lack of peer interactions can be lessened by applying help seeking strategies. The qualitative data helped uncover key areas of SRL strategies that students should practice to overcome those challenges: goal setting, strategic planning, and help seeking strategies.

According to the questionnaire, elaboration and task strategies have the highest means, with 4.76 and 4.57 respectively, whereas goal setting and help seeking have the lowest means, with 4.10 and 4.19 respectively. It shows that participants have a high level of mastery of SRL strategies such as elaboration and task strategies, but need more support with learning about goal setting and help seeking. Elaboration has the lowest standard deviation of 0.42, whereas help seeking has the highest standard deviation of 0.83, showing a high variation of participants' evaluation of their mastery of help seeking.

The results revealed that goal setting and help seeking are SRL strategies that MOOC learners should practice the most, which also matched with interview data that goal setting and help seeking are two of the four challenges MOOC learners are facing. It is important to focus on learners with a low level of mastery in goal setting and help seeking, and design interventions to help learners build SRL skills more effectively.

Recommendations and implications

How can MOOCs be improved to help learners practice these SRL strategies like goal setting and help seeking? In order to foster help seeking, a sociocultural perspective is chosen because each MOOC includes a learning community. Because MOOCs attract learners with different backgrounds and levels of expertise, in the context of legitimate peripheral participation, some learners who are new to the subject are at the periphery of the community, whereas others are considered full participants (Lave & Wenger, 1991).

The recommendation proposed is an embedded chat feature based on the idea of connecting more advanced learners to learners who need help in a community of practice. When learners need help and open the chat, they can see a list of other learners who are available to help, as well as their learning score which has been calculated using the course surveys, their engagement on discussion boards, and their assessment results. The learning score shows the level of expertise a learner has on the subject, and can be seen as the learner's position in the community of practice. Learners are advised to ask for help from people with learning scores higher but not too high compared to their own scores. This simulates the community of practice, where more advanced participants help less advanced ones move closer to the center. After a learner identifies a potential helper, they can connect in real-time and work on the problem together.

One expected effect this solution will have on learners is that it can encourage them to ask for help, since the chat feature is part of the platform and is easy to access. By making it easier for learners to ask for them, this solution can help learners practice the help seeking SRL strategy. Another expected effect is that the learners can feel a greater sense of belonging to the MOOC community. They can realize that they are not simply individual learners, but learning community participants who can get help and offer help to others.

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International Society of the Learning Sciences

How young children pursue their interests with questions

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Abstract: This case study is an investigation of how children pursue their interests and concerns in interaction with adults. This processual focus led us to study children's spontaneous questions, which have mostly been at the margins of research on children's learning and development. Our analysis found that questions are important interactional tools that allow children to simultaneously pursue their interests and concerns while also working within the familiar asymmetries of adult caregiver and child.

Introduction

One of Piaget's insightful ideas was that "There is no better introduction to child logic than the study of spontaneous questions" (Piaget, 1923, p. 162*).* Piaget himself did not really study children's spontaneous questions. Instead, he favored making inferences about children from their spontaneous *answers* to his questions and the tasks he posed for children. Mostly, developmental psychology followed Piaget in giving limited attention to naturalistic observation, favoring Piagetian style clinical interviews or experimental tasks as preferred methods. As a result, the topic of children's spontaneous questions has been largely at the margins of the study of children. This study seeks to make children's spontaneous questions and their role in children's lives and their learning more central.

More broadly, this study seeks to contribute to a line of research that establishes children's interests and concerns as a core topic for the learning sciences (Stevens, 2020). Our goal is to understand *what* children's interests and concerns are and *how* children pursue these interests and concerns. This processual focus has led us to children's questions. In this paper we build on an original insight of one of the founders of conversation analysis, Harvey Sacks, who identified a type of question children use that a) indicates an understanding of some of the basic machinery of conversation (i.e., adjacency pairs), b) recognizes their unequal rights in interaction with adults, and c) pursues their interests (e.g., getting 'the floor' in conversation with adults) in the context of this recognition. When children want the floor, they will often pose the question (to a parent or other adult caregiver), "Guess what?" That question invites an adjacent 'answer' in the form of another question from the adult, "What?". This responding question from the adult is then a first part of a new adjacency pair and the second part answer from the child is expected *and* gives them an open floor to share what they want to share (Sacks, 1972). We wondered: what are some of the other ways that children use spontaneous questions? What occasions spontaneous questions, what work do they do in interaction, and what do they tell us about children, particularly when embedded in the context of extended interactional sequences that involve joint projects and joint inquiry with adults (Goodwin, 2007; Keifert & Stevens, 2019; Stevens, Keifert, Davis, & Mehus, 2012)? We analyzed four cases from one family, centered around a 4-year-old boy named Ben, demonstrating how Ben uses questions to initiate, secure, and pursue his learning and project interests with his adult caregivers. In our discussion, we explore how these cases may generalize to other children and in differing family arrangements.

Data collection

The case study of Ben and his family is drawn from a large corpus of recordings collected with pre-school aged focal participants in their homes and at their preschools. The goal of this larger study was to directly investigate, rather than speculate about, how different home and school contexts organized learning and participation and how children responded. The methods that we used to analyze four segments selected from the recordings made with Ben's family involve interaction analysis of ethnographically collected video recordings (Hall & Stevens, 2015; Stevens, 2020). To select children's questions out of the much larger data corpus, we used previously coded content logs that identified children's questions. We then created a computer program to extract the portions of the content logs that identified children's questions and then looked at the frequency and density of questions within families and across families. This allowed us to identify extended segments of the recordings to transcribe and from these transcripts we selected the segments considered here.

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Summary of cases

For young children, adult caregivers largely control and structure their time, often around activities that adults regard as necessary. This was the case for Ben. Ben nonetheless used questions to find openings *between* these adult-organized activities to pursue his own learning and project goals. In the first case, Ben used request-centered questions to pursue a paper airplane project immediately after a family dinner, repeatedly seeking his mother's help even though she had arranged some time alone for herself. Ben also used questions to shape the substance of an adult-organized activity in the direction of a preferred interest of his with the recognition that it was not in his power to stipulate the activity. The second case shows how Ben's question moved the family to make his preferred pasta dish for the family's dinner. The third case showed how Ben uses request-centered questions to effectively restart a craft project by shifting collaboration to one parent, after recognizing that the other parent would not make herself available at the moment. Finally, even when Ben's projects got deferred, Ben used questions to work to be involved in new activities of his interest. This showed in the fourth case, in which Ben was collaborating with Dad on a craft project when Dad got diverted by a common household task (replacing batteries in a device). Ben asked a question similar in form to what conversation analysts call a pre-invitation (Goodwin & Heritage, 1990) to seek to be involved in the new activity of interest (replacing the batteries). Across the four cases, Ben used questions that indicated a dual recognition of his asymmetric rights in conversation and of basic machinery of conversation that would allow him to pursue his learning and project interests even with this asymmetry.

Discussion

In academic psychology, children's questions have received little attention despite Piaget's endorsement of what they might reveal. When they have been considered, they are almost always framed in narrowly cognitive terms, as information seeking utterances (Chouinard, Harris, & Maratsos, 2007; Davis, 1932). While we don't dispute this characterization, this analysis and others (Stevens, 2020; Keifert & Stevens, 2019; Stevens, Penney, Keifert, Davis, & Mehus, 2012) enlarge it significantly, suggesting that children are using request-centered questions as "social action" (Goodwin, 1990)—to organize and direct activities in their social and material worlds. Questions were interactional tools that allowed Ben to work around and through the familiar asymmetries of adult caregiver and child to pursue his interests and concerns. Of course, these examples are drawn from only one home and we expect important variations within families (Keifert, 2020), across families with different cultural backgrounds and families with different kin relations. Directed towards understanding *what* young peoples' interests and concerns are and *how* they pursue them in their everyday lives, this study contributes to a line of research that establishes children's' interests and concerns as a core topic for the learning sciences (Stevens, 2020).

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International Society of the Learning Sciences

Shifts in Positions, Epistemic Authority, and Epistemic Agency in a Secondary Mathematics Classroom

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Abstract: In this study, we investigate the interactional positions negotiated among students and the teacher during joint mathematical exploration in the classroom. Using qualitative coding of two video episodes in a secondary mathematics classroom, we found participants take up positions of uncertain knower and explorer in addition to positions of knower and actor identified in previous research. These additional positions help illuminate collaborative knowledge building and negotiation of shared epistemic agency and authority in learning.

Student collaboration and productive disciplinary engagement, such as exploration of disciplinary questions, is seen as a strategy to bring about meaningful learning but is still a challenge to support in classrooms (Damşa et al., 2010). Thus, it is crucial to understand teacher and student interactions that position students as active epistemic agents. We examine how joint mathematical exploration is established and maintained as students and the teacher investigate mathematical questions. We aim to identify the interactional positions the teacher and students take up as evidenced by negotiation moves. We investigate the following questions: (1) What positions do students and teachers take on while establishing and maintaining joint exploration? (2) How do shifts in positions reflect how epistemic authority and agency are distributed?

Theoretical Perspectives & Background

We combine a sociocultural perspective toward classroom interactions and positioning theory (Davies & Harré, 1990) as a theoretical lens to investigate the roles that teachers and students move between in instances of joint exploration. We define *joint exploration* as "the collaborative activity of investigating disciplinary questions and ideas among students and/or teachers through interaction" (Dyer et al., 2021, p. 548), and in which students and the teacher take on and shift between various socio-epistemic roles. Traditionally the teacher takes on a role of someone who gives knowledge and requests actions (Amit & Fried, 2005), and the student receives knowledge and performs actions. Within joint exploration, students would need to take on active roles in guiding the exploration process and in deciding when and how ideas are validated. Thus, this type of activity likely requires negotiation of authority over disciplinary knowledge and redistribution of epistemic agency. Previous research, using discourse analysis methods, has found that students take on and shift between positions of *primary and secondary knower*, as those who give and receive information, and *primary and secondary actor*, as those who request and perform actions (González & DeJarnette, 2015; Lo & Ruef, 2020). In joint exploration, rather than only exchanging information, individuals jointly explore and exchange strategies and may actively seek knowledge together, not in another individual, but tested and validated among the group. Therefore, we hypothesize that aspects of joint exploration include different types of negotiations, and thus, positions.

Methods and Data Sources

To characterize the teacher and students' interaction, we analyzed transcript and video of two episodes of joint exploration during small group work identified in a previous study (e.g., Dyer et al., 2021). These episodes occurred during mathematics lessons in a class with grade 10 and 11 students. We illustrate these findings using one episode of joint exploration when James, a student, poses a new problem when the teacher was with his group. The two students and teacher are not certain of the answer to this question in the beginning; however, it ends with students having consensus and the knowledge to answer this problem.

The first two authors coded the video and transcript of the two episodes using Lo and Ruef's (2020) group work positions coding scheme and resolved disagreements through discussion. These disagreements revealed positions not well-captured in the existing coding scheme. Thus, the researchers used open and axial coding to characterize the negotiation moves associated with these new positions as additional codes and applied the revised coding scheme to the episodes. These new codes included: "E1-Primary Explorer", "E2-Secondary Explorer", and "K1-U: Primary knower uncertain." Two researchers coded the episode with this revised coding scheme, checked for inter-coder agreement, and resolved any disagreements through discussion.

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Results

Our analysis found that individuals took on positions in which they were exploring ideas collaboratively and the "known" answer was not yet clear. Rather, the "known" answer was the object of their investigation. These positions are not adequately captured by the knower and actor in previous analytical schemes (Lo & Reuf, 2020). Thus, our analysis identified added the positions of "E1-Primary Explorer", "E2-Secondary Explorer", and "K1-U: Primary knower uncertain" (RQ1). The new positions of uncertain knower and explorer allow us to understand knowledge as not solely possessed by an individual but constructed through joint activity.

The position of *primary knower uncertain* captures negotiation moves that propose knowledge in a way that is tentative. This position happened while establishing joint exploration, such as when a student, James, suggested a possible solution. We were not able to accurately capture James' position by the "knower" positions, since James appeared to suggest a possible idea for others to consider rather than stating a relevant piece of information that he seemed to be confident about.

The position of *primary explorer* captures moves to seek knowledge through investigation when it is not known for certain. This position occurred while maintaining joint exploration when the students and the teacher sought knowledge that they did not yet have. For example, James took on a position of a "primary explorer" by leading the charge to find the solution. Unlike the primary and secondary knower, James did not have the knowledge that was being sought and was not seeking knowledge in another person. James is positioned with some knowledge of how to go about exploring that requires him to have intellectual courage and have a recognized epistemic authority, not simply request or perform an action associated with the "actor" position.

The position of *secondary explorer* captures moves that position people to support the investigation to seek knowledge. This position occurred while maintaining joint exploration. Sergey, the other student, supported the suggested exploration path and refined the offered solution. This position has less authority than primary explorer since the position follows the pathway that was led by the "primary explorer."

Positional shifts often coincided with the redistribution of authority and agency (RQ2). For example, James and Sergey shift from being the primary and secondary explorers to primary knowers and start seeking confirmation in each other once the solution has been tested. Similarly, a student took on a "primary knower uncertain" position while establishing joint exploration and transitioned to explorer positions in maintaining it.

Significance

The three new positions captured the interaction regarding the knowledge building in group work, including how students negotiated shared epistemic agency (Damşa et al., 2010). They offer a way to characterize negotiation moves that are at the heart of authentic collaborative learning, in which knowledge is not solely possessed by an individual but constructed through joint activity. Moreover, the shifts in positions illuminate the redistribution of authority and agency and how joint exploration is established and maintained. This study motivates thinking about the contributions of how teachers, educators, and curriculum designers might design and think about activities in a way that allows students to take on positions of explorers and teachers to redistribute epistemic agency.

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Establishing a teacher community for innovation in Chinese classrooms

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Abstract: To help Chinese teachers understand and implement competency-based curriculum design, we established a teacher innovation community in China. During the summers of 2020 and 2021, K-12 teachers and researchers jointly designed STEM courses on climate change during 6-week workshops. Researchers use social platforms to share teaching experience to help teachers better understand and implement innovative courses.

Research background

Countries all over the world are vigorously promoting competency-based curriculum teaching reform. Since 2017, the Ministry of Education of China has begun to revise the syllabus of K12 schools, and put forward relevant concepts such as core literacy of Chinese students. But at present, most teachers still only focus on teaching content in the classroom, and don't really understand the competency-based curriculum design. This work presents a new study of a professional development community for K12 interdisciplinary teachers to design and enact new competency-based inquiry lessons.

Research questions

How can we best help teachers to complete a good design that they will actually use in their own teaching?
How can we help teachers make progress in changing their practice? How can we help them to help each other?

Methods

Design-Based Research is a method used to improve design practice and enhance the scientific understanding of how design affects learning (Barab & Squire, 2004). Design-based research is suitable as the methodology of this research, because it will help generate new understandings, theories, products and strategies, explain and potentially influence knowledge construction and learning in the professional community of teachers. We engaged in two cycles of design, in the summers of 2020 and 2021 respectively, with overlapping groups of teachers. We made revisions in 2021 based on the outcomes of 2020. Below we describe these methods

2020 Workshop:

The pretest revealed that almost 70% teachers have no project-based learning experience. The main objective of the 2020 summer workshop was how to design STEM inquiry units, and teachers met for six weeks to engage in design activities, working in teams. Teachers made use of the WISE (Web-based Inquiry Science Environment) platform to create interdisciplinary climate education projects.

Participants: There were 45 K12 teachers participating in six weeks of online workshops, from a range of disciplines, including science, math, language, social studies, geography and art.

Outcomes: ten teachers from ten schools developed lessons and tried them in classrooms (Figure 1).

Figure 1

Schools are implementing relevant courses on garbage disposal

Discussion: A startling outcome was that teachers did not risk letting students explore independently. Task-

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driven teaching was more comfortable, with teachers paying more attention to integrate subject knowledge into projects. Teachers did not fully understand the goals of project-based learning, and were cautious.

2021 Workshop:
The pretest revealed that most teachers have project-based learning experience. But did not understand the notions of competency-based curriculum designs, which was chosen as the main focus for the 2021 summer workshop. The workshop ran for five weeks, with weekly meetings of one hour.
Participants: There were 59 teachers from 31 schools,19 returning from the 2020 workshop. Teachers met in Zoom and other formats, and represented a wide range of disciplines and grade levels, as in 2020.
Outcomes: ten lessons were designed, with twelve teachers (so far) trying out their designs in classrooms (Figure2)

Figure 2

Guangdong Middle School - implementing the "Future City Cantonese Architecture" unit

Discussion: Teachers were engaged by the topics and worked hard to create STEM inquiry. Those returning from 2020 were able to work in teams with newcomers, some improving on their designs from 2020. Teachers continued to improve their teaching strategies for students' skills in the 21st century. Once again, however, we found resistance from teachers to implement new kinds of inquiry in their classroom. We began working more closely with one group of teachers to add smaller scale “icebreaker” activities to help get teachers started.

Conclusions

It was an engaging experience for these teachers to design an inquiry unit (often in STEM topics), but still another challenge in how to use those designs effectively with students. Teachers have no experience with these forms of teaching, and did not learn in this way when they were students. So, these new inquiry approaches are unfamiliar, and teachers found themselves somewhat paralyzed when they tried to engage these methods. We found that teachers need more guidance, particularly at the outset, and are now developing methods for support.

This research has established a teacher community for innovation in China. The 2020 and 2021 summer workshops enabled K12 teachers and researchers to jointly design climate change-themed STEM curricula. The workshops and subsequent school trials also allow us to discover the problems of teachers, conduct targeted discussions, and help them to design competency-centered courses according to their school conditions. Members of the research team visit these classrooms and capture videos of teachers to share with other teachers, in order to help them understand better.

From a learning sciences perspective, this effort can help us investigate the specific challenges experienced by teachers, account for their difficulties, and develop support. This project is significant because it is part of a wider effort called the Critical Action Learning Exchange (CALE) that includes teachers from many countries, and tries to develop a critical action curriculum that is appropriate to cultural context.

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International Society of the Learning Sciences

Emotion as a Condition and Target of Learning Design During Emergency Remote Teaching

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Abstract: In this study we seek to understand the recursive relationships between feeling, sense-making, and rapid online course design at the onset of COVID-19. To elucidate how emotion was implicated in learning design decisions, we offer a qualitative analysis of nine instructor interviews from diverse academic disciplines. Originally developed for an open online course, these interviews exemplify how instructors at a large midwestern university moved their residential courses online at the onset of the pandemic.

Introduction

The purpose of this research is to elucidate the relationships between feelings, sense-making, and the practice of learning design during the period of emergency remote teaching during the early months of COVID-19 (Hodges et al., 2020). To advance these insights, we draw on situative theories of learning (Lave, 1991), emotional configurations (Vea, 2020), and reification (Wenger, 1998) as analytic lenses. Through a qualitative analysis of nine instructor interviews in an open online course, we highlight how instructors' and students' emotions operated recursively as both a *condition* and *target* of learning design. In detailing the recursive dynamics of emotion, we specifically attend to the process of reification and the ways that emotion was both reified and served as a condition for reification. The research question that guides this study is: *How did instructors relate feelings, sense-making, and learning design during the period of emergency remote teaching at the onset of the pandemic?*

Theoretical Perspectives

Situative theories of learning foreground *meaning* as a process of negotiation between people in a specific social context. This process of (re)constructing meaning is "not just doing in and of itself" but the "doing in a historical and social context that gives structure and meaning to what we do (Wenger, 1998, p. 47).

Emotional configurations can be understood in similar terms as situative theories of learning. Rather than conceptualizing emotions such as grief, anger, and anxiety as static, internalized states, emotional configurations attend to the relationships people make between feelings, sense-making, and social practice. In this way, emotion becomes meaningful when it shapes—and is shaped by—social practice and sense-making (Vea, 2020).

Following Wenger (1998), we understand reification as the process by which people project meaning onto the material world. This process of reification gives material "points of focus around which the negotiation of meaning becomes organized" (p. 58). In the context of our study, we are specifically interested in how emotion—as a target of learning design—becomes reified, and as a condition for learning design, how it serves to reify other design considerations.

Data and Method

Our data set consists of nine academically diverse instructor interviews created for use in an open online course on resilient teaching. The interview protocol consisted of five questions, which instructors could answer via video call or through a written response. We used directed content analysis (Hsieh & Shannon, 2005) and a conceptual framework developed by Vea (2020) as a starting point for analyzing the data. In the first round of coding, the researchers open-coded the data set for language that explicitly referenced emotional states (e.g., anxiety, worry). After the initial round of coding, two coders worked within a smaller subset of coded data to identify segments of discourse where emotion was implicated within instructors' course design process. After collecting segments of data that linked emotion to learning design, the researchers began to generate sub-themes that were common across multiple segments of data. During the iterative process of generating sub-themes and merging sub-themes into larger themes, the researchers were guided by theoretical considerations from situative theories of learning and emotional configurations.

Findings

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We detailed two broad themes to characterize the ways instructors related feeling, sense-making, and course design during the period of emergency remote teaching. Collectively, these findings show how emotion functioned recursively as a *condition* and *target* of course design.

Emotion as a condition of practice

Emotions such as isolation, concern, and anxiety were common among instructors during the period of emergency remote teaching. The loss of classroom community and collaboration in particular were often cited as catalysts for these emotions.

As a condition of learning design practice, the emotions of concern and anxiety functioned to reify instructors' desire for community and connection within online classes. For instance, some instructors articulated that the role of the teacher in emergency remote teaching shifted away from didactic lectures towards relationship building within the class community.

In an effort to keep the class connected, some instructors adopted a"flipped classroom" where short video lectures were pre-recorded and posted online, and synchronous discussions were offered as opportunities to discuss the recorded material. In this way, feelings of concern and worry flowed through the practice of course design, and motivated a desire for increased community and connection; these desires subsequently reified community building practices such as the "flipped classroom."

Emotion as a target of practice

While emotions such as concern and worry flowed through the practice of course design, emotion was also reified as an explicit target of design efforts as well. For instance, instructors overwhelmingly acknowledged that student stress and anxiety had increased due to the pandemic. To alleviate those negative emotions, instructors shaped new practices and materials with the intent of positively impacting students' emotions. In one illustrative example, an instructor included light-hearted hippopotamus videos at the beginning of class time explicitly to "lighten the mood."

Reifying student emotion as a target of course design also came with certain tensions, particularly concerning the course goals that had been articulated before the pandemic. While many instructors wanted to provide additional flexibility and accommodations during this difficult time, there was a perception that doing so would be inauthentic to the professional field they were training students for. When a theater instructor explained her decision for extending deadlines, she noted that it ran contradictory to the common practices of the profession: "In theater, deadlines are very firm (opening night is opening night) but in these stressful times, it would have been inhumane to be that strict." These tensions suggest that reifying emotion as a target of learning design implicates other considerations within the milieu of the learning environment.

Discussion

While there is little doubt that emotion figured prominently in learning design during the phase of emergency remote teaching, the question remains how such insights will influence the field of Learning Sciences more broadly. One promising direction for future inquiry may be attending to the tensions that arise when emotion is reified as a target of learning design. While our study showcased how reifying emotion as a target of learning design proved incongruous with pre-defined course goals, future studies may find that reifying emotion comes with different tensions given different contexts.

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International Society of the Learning Sciences

Digital Literacies in Algorithmic Cultures: Critical Literacy as 'Working the Algorithm'

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Abstract: Research on literacy learning and algorithms has been limited to how youth understand their operations as computational systems. Through a case study of one young adult's practice of 'working algorithms' across social media platforms, this poster presents new pathways for researching critical, digital literacy learning in algorithmic cultures. It provides evidence of how youth use their literacies in the critical production of algorithmic cultures, and toward more just and diverse communities.

Rationale and research focus

Humans' everyday experiences with literacy are increasingly entangled with non-human actors, such as computational objects like bots and data, and larger computational systems such as algorithms and platforms. Scholars across disciplines have worked to understand the implications of these entanglements for the production of culture and information at the same time that the implications of these entanglements have impacted everyday life at multiple scales: from the online amplification of post-truth politics across the globe, to the algorithmic personalization of digital ads for individuals. Analyzing these communicative conditions that are produced through the relations of human and non-human agents online, scholars have employed terms such as algorithmic culture (Galloway, 2006) and platform society (Van Dijck et al., 2018). Meanwhile, learning scientists are contending with changing experiences of literacy in these collective, global conditions—forced to think anew about evolving demands on critical literacy (e.g., Leander & Burriss, 2020).

This poster poses novel questions that contribute to this emerging area of inquiry, and it presents worked examples from the third year of a five-year design-based study of adolescents' (14-17 yrs-old) and young adults' (18-22 yrs-old) literacies with emerging technologies and digital cultures. In developing these worked examples, the poster follows Gee's (2010) recommendations for using small pieces of data to illustrate the potential of new theories or ideas, especially around emerging digital literacies. These worked examples bring into sharper relief the complete imbrication of human and non-human relations in the production of *algorithmic cultures* through youths' uses of their literacies, and it develops theories of digital literacy learning to better account for such imbrication. *Algorithmic cultures* refer to the processes by which the constant flow of human activity online creates 'big data' that is parsed and fed into algorithms that help shape new culture phenomena (Galloway, 2006).

Worked examples focus on one young adult's, Mella's (20-year-old, gender-queer Canadian), uses of her literacies across social media platforms, including TikTok, Facebook, and Instagram. Analysis of Mella's practice of what she calls *working the algorithm* across platforms provides novel insight into how contemporary youth practice critical, digital literacies while participating in, and producing, algorithmic cultures. Questions guiding analysis of the poster's worked examples of Mella's literate practice of working the algorithm will open productive discussions for learning scientists researching emerging forms of learning online, and especially those researching critical, digital literacies, which cannot ignore the imbrication of human and algorithmic activity: **(1)** What agency do humans have in the co-production of posthuman, algorithmic cultures? **(2)** How do humans shape algorithmic cultures to create diverse communities and to support diverse identities and personal desires beyond those imagined by the social media corporations that produce and constantly adjust algorithms?

Conceptualizing critical, digital literacies in algorithmic cultures

Adolescent literacy learning, for youth such as Mella, requires developing facility in the discourse practices of specific cultures, and critical literacy learning requires a developing understanding of the ideologies and systems that shape discourse and participation in such cultures. Learning scientists have recently begun developing critical literacy frameworks for contemporary online data flows, and these frameworks position youth as authors and interpreters of online data collected about them (e.g., Stornaiuolo, 2020). However, attention to algorithms has been limited to how youth understand their operations as computational systems. Research on critical literacy must also account for youths' participation in, and co-production of, culture in relation to algorithms. Critical digital literacies should encompass how youth learn to *work* the algorithms with which they interact online for their own purposes. As Mella's case illustrates, those purposes include producing cultures meaningful to them, and critically resisting, and re-authoring, the data-driven, normative, neoliberal, and sometimes racializing (Dixon-Roman, 2016), cultures that most corporate algorithms produce.

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‘Working the algorithm’ as emerging critical, digital literacy for cultural production and participation

Data come from a year-long, ongoing relationship with Mella established through a multiyear design-based research project. These data include semi-focused interviews related to her online life. Mella describes her daily life on social media platforms as less about ‘liking,’ and ‘posting,’ and more about what she calls ‘working the algorithms.’ Table 1 presents three categories of social practices and related literacy practices in which Mella engages to critically co-produce algorithmic cultures. For example, in relation to her social practice of intentionally co-authoring social media algorithms, she discusses specific literacy practices of posting, liking, sharing, and ignoring posts to train algorithms on TikTok to create a safer more inclusive space for herself to share queer content. In relation to her social practice of maintaining her well-being in relation to charged discourses, Mela describes writing DMs (direct messages) in response to users’ politically charged content, but not actually sending them. By not sending these DMs, she is training the algorithm not to include her in these charged discourses, whilst still engaging critical conversations on her own terms. In relation to creating in-person communities from online cultures, Mella uses mobile apps to create queer content when she is in public spaces in order to prompt the apps to connect her (e.g., by suggesting new friends to follow) with like-minded users nearby. She thereby works the algorithms to create community and culture around her, aware of the location-based technologies that collect geographical data for social media algorithms. Short, worked examples of each literacy practice are provided on the poster for discussion.

Table 1 *Mella’s critical literacies for working algorithms*

	Intentional co-authoring of platform algorithms	Maintaining well-being in relation to charged discourses	Creating in-person communities from online cultures
Literacy practice 1	*Reading to monitor and distinguish between platform’s algorithms*	*Reflecting offline rather than engaging online*	*Reads queer identities offline through trends seen online*
Literacy practice 2	*Posting, liking, sharing, and ignoring to train algorithms for her own purposes*	*Writing reflective messages that she doesn’t send*	*Discusses queer issues offline to later re-train algorithms online*
Literacy practice 3	*Using platforms’ mobile apps based on location to train algorithms*	*Discusses online content in personal, safe relationships offline*	*Trains algorithms to connect her to other queer users in close physical proximity*

Conclusion

Mella’s case illustrates that critical digital literacy learning requires understandings of how humans’ actively co-author culture and social life with non-human agents such as algorithms. Mella’s uses of her literacies in working algorithms are critical because they intentionally resist the cultural normativity and racializing tendencies of social media algorithms driven by big data. If, as learning scientists have argued (e.g., Stornaiuolo, 2020), algorithmic cultures tend toward aggregating big data into normalized ‘big culture,’ then learning critical literacies that work algorithms toward more just, diverse purposes is essential.

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Designing for an emerging paradigm in computer programming - towards hybrid human-computer creation of artifacts

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Abstract: Computer science education has experienced many noticeable changes since its inception. Today, students encounter considerably more user-friendly and intelligent IDEs, far less confusing error messages, and much simpler program compilation processes. Learners are also likely to encounter programming environments that can combine human created artifacts with programmatically created content. Even so, much of computer science education assumes a paradigm where only the computer directly manipulates the final artifact. This paper describes an emerging human-computer hybrid paradigm as seen through Scratch, Minecraft Education Edition, and the Dash and Dot. By thinking about these three platforms, the paper motivates more intentionality in how we design for learning in this hybrid paradigm.

Introduction

Learning computer programming has generally made significant advances over the past several decades. Long gone are the days of paper punch cards that are fed into room-sized machines. Today's programmers can conceivably execute computer programs from anywhere in the world. The environments for writing code have also changed in dramatic ways. Today's integrated development environments provide countless tool-tips, automatic completion, and easy linking among source files, libraries, and other resources. Moreover, with the emergence of block-based programming, users, kids, and adults alike, can author intricate threaded computer programs without typing a single line of code. Broadly speaking, these advances have shifted who is able to create computer programs, and how the programs are used.

One thing that has seemingly remained stagnant in the world of computer programming, however, is the relationship between the human, the program, and the resultant artifact. By and large, programmers write code for the computer to execute in the creation of a digital artifact. The creation of the computer program is the responsibility of the programmer. The program subsequently creates the artifacts. If the artifact is not satisfactory the programmer adapts the code and reruns the programs. They repeat this process until they are pleased with the outcome. This process has worked well for decades and will likely remain a dominant paradigm. That said, this paper explores an alternative paradigm that involves both the human and computer program directly contributing to the final artifact. The paper describes three examples that demonstrate how this paradigm is enacted and serve to highlight ways that it differs from the traditional approach. These points of distinction inform some suggested considerations that may be unique to this human-computer-hybrid programming paradigm. Furthermore, the novel design possibilities that they afford may give rise to more programming experiences utilizing this paradigm.

Case studies

This paper uses Scratch, Minecraft Education Edition, and the Dash and Dot robot platforms as driving cases for this hybrid paradigm. The reader is encouraged to explore these three platforms at their leisure. Important aspects of these three platforms can be represented in terms of two dimensions. The first dimension considers how much the programming environment compartmentalizes the human created artifact (i.e., to what extent can the computer program permanently damage the human created components). The second dimension is about the resultant artifact's physicality (i.e., is it virtual or physical). Looking across Scratch, Minecraft, and Dash and Dot, we see a shift from compartmentalized environments to decompartmentalized, and from virtual artifacts to physical artifacts. The compartmentalized environment of Scratch meant that the code could minimally modify any student created artifacts. On the other hand, in both Minecraft and with Dash and Dot, the actions of the program can cause extensive, seemingly irreparable changes to the human-created artifacts. We also see a transition from virtual artifacts to physical artifacts. Both Scratch and Minecraft exist within virtual contexts where the artifacts created are digital. With the Dash and Dot SketchKit, the artifacts are physical in nature. These shifts will be important as we think about how to design for learning within this new paradigm.

Discussion

With these three scenarios in mind, we now transition to discussing what it means to design for this paradigm by thinking about some of the challenges and opportunities they present.

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Creations do not (necessarily) rely on code

The first commonality is that in all three scenarios, users can create content or artifacts without coding. This includes sprites and backgrounds in Scratch, intricate buildings in Minecraft, and drawings with Dash and Dot (as derived from pushing a sequence of buttons to guide the robot), for example. This difference necessitates both intentionality and flexibility in the design of the experience. Intentionality is needed to authentically engage users in coding. Absent opportunities for programming to enable obvious advantages, some youth will invariably elect not to code. Hence, it is essential to consider how the benefits of coding are articulated to participants and the types of activity structures that make these benefits apparent.

Errors are costly

Whereas the dominant computer programming paradigm tends to be forgiving to errors, within these hybrid human-computer collaborations, errors can be quite costly, with the exception of Scratch. In Minecraft the propensity for significant and costly errors is quite high. Something as simple as running your code facing the wrong direction can lead to hours of time spent undoing that action. In the case of the Dash and Dot robot, an error can ruin a manually drawn sketch. In both platforms, there are various strategies to overcome this problem. For example, students might save a copy of their world before running their code, or they can use the agent to build and watch as the agent completes the different actions. Similarly for Dash and Dot, students can reduce the cost of coding errors by doing additional tests on unwanted materials and carefully watching the robot execute the instructions received.

Programmatic replication of human-created artifacts

The high cost of errors is one motivation for having students complete their entire designs using coding. If all aspects of the artifacts are created with code, there is increased reproducibility and easier ways to address any errors. For instance, if the program can create the entirety of the Minecraft structure, including the intricate details, users do not have to deal with recreating those parts if something goes awry. That said, one reality of these design environments is the ways that manual manipulation of the materials (i.e., Minecraft blocks, graphics, or sprites) can often spur student ideation. Hence, it is not simply a matter of students creating their desired components using coding. Without the manual design work, students may lose opportunities to realize their intended artifact. Instead, the high cost of errors might motivate additional innovation in computer programming where, presumably using artificial intelligence, a program can be generated to programmatically create what a user may have manually created. This would make it easy to redo existing artifacts.

Taking a step back though, the high cost of errors disincentivizes utilizing coding and alters the debugging process. For example, we might see that students undertake better decomposition of their programs to be more certain that it will work as intended. Some of these changes in behavior may be associated with better learning and programming outcomes, while others may not. These are questions for further exploration. Either way, designers of these environments should consider how some of the characteristics of this type of human-computer hybrid environment influences different ways of engaging the programming process.

Conclusion

The field of computer science continues to see rapid advances in how we educate future computing professionals. From increasingly intuitive programming environments to developing more inclusive and culturally sustaining curriculum, to integrating wearables and e-textiles, many aspects of computer science education have significantly changed throughout the past few decades. As youth experience these learning innovations, they are regularly introduced to a relatively new paradigm in computer science that is typified by the combination of human and computer program generated artifacts. Operating in this paradigm challenges some of our typical assumptions and practices for teaching computer science. Nonetheless, this paradigm also holds significant promise for realizing the potential of human-computer collaboration. To best leverage these potential developers, practitioners, and researchers need to be intentional about designing for this space and create learning experiences and platforms that better reflect the unique constraints and challenges that exist along the spectrum of this paradigm.

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Justice-Centered Ambitious Science Teaching in Community Spaces: Foregrounding Creativity, Connectedness and Joy

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Abstract. This poster explores the unique and powerful affordances of justice-centered ambitious science teaching (JuST) in two intergenerational community spaces as reflections of an interdisciplinary theory of learning. The results of a cross-case analysis exploring ways JuST practices impacted learning in two related but distinct educational settings spaces revealed boundaries between teaching and learning as blurred, agentic creativity that led to connectedness and joy, and leadership by people of Color as shaping perspectives and priorities.

Major issues and significance

We lack lived examples and nuanced understandings of educational settings that align with current, interdisciplinary theories of learning, accounting for the cultural, social and emotional aspects of learning, while maintaining criticality related to fundamental assumptions of what science is, who does it, and for what purposes (Nasir, et al., 2021). This cross-case analysis comparing learning affordances of a teen showcase with those from a neighborhood forum revealed ways that intentionally and creatively structuring science education in community spaces to be justice-centered and ambitious has the power to lead to deep and equitable learning. Compared to formal learning settings, community spaces can more easily draw together and connect people from different generations, people who have different areas of expertise, and people who span cultural backgrounds, thereby potentially challenging typical roles of leader and follower, teacher and learner. Learning in community spaces is not held hostage by the same political and accessibility pressures felt by schools, inviting agentic creativity. It also invites unique ways of relating, connecting and sharing emotions around shared interests. Agentic creativity, connectedness and joy are transformational elements of a justice-centered ambitious science teaching lens (explained below) that offers a framework for considering how particular aspects of science learning in community spaces can lead to deep and equitable learning in potentially unexpected ways. The two cases share a common focus on science learning used to promote COVID safety, especially for communities of Color. Both cases involve leadership composed primarily of people of Color. This study aligns strongly with the conference aims: to promote equity, investigate innovative learning environments, and elucidate theories of learning.

Analytical and methodological approaches

Learning is rooted in the intersecting facets of human development (biological, social, cognitive, emotional); thus, it is necessary to support the whole-person development by creating learning environments that address these needs (Nasir et al., 2021). Learning takes place in cultural practices across people's lives as experienced and embodied through social interactions, beyond the ways reflected in most current classrooms. Implications of this more expansive and interdisciplinary theory of learning involve fostering deep learning, engaging learners as their full selves and disrupting patterns of oppression and inequity (p. 557). Creativity, connectedness, and joy are transformational foci as they touch on the social, cultural and emotional realms of human development and push the boundary in what counts as science and what science is for.

Ambitious Science Teaching (AST; Windschitl, et al., 2018) outlines sets of teaching practices that center collaborative sensemaking. Though AST intends to offer all learners access to meaningful science learning, these practices fall short of challenging the inequitable and unjust contexts, constraints and consequences that shape learning for marginalized learners. As a response, we articulate a goal of Justice-Centered Ambitious Science Teaching (JuST) that explicitly identifies equity imperatives beyond simply access. Leaning on Phillip and Azevedo's (2017) work, JuST practices challenge the core foundations of what it means to do science, by whom and for what purposes. JuST practices thus align with Nasir et al.'s (2021) learning theory, highlighting the range of community and cultural experiences across life courses and across multiple settings that count as science learning while also underscoring the need to attend to, name and disrupt the systemic injustice at work. From these frameworks, creativity (agency), connectedness (relationship), and joy (emotion) become points of emphasis in designing for transformational environments.

In this study, we employed a cross-case analysis (Stake, 2006) to explore the ways JuST practices nurtured participants' engagment in two diverse events related to the same overarching project, which shared a common focus on becoming COVID literate in order to keep our circles safe, especially for communities of Color. Particularly, we asked

questions about how creativity, connectedness, and joy were realized in community spaces designed for transformational science learning and what design elements led to these outcomes. The first case explores a public showcase where middle school teens who participated in a seven-week afterschool science club shared the practices, findings, and implications of their inquiries with family, school personnel, and others through hands-on demonstrations and video-based public service announcements. The second case explores a neighborhood forum organized by an intergenerational team of urban community members to offer fellow residents opportunities to engage with three physicians employed at a local hospital. This forum was facilitated by Author #3, a young Black man who leads and facilitates ongoing community work with the organizers. Both initiatives focused on critical equity teaching and learning in and through science. Primary data included photographs, transcribed recordings, and written field notes from both events. Codes were generated from the analytic framework and included agentic creativity, connectedness, emotion, ways of knowing, and criticality.

Major findings, discussion and implications

Creativity, connectedness, and joy were realized in both community spaces through expansive aims and experiences prioritized by people of Color who led the learning in each setting. Throughout the teen showcase, in student-led interactive stations as well as student-created films, youth, the majority of whom are students of Color, positioned themselves centrally as scientists, science educators, and other experts. Authoring the questions that were pursued (COVID myth posters), defining scientific methods employed (mask experiment data), creating scientific explanations (solo cup tower-building to stimulate protein synthesis), and drawing implications (COVID prevention messages in public service announcements), youth shaped and owned science, meaningfully expanding the forms and formats traditionally considered to be "science." Participants were engaged physically and in many different forms. As stars of the scientific show who taught adults including family members, school personnel and unknown others, youth engaged groups of attendees with rigorous science *on their own terms* - wearing Einstein wigs, throwing COVID stuffies to interrupt protein building, and pretending to be doctors to diagnose attendees' dramatized imaginary symptoms. Laughter was core to the science doing, thinking and talking; youth designed laughter into their science and did not edit it out for public professional presentations. Youth situated their messages in student-scripted dramas that contextualized *their* understandings of science, COVID and community (e.g. situating a storyline in the context of *Twilight*, a familiar teen novel turned movie).

In the Neighborhood Forum, Author #3 and the community organizers, all people of Color, selected and directed the activities, ways of interacting and foci of the discussions. Though physicians had prepared to explain the science of COVID, community members were the drivers of the conversation. Not only did community members choose the focus of the science that was to be shared by authoring the questions, they situated these questions in their own lived experiences. Scientific ways of knowing, which for many people of Color are situated in mistrust of the medical field, took back seat to historicized and lived ways of knowing. Laura, a mother of teenagers who have not yet been vaccinated, cried as she shared her rationale, "My children are my whole life! I am their own sense of protection." After she explained her tensions in navigating messages about vaccination, physician Amy validated the sense of pressure associated with parenting, responding with a surprising answer, "Don't trust us because we're experts; instead prioritize the voice of an expert who has, over time, earned your trust." Community leaders, along with other neighbors in attendance, served as judges of the usefulness of the event, highlighting what mattered most to them, namely humility and accessibility. Feeling heard and understood mattered more and was valued over being convinced by studies and citations. Evidence of relationships being built was seen throughout in honesty, transparency, tears, laughter and explicit words of appreciation.

Science, in its traditional form, prioritizes some people while invisibilizing others. In order to meaningfully address equity, what counts as science, what science is for, and who benefits from science had to be critiqued and expanded. Centering voices from marginalized groups, nurturing creativity and agency while legitimizing the outcomes, and honoring the necessarily emergent nature of the learning interactions and outcomes contributed to the transformational power of science learning in these community spaces. Attending to the cultural, social, and emotional aspects of learning afforded by community spaces, JuST practices that centered sensemaking in expansive ways for expansive purposes led to a) creativity in forms of what counted as legitimate scientific data, analyses, expressions and interactions; b) connectedness across generations and social groups through roles, personal recognitions and physical positioning in circles; and c) joy and other emotions steeped through most interactions that were both light-hearted and deeply felt. When we view learning through a critical lens, we reimagine the potential and importance of creativity, connectedness, and joy.

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International Society of the Learning Sciences

An exploratory study of how informal educators engage with formal educators in a community of practice

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Abstract: Expanding graduate programs for educators in the Learning Sciences beyond a traditional focus on classroom instruction requires widening learning contexts to engage out-of-school educators. In this preliminary study, a cohort of 24 in-school and out-of-school educators formed a community of practice. Their engagement in discussion forums was analyzed. Preliminary results suggest that reflections through storytelling resulted in higher levels of interaction between formal and informal educators.

Introduction

This poster describes the development of an online graduate Learning Design Master's program in Uruguay which seeks to integrate both in-school and out-of-school educators in a community of learning designers, thus providing opportunities to understand how informal and formal educators make sense of learning spaces and experiences both in and out of schools.

This ongoing study is informed by notions on communities of practice (CoP). CoPs are formed by groups of people who share similar interests which are expressed through specific shared activities (Wenger, 1998). The CoP framework suits this research context as it provides opportunities to explore engagement and knowledge-sharing across different contexts. Engagement is an essential component of a CoP and a fundamental process of how we learn (Wenger, 1998), thus, the first step of this exploration focused on how formal and informal teachers engaged within their community.

Methods

This in-progress design-based research (Barab & Squire, 2004) project incorporates elements of case study to explore the relationships between educators and the development of their community using a communities of practice (CoP) framework. The current iteration of this study is asking the following questions: how do formal and informal educators engage and share knowledge in a community of practice? To answer this question, this study analyzes the levels of engagement among participants, the themes that lead to higher levels of interaction and the practices that support knowledge sharing between formal and informal educators.

A cohort of 24 educators, (12 out-of-school and 12 in-school educators) coming from a wide variety of backgrounds (37.5% STEM, 37.5% Education, and 25% other Human Sciences) participated in the first year of an online master's degree in Learning Design. The first class of this program positioned teachers as co-designers of learning spaces and artifacts for community-based learning spaces such as museums, non-profit organizations, and after-school programs. The course also served as a foundation to start building a community of practice by providing opportunities for discussions, collaborative and inquiry-based activities, as well as design projects.

Educators were requested to participate in five discussion forums during the course. Each discussion topic was based on one of Engeström's (2017) five layers for expanding education: bringing elements of societal practices into other learning spaces, conceiving learning spaces as communities of learning, promoting learning in activity systems outside school, involving alternative funds of knowledge and epistemologies, and taking local, regional, and global movements as contexts of learning. This theoretical perspective, while originally conceived for science education, served as a means to organize students' discussions about community and knowledge across multiple spaces.

To measure engagement with each discussion topic, a matrix adapted from Hafeez et al. (2018) was used to systematize the data collected from the discussion forums. The matrix presents four layers of analysis: intensity, referring to the number of replies, topics discussed, and the number of views; duration of engagement, measured by the total period of discussion in days; stage of engagement, which describes which participants tend to initiate or end discussion topics; and degree of centrality, where the number of times a participant has engaged in a discussion is counted, including the number of words.

The five topics selected for this preliminary analysis were all organized as text-based discussions in the Moodle learning management system. One limitation to this data collection process was that other forms of communication and knowledge sharing were excluded such as video discussions and collaborative annotations.

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Preliminary findings

After analyzing the five discussion forums, it was found that two of them sparked a significant amount of interest: "What makes an educator" was a question that sought to extend a prior discussion about activity systems outside schools. The question engaged 24 students, and 10 of them received at least one reply. There were 208 views of the discussion forum, and the total number of posts was 49. The second most discussed topic was "Where does knowledge come from?" where participants discussed funds of knowledge and indigenous epistemologies. Participants in this discussion were encouraged to engage in storytelling to describe how their local communities had acted as funds of knowledge in their lives. The question engaged 24 students, and 7 of them received at least one reply. there were 195 views of the discussion, and the total number of posts was 37.

Regarding the differences between formal and informal educators, the five discussion topics were initiated by formal educators. However, participation was higher among informal educators (68% of total posts) who also showed more interest in prolonging discussions by replying to previous comments more often (78% of total replies to posts) and participating in the discussions even three to four weeks after the thread had been initiated. The two most discussed topics were also the topics with the highest levels of participation from informal educators. The only question that showed lower engagement from informal educators compared to formal educators was "How does social media affect our lives?", a question which required students to reflect on a specific reading providing factual arguments.

Discussion

One noticeable finding in terms of discussion engagement across participants was that the most discussed topics involved narrating stories based on personal experiences both in-school and out-of-school. Unlike the other three topics where participants had to provide arguments to support specific claims, these two topics specifically encouraged storytelling to connect previous discussions with personal experiences. This approach seems to have served as an inclusive point of access for both types of educators in finding common grounds to make sense of their personal learning experiences.

Further analysis needs to incorporate discourse analysis to visualize what funds of knowledge educators tap into when developing their answers to the discussion questions and to determine whether tacit knowledge is transferred among educators in the discussion process. For this discourse analysis, it will be necessary to incorporate other sources of discussion which were not considered for this study such as video discussions and collaborative annotations.

For the current iteration of this graduate program, a more systematic approach to storying as knowledge sharing is being implemented where stories from different educators are intertwined in a single digital experience.

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International Society of the Learning Sciences

Title: Measuring Belonging for Neurodiverse Computer Science Students

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Abstract: Neurodivergent students can thrive in undergraduate Computer Science programs with support, but research on effective learning and teaching practices is limited. The neurodiversity movement advocates an approach to research and design that examines social (i.e., external) barriers to student success and seeks to remove or mitigate them. We suggest that this research must begin with productive measures of student success. This poster presents a survey instrument to measure neurodivergent CS students' *sense of belonging*.

Keywords: belonging, computer science, neurodiversity, research, intersectionality

Introduction

Neurodivergent students (e.g., with autism spectrum disorder and other neurological differences) experience the world differently and often possess highly valued skills, such as creativity and systematic thinking (Baron-Cohen et al., 2009). These are especially valued skills in Computer Science (CS), such that major international employers like Microsoft now actively recruit neurodivergent people. But, with neurodivergence often comes disability, largely as a product of outside barriers that limit neurodivergent success (Kapp, 2020). Post-secondary programs, for example, are usually designed for neurotypical students (Fabiano et al., 2018), creating unnecessary challenges for neurodivergent students, who then struggle with mental health, sensory processing disorders, and communication (White et al., 2011). Standard accommodations, even when provided, do not mitigate this problem (Sarrett, 2018). Most neurodivergent students drop out of four-year post-secondary institutions (Wei et al., 2014) despite high levels of interest in CS (Wei et al., 2013).

CS teaching practices and learning environments can be designed for inclusivity, but in order to do this, there is a need for research to identify incongruities between student needs and existing practices. For example, instructors teaching facial recognition software coursework in Artificial Intelligence classes may assume that students can, inherently, correctly interpret facial expressions. Neurodivergent students do not always possess this skill, and accommodations like time on tests or extended deadlines will not be sufficient. But what if instructors in this case taught about facial expression as well, or created collaborative projects where students were expected to examine their biases about facial expression interpretation? This is just one example of an opportunity to research student needs and design for better, more inclusive learning.

We suggest that the first step research step in designing for inclusivity for neurodivergence in CS is to determine reliable metrics of student success. Grades and graduation rates are insufficient because they do not accurately reflect learning for neurodivergent students. Instead, we believe that *a sense of belonging*, a necessary factor for both neurodivergent and neurotypical students (Morrow & Ackermann, 2012; Vaccaro et al., 2015), can be used to formatively and summatively assess how *all* students are succeeding.

Measuring Belonging for Neurodiverse Students

This poster presents the development of a survey instrument for neurodiverse students' sense of belonging in Computer Science, and we invite discussion about the constructs measured and research directions. Examples from existing measures that may be useful to measuring belonging are presented in Table 1, below.

Table 1
Measures of Belonging in Neurodiverse Computer Science Programs

Measure	Example Question	Source
Mastery	I am confident in my mathematics abilities.	Mooney & Becker, 2020
Self-Advocacy	I feel uncomfortable advocating for my rights and responsibilities as a student with an invisible disability.	Lombardi et al., 2011 (modified for neurodiversity)
Relationships	My instructors make me feel valued.	Mooney & Becker, 2020
Neurodiversity	Do you consider yourself to be neurodivergent (e.g., autism spectrum disorder, ADHD, dyslexia, etc.)?	Kapp, 2020

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A *sense of belonging* is vital to all students' success (Morrow & Ackerman, 2012), but especially neurodivergent students in post-secondary programs (Vaccaro et al., 2015). Belonging for students with disabilities depends on—and in turn impacts—students' sense of mastery of their student role, ability to self-advocate, and ability to develop relationships with peers and faculty in their program. Accordingly, measuring belonging requires measurement of these underlying variables. Table 1 provides examples of survey instrument questions for each. Additionally, an intersectional (Collins & Bilge, 2020) perspective suggests the need for questions that acknowledge the complex experiences of discrimination and privilege students face. Women and many ethnic or racial groups remain underrepresented in Computer Science as a field, for example, but are also least likely to receive diagnoses and services for autism and other neurodivergent conditions. Existing instruments account for belonging among underrepresented students in CS based on gender and ethnicity (e.g., Mooney & Becker, 2020), but to date, no survey instrument also accounts for neurodiversity. In addition to measuring mastery, self-advocacy, and relationships in a way that accounts for intersectionality (see Table 1, Relationships Example), measures of neurodivergent student success should also address demographic questions about whether students consider themselves a minority (Mooney & Becker, 2020) or neurodivergent. There are many reasons students may lack formal diagnosis, but still rely on additional supports that could be provided without risk of unfairness (e.g., providing facial expression interpretation guides). Although most universities rely on a medical model of disability to determine fair access to supports, many support services recommend accepting self-diagnosis as evidence of student needs. Taking this approach in research will support identification of the ways that teaching practices and learning environments can change to meet the needs of all students.

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International Society of the Learning Sciences

Turning Ourselves Inside Out: Reading and Creating Graphic Medicine in Community

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Abstract: An interdisciplinary team designed a graphic medicine project to address health inequalities, implementing it in public libraries with underserved populations. Participants read graphic novels about experiences with illness, then create a 4-8 panel comic about a health-related experience of their own. Research questions are 1) what personal insights about health arise when reading and discussing graphic narratives? and 2) what community insights about health arise when creating and sharing stories in the comics format?

Issues addressed and potential significance of the work

The recent pandemic has brought mainstream attention to the health disparities beneath the surface of our wealthy nation. Researchers attending to these issues know that underserved populations such as Black, Latinx, and Indigenous communities and those from lower socioeconomic backgrounds suffer not only from lack of access to health care, but also access to health information. This paucity of information is actually a two-way street – while these populations receive less health information, their health experiences remain underrepresented in medical research. The health perspectives and experiences of underserved groups must be brought forward and made visible to decrease persistent health inequalities.

An effective tool for addressing this inequality in health information comes from the emergent field of graphic medicine. Graphic medicine refers to health narratives and medical information created and shared in the format of comics, which, when collected, create a sequential art story called a graphic novel. Originally conceived as a way to increase the empathy of medical students, it has expanded to include the communication of health information to various populations as well as a tool for participatory personal expression of health experiences. In their *Graphic Medicine Manifesto*, the interdisciplinary field's founders state, "Graphic medicine is also a movement for change that challenges the dominant methods of scholarship in healthcare, offering a more inclusive perspective of medicine, illness, disability, caregiving, and being cared for" (Czerwiec, et al, 2015).

This paper reports the initial findings from a graphic medicine project hosted by public libraries in three communities with underserved populations, including rural and urban locations. The project curriculum was iteratively designed by an interdisciplinary team, which includes researchers from learning sciences, information science, English, journalism, and health services. The project research questions are 1) what personal insights about health arise when reading and discussing graphic narratives? and 2) what community insights about health arise when creating and sharing stories in the comics format?

Theoretical and methodological approaches

Our research is guided by sociocultural-historical theories, bringing the focus of the analysis to people learning in context through mediational means, in this case, language and images (Cole, 1996). Graphic novels lend themselves to Bakhtinian analysis through their heteroglossic structure that "borrows pervasively from other cultural genres and discourses, and in doing so appropriates a range of cultural and intellectual ideas and narrative and discursive forms" (McCallum, 1999, p. 258). Through the lens of "funds of knowledge," we view the participants as "competent, they have knowledge, and their life experiences have given them that knowledge" (González, Moll, & Amanti, 2005, p. x). Each participant brings their funds of knowledge to the library program and actively produces meanings for the texts they read, discuss, create, and share. As researchers, our close attention to these activities in context illuminates the informal learning experience.

This qualitative research project takes the form of a comparative case study (Merriam, 2009) in three public libraries. A maximum of 10 patrons sign up through each library location, for a total of 30 participants. Data includes a) pre- and post-program surveys about experiences with graphic novels/comics and with health and health care, b) video recordings of the eight online program sessions, and c) the four to eight panel comic stories created by participants.

The research team qualitatively codes data from the surveys, sessions, and participant-created comics through the lens of the previously discussed theoretical framework. Team members complete a round of open coding, then compare results to create a series of closed codes. Using these closed codes, team members re-code

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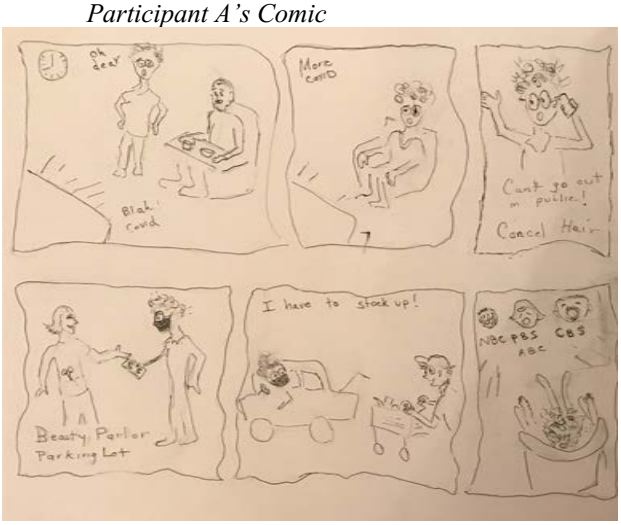
the data corpus until an acceptable level of agreement is reached (Merriam 2009). This process will be completed by June 2022.

Findings and implications

Initial findings come from a rural library, where the solicitated participants were older adults in their 60's and 70's. Led by a member of the research team, the group first discussed the book *Cancer Made Me a Shallower Person: A Memoir in Comics* by Miriam Engelberg, followed by *My Degeneration: A Journey Through Parkinson's* by Peter Dunlap-Schohl. In the earliest conversations, participants often commented on new knowledge gained about the disease discussed, i.e., "I didn't know that…" As discussions continued, participants shared more of their personal health experiences the had some similarities to the experiences of the comic authors. A common theme amongst these senior citizens was concern about losing greater control of their bodies and the burden it will place upon others.

While initially apprehensive about their ability to create a comic, they all reported feeling capable thanks to the step-by-step coaching from another member of the research team. In the next to last session, this member asked everyone to reflect on a moment from their experiences in the pandemic in order to create a storyboard. As they shared their drawings, common themes arose of anxiety and its impact on the body. For example, in Figure 1, Participant A uses motion lines to represent information bombarding her, with the final panel showing her body shaking while watching the news.

Figure 1
Participant A's Comic



As the project continues in new locations with different kinds of participants, the research team look forward to comparing and contrasting the insights about health that the graphic medicine format affords people both personal and as a community.

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International Society of the Learning Sciences

Thrive Online: Preparing Learners for Success in Online Learning

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Abstract: The need for students to learn online continues to increase. Many students report feeling unprepared, lacking the skills and confidence to succeed. Efforts are needed to bridge a student's transition from traditional learning environments to online. We developed Thrive Online, an asynchronous short course aimed to increase students' knowledge, skills, attitudes, and self-efficacy to learn online. A pilot study evaluated the impact of Thrive Online with a sample of 28 students, with results reporting promising data this course can support students' successful transition to online learning.

Online learning

The adoption of online courses has temporarily or permanently increased due to the COVID-19 pandemic (Arum & Stevens, 2020), which relied on emergency remote teaching and learning (Hodges et al., 2020). Online classes are different, and when developed in haste, they may lack some of the traditional safeguards of traditional classes that help students. Indeed, some students in fully online classes report feeling more disconnected from their peers and instructors, feeling more responsibility to be self-directed, since they receive less help from their instructor and can also feel intimidated by the technological expectations of the online learning environment (Holley & Oliver, 2010; Otter et al., 2013). Students transitioning from a traditional high school to college may feel disconnected from their peers in an online classroom because they are unfamiliar with how to appropriately connect to other learners.

In education, it is important to focus on assisting students in learning how to learn (Barron & Darling-Hammond, 2008) and build not just content knowledge but also 21st-century skills. These skills will help learners navigate formal learning opportunities, cultivate new mindsets and learning habits (Fischer, 2000)., and meet the demands of changing technologies and job expectations. Formal education should prepare learners with these skills and the desire to be a lifelong learner. In addition, it should enable them to be flexible as new expectations arise so the learner can be successful in whatever learning environment. This is a description of an effort to improve student learning capacity and self-efficacy to successfully learn in an online environment.

Thrive online design

In the last year, we have collaboratively designed and implemented the Thrive Online course to address the various needs of learners at a large private university in the United States. This course was designed to increase students' knowledge, skills, attitudes, and self-efficacy navigating the online learning environment and is guided by Gagné's principles of instruction (Gagné et al., 1992). The Thrive Online course is a 2-week asynchronous course. It was designed with five strategies: (a) creating engaging activities, (b) creating an environment that values the knowledge and experience of the learners, (c) regular communication with instructors and teaching assistants (Tas), (d) manageable workload for the learning conditions, and (e) multiple means of processing the material to diversify and scale the learning materials that are relevant and applicable to the students' learning needs. Using these strategies, the course material include: (a) orientation to the learning management system, (b) online learning technical skills, (c) learner wellness, (d) online learning strategies, (e) developing a growth mindset, (f) accessing campus resources to support online learning, and (g) connecting with instructors, TAs, and other learners.

Methodology

We used design-based research (Barab & Squire, 2004; McKenney & Reeves, 2018) to frame our approach and develop the course, providing an opportunity to iteratively tackle a problem of practice in online learning. We designed learning modules and resources with input from learners and pilot studied the implementation. We used mixed methods (Creswell & Plano Clark, 2018) to capture the experiences, knowledge, beliefs, and attitudes of learners. This work is guided by the following research question: How do students' perceptions, knowledge, and confidence with online courses change after participating in the Thrive Online course?

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Participants

Participants included 28 undergraduate and graduate students who were enrolled in an online course at the university. Participants were randomly selected from over 20,000 students; participation was voluntary.

Data collection and analysis

Data was collected from pre/post-surveys focused on participants' knowledge, attitudes, and self-efficacy. We incorporated a Short Instrument to measure Students' Confidence with 'Key Skills' (SICKS; Bray et al., 2020). Using results from the SICKS, students gained an understanding of their deficiencies and strengths in online learning and set goals accordingly. All data is informing future design changes and improvements. Quantitative data from the surveys was analyzed for differences from pre to post.

Results and implications

The pre/post surveys provide a promising picture of the support that the Thrive Online course gives to students. The survey focused on student perceptions, knowledge, and confidence in connecting with other students online, the value of connecting with others online, value of improving their knowledge and skills in online courses, managing their mental health, setting goals, and applying the skills and strategies they have learned. The percentage of students who were undecided, disagreed, or strongly disagreed about these different areas was higher before taking the Thrive Online course. There was an increase from pre/post in all areas for students who strongly agreed. After taking the Thrive Online course, 63% of the participants indicated that they strongly agreed they now know how to connect with other students in the online environment. And with that, 57% strongly agreed that it is important to connect with other students in the online environment.

It is promising that with a short 2-week bridge course students are noting positive changes. As a pilot study and with iterative design we believe the Thrive Online course will continue to be helpful for all online students at the university. With a very small sample size in this pilot work though, we cannot make sweeping claims, but as Glazier (2021) points out that to make human connection online, there must be intentional actions, whether you are an instructor, TA, or student. Thrive Online provides a means for this to happen.

Thrive online next steps

We continue to explore when the most valuable time is to expose students to these learning principles and techniques to successfully implement new knowledge and skills into their credit carrying online courses. Future iterations will include supports for the unique needs of marginalized student learners. We also want to know more about student confidence and ability to succeed in an online learning environment.

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International Society of the Learning Sciences

Can Schools Fix the Gender Gap in STEM? A Comparative Study in the Global South about Gender Participation in Maker Education

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Abstract: Research established that most learners perceive STEM learning environments as settings that exclude diverse ways of thinking. We investigate factors behind this trend in two sites that recently implemented fully-equipped makerspaces, but have deeply different socioeconomic contexts. We identify factors associated with increased self-efficacy and attitudes toward STEM among male and female students.

Introduction

Research in the past decades has established that STEM learning environments are not only largely male-dominated but are also widely perceived as such (see, for example, Nasir & Vakil, 2017). Building on Turkle and Papert's (1992) foundation of "epistemological pluralism," researchers have discussed principles of a maker, constructionist education that equally acknowledges the repertoires of different groups of learners (e.g., Buechley et al., 2008). This research tradition led to remarkable advances on diversity in STEM education. However, it focuses almost exclusively on contexts in the US and Europe. Driven by the question of applicability to contexts in the Global South, we investigate factors that may influence STEM learning in makerspaces in two contexts: one school in Hong Kong serving affluent families and two schools in an economically depressed area in Brazil. These schools underwent dramatic curriculum redesign, including extensive professional development on maker education. We present analyses of *quantitative survey data* from both sites to identify factors that affect the attitudes of girls and boys towards and self-efficacy in STEM.

Data collection and analysis

Students answered an online survey (Table 1) containing open-ended, multiple-choice, and multiple-answer questions gathered from validated instruments to assess students' self-efficacy in science and engineering and their attitudes toward STEM (Siegel & Ranney, 2003; Wang & Berlin, 2010).

Table 1: *Comparison of data collected in Brazil and Hong Kong*

	Country		Type of variable		
	Brazil	**Hong Kong**			
Number of schools	2	1			
Number of respondents (N)	242	89			
Response variables					
Attitude toward STEM	Y	Y	Quantitative		
Self-efficacy (Engineering)	Y	Y	Quantitative		
Self-efficacy (Science)	N	Y	Quantitative		
Explanatory variables					
Mastery of makerspace techniques	Y	Y	Quantitative		
Grade	Y	Y	Categorical		
Gender	Y	Y	Categorical		
Participation in experiments	Y	Y	Categorical		
Perceived expectations of parents	N	Y	Quantitative		
Grades	10, 11, 12	7 and 9			

Results

Data from each nationality were analyzed using linear regression models (Cohen, 1992) for each gender and response variable separately. Due to space considerations, we report the results in an abbreviated table (Table 2).

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Full tables are available at bit.ly/russoetal-isls-2022. The analysis revealed that groups of students had different significant predictors for their attitude towards STEM and self-efficacy.

Table 2: *Unstandardized regression and part correlation coefficients for linear regressions*

	Class experiments		Parent expectations		Techniques		Grade	
	β	Part corr.	β	Part corr.	β	Part corr.	β	Part corr.
Hong Kong								
Attitude towards STEM								
Female	–	–	1.20*	.26	.34*	.27	-5.51†	-.21
Male	–	–	–	–	–	–	–	–
Self-efficacy (engineering)								
Female	–	–	–	–	.18**	.42	–	–
Male	–	–	–	–	.14†	.35	–	–
Self-efficacy (science)								
Female	–	–	.54†	.26	–	–	-3.30 †	-2.9
Male	8.68†	.48	–	–	–	–	–	–
Brazil								
Attitude towards STEM								
Female	–	–	*NA*	*NA*	.24***	.32	-6.86***	-.40
Male	–	–	*NA*	*NA*	.19**	.30	-3.34†	-.17
Self-efficacy (engineering)								
Female	–	–	*NA*	*NA*	.09*	.23	-.23*	-.23
Male	3.72***	.35	*NA*	*NA*	.15***	.43	–	–

Note: †$p \leq 0.1$. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

Discussion and conclusion

When analyzed as a whole, these results highlight a bigger issue regarding the role of schools in effective societal change across class and gender. Consider that the school in Hong Kong offers state-of-the-art makerspaces and laboratories, including female maker teachers, arguably the peak of hands-on K-12 technology education. Still, gender differences persist and differentially influence girls' and boys' self-perception (e.g., participating in class experiments is a statistically significant predictor for self-efficacy in science for boys in both countries, but not for girls). If this phenomenon can be observed even at those close-to-optimal school conditions, one may wonder what the limits are in terms of how much effect in systemic change schools can have. It is necessary to acknowledge that schools are parts of a broader system with their own paradigms and prejudices, and that kids may bring those values into schools in significant ways. Gender questions in STEM education should be more broadly contextualized--not assigning to schools the entire responsibility of addressing them, but considering larger societal questions and movements.

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International Society of the Learning Sciences

Studying the Development of Marginality in Collaboration: Methods for Examining the Interplay of Peer & Teacher Interactions

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Abstract: Inquiry-based science learning environments emphasize learners' engagement in scientific practices, yet we need to better understand how to promote equitable interactions to ensure all students benefit. Using Wenger's (1998) concept of marginal non-participation, the present study examined patterns of interaction across teacher- and student-led phases of instruction for a focal group in which marginality was previously observed. Findings indicated reliance on ignoring off-task commentary across both phases of instruction, facilitating marginality for two group members.

Introduction

When power is redistributed from teachers to students in inquiry-based science classrooms, peers shape each other's participation in scientific practices and thus may play a role in mediating their teammates' ability to identify with the discipline. Further, as teachers retain the authoritative role of orchestrator and convey motivational messages, teacher discourse and instructional practices likely inform equity in peer interactions (e.g. Cohen & Lotan, 1995; Forman et al., 2017; Modrek & Sandoval, 2020). Yet, after accounting for the benefits of authentic inquiry, reform-oriented curricula can intersect with the question of equity in a potentially adverse fashion: extant research indicates small group learning can involve inequitable opportunities to learn and develop discipline-linked identities (e.g. Carlone et al., 2011). To address this problem, the current study employed microgenetic methods to examine the development of marginality inside collaborative groups in middle school inquiry-based science, with a focus on the interplay of teacher-student and peer interaction across teacher-led and student-led phases of instruction.

Theoretical Framework

Marginality is an adaptation of Wenger's (1998) concept of marginal non-participation and describes movement away from deepened, fuller participation in a community and its defining activities. From this perspective, learning has four facets: belonging in a community, engaging in that community's practices, making meaning of one's experiences with the community and its practices, and the process of becoming a member in said community of practice. Importantly, Wenger's social theory of learning aligns well with science education reforms' reconceptualization of proficiency in science, as proficiency now involves socialization into the role of a scientific thinker. The new indicators of proficiency include making sense of scientific explanations, producing and evaluating scientific evidence and explanations, understanding how scientific knowledge develops, and engaging in scientific practice and using scientific discourse. Inquiry contexts inform learners' opportunities to be recognized as a member of community of competent thinkers in the science classroom, opportunities to practice norms of the discipline, opportunities to experience meaning-making about scientific concepts, and opportunities to become a scientific thinker or pursue a career in science.

Methods

An intensive qualitative case study was conducted to clarify the role of teachers in tandem with peer interactions for constructing marginality. We used videorecorded observations and end-of-semester student interviews previously collected in a larger study: participants were selected from the classrooms of four seventh-grade science teachers in an ethnically-diverse, suburban middle school in the United States and all classrooms were participating in a series of inquiry science units over the course of a semester. Students used evidence to build, revise, and evaluate scientific models; they also engaged in both oral and written argumentation as part of the process. While features of the curriculum should support a shift of authority to students and offer increased opportunities for learners to engage in discussion and peer interactions, previous findings also suggest students peer interactions can be oriented toward constraining participation by groupmates, thus raising questions about the nature of exclusion in collaborative groups and inquiry science classrooms. The present study expanded analyses of a single group for whom group-level marginality-relevant interactions during student-led group

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activity had already been coded and presence of marginality for at least one group member had already been established. We used a purposeful operational construct sampling strategy (Patton, 2015) to choose a group and class date, with the selected group having previously been identified as having episodes of marginality for more than one group member and the student-led period being of an uninterrupted and extended duration. We selected videorecordings of teacher-led instruction for the previously coded class period's group activity. This included ~18 minutes of student-led activity and ~25 minutes of teacher-led whole-class activity. Semi-structured interviews with students in the selected group were reviewed to support interpretation of teachers' role in constructing marginality. Analyses of all data sources were triangulated.

Results & Discussion

The primary task the teacher assigned the class for the observed period was to discuss and evaluate the first in a series of pieces of evidence intended to support competing models of cell nuclei. The first ten minutes of the class period involved the teacher giving directions to the class and checking in with groups around the classroom, stopping multiple times to ask different students outside the focal group to sit still. Prior to the groupwork phase of the period, the teacher offers positive evaluations and comments emphasizing speed of response to two of the four focal group members (e.g. "You're fast, you're amazing"; "Ooh, you two are *really* fast!"; "Your hand went up really quick, how would you rate Evidence A?"; calls on each of the two students to answer questions; evaluates the two students' responses as correct). The teacher also asked one focal group member to return to his seat in one instance and ignored his raised hand in another instance, only for him to blurt out nominally on-task comments in the whole class discussion. Upon transitioning to the groupwork phase, the dynamic of two group members being on-task and two mostly being only nominally on-task continued. Three patterns were identified across the entire class period. First, the group as a whole and the teacher alike struggled with one student's frequent nominally on-task comments, as these typically diverted the teacher or the whole group away from the primary task. The teacher and groupmates alike responded to this most often by ignoring the comments, but occasionally responding briefly before explicitly redirecting him back to the intended task. Second, the tendency to ignore the nominally off-task comments eventually escalated to the group splitting, with two on-task members avoiding interaction with the two off-task group members. Third, the failure to channel the first nominally off-task group member into productive forms of engagement also created space for constructing the second off-task group member as marginal with respect to the peer group. In sum, within a class period, the teacher's interaction with focal group members mirrored focal group members' peer interactions. These findings raise the question of whether group members were specifically emulating the teacher's approach to interacting with a potentially disruptive groupmate, or drawing on other motivators. Accordingly, additional analyses in progress will be presented. These will include more class periods for the same group and one additional group, with attention to interactions occurring earliest in the semester, norms of interaction developing over the semester, teacher and student talk reflecting motivational messages, and other instances of teacher intervention during groupwork phases.

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Becoming a STEM Teacher: Examining teachers' practice-linked identities through practice-based autobiographies

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Abstract: To provide equitable high-quality STEM education, teachers must be prepared to engage with the tools and practices *and* to adopt STEM identities. This project investigates the ways teachers' self-described histories and conceptions of materials and relationships embedded in their STEM experiences fostered or inhibited practice-linked STEM identities. Preliminary findings explore how practicing and pre-service educators conceptualize STEM and how their understanding of STEM both supports and challenges their teaching practice.

Introduction

Engagement in science, technology, engineering, and mathematics (STEM) disciplines continues to be lauded as a means to prepare youth for a multitude of possible futures. However, equitable access to learning environments where these skills are centered continues to be elusive, not least because many of the teachers who are expected to incorporate these skills into classrooms do not see themselves as STEM educators (e.g., Stamatis et al., 2021). In this preliminary analysis, we conceptualize STEM as a "figured world" (Holland et al., 1998). From this perspective, the ways an individual conceives of the world of STEM education has implications for how they perceive their own participation in the STEM education community of practice and how they use the material and interpersonal resources available to form practice-linked identities (Nasir and Cooks, 2009). We ask:

1. How do these teachers understand their own practice-linked identities with regards to STEM & CS?
2. What materials, relationships, and ideas do the teachers name as resources that strengthen or challenge their identities in STEM & CS?

Background

We frame this study through notions of practice-linked identities (Nasir & Cooks, 2009; see also Keiler, 2018) to build understandings of the ways educators who are learning to teach STEM subjects use material, relational, and ideational resources to adopt identities as STEM educators. Nasir and Cooks (2009) define learning and identity in practice as "shifts in the use of artifacts...for problem solving, sensemaking, or performance" and identity to be "one viewing participation in the practice as an integral part of who one is" (p. 42). We use this analytical frame within the larger sociocultural context of "figured worlds" and understand STEM as a "socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (Holland et al., 1998, p. 52). From this framing, we see the resources identified by teachers and the ways in which they interact with these resources as informed by individual's understanding of STEM and what it means to be a legitimate participant in the STEM education community (Wenger, 1998).

Methods

This project incorporates multiple sets of data with more than 90 educators who were engaged in teaching STEM in formal educational contexts. In the first dataset, pre-service elementary teachers wrote "mathographies" about their experiences with mathematics at the beginning of a mathematics teaching methods course (Drake, 2006) and then completed a follow-up reflection at the end of the course. In the second dataset, in-service teachers seeking an add-on endorsement wrote autobiographical essays about their experiences with computer science. The final data set is a series of ethnographic interviews with pre-service and practicing teachers where questions were codesigned to elicit understandings of teachers' identities with STEM. Teachers were asked to describe their previous experiences with STEM and the ways that they identified or did not identify as STEM educators. Preliminary analysis used rounds of emic and etic coding to establish understandings of the ways that teachers described materials, relationships, and ideas and how their descriptions mapped onto their identities as STEM educators. Following Nasir and Cooks (2009), we also looked for the ways that participants across data sets described their experiences with and goals for learning STEM tools, practices, and expertise.

Findings

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Across these projects the context of data collection was within programs explicitly designed to train educators to build practice-linked identities in STEM through engagement with tools and materials, specific practices, relationships with other participants, and engagement in communities of practice beyond their own institutions. While several educators used their reflections and discussions to reinforce the ways they were developing these identities, the ways participants identified with STEM varied depending upon their past experiences, the strength of the relationships they built, their access to experts and peers outside of these programs, and their feelings of agency within their schools and careers. Expertise in STEM fields was sometimes a barrier to identifying as a STEM educator because some of these individuals did not identify as "teachers." However, perceived lack of expertise with STEM was also a barrier when teachers felt their participation in the STEM community of practice was not legitimate or would always be peripheral.

For example, our initial analysis pointed to the ways that some participants described alignment with computer science education because of early experiences playing video games. These educators' willingness to see themselves as having previously engaged with STEM materials and environments meant that they saw fewer barriers to accessing and engaging with the tools and practices taught in these programs.

Conversely, participants who described negative childhood experiences with mathematics often experienced anxiety when tasked with completing time-based assessments, such as fact fluency tests, or engaging in conceptual or procedural work around rational numbers, seldom identified as "being a math person," despite speed of computation being an indicator of mathematical understanding.

In contrast, a few individuals who had transitioned into education from previous STEM careers, such as engineering, had established expectations for a STEM community of practice prior to engaging in these programs. While some of these educators leveraged that experience to suggest norms and collaborate to build relationships with peers, others expressed frustration with "teachers that don't have a ton of experience" and even used their expertise to set up barriers for participation such as refusing to engage with peers until they had mastered certain skills or computational literacies. While these teachers had framed themselves as STEM experts, their ideas about the figured world of STEM did not necessarily align with the kinds of ideas required for educators.

In alignment with Nasir and Cooks (2009), our initial analysis suggests that access to materials and relationships supporting engagement with the STEM education community make it easier to have an in-bound trajectory toward a STEM identity. Even an understanding of the discipline that might be considered illegitimate by experts can lead to an in-bound trajectory if the individual feels successful and supported in what they believe are the practices of the community. Participants' adoption of identities as STEM educators was also sometimes complicated by their other identities and by their understanding of what it meant to be a STEM educator.

Significance

Nasir and Cooks (2009) call for examining learning and identity as "intimately related to one another but also…[as] distinct processes" (p. 58). Our emerging findings align with these researchers' notions of practice-linked identities as mediated by "engagement, persistence, and goals" (p. 58). As teacher educators and researchers continue to seek ways to support more equitable access to STEM skills for students, we must also consider the ways that educators have access to the tools, relationships, resources, and ideas that will allow them to develop in-bound trajectories to communities of practice and figured world(s) of STEM (Holland et al., 1998). By continuing to develop understandings about the material, relational and ideational resources that STEM educators require to embrace these identities, we can better support them to build the confidence necessary to offer access to all students.

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The hidden meaning of physical interaction with exhibits: the relevance of the Instrumented Activity Situation model

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Abstract: Authors discuss the relevance of The Instrumented Activity Situation (IAS) model in analysis of visitor–exhibit interactions. Observing visitors playing with exhibits in science museums raises questions about the relevance of the actions they undertake. We argue that visitors' conceptual understandings of scientific phenomena are seeded via rapid iterative cycles of explorative co-attuning between processes of instrumenting and instrumentalization. In our analysis we have demonstrated how the adapted IAS model helps to analyze visitors' interactions with exhibits.

The major issue addressed

Observing visitors playing with interactive exhibits in science museums raises questions about the relevance of the actions they undertake. Observation of these processes prompts museum facilitators to intervene and provide visitors with instructions. But does such "mistaken" interaction lead visitors to new knowledge? The phenomenal logic of exhibits is deliberately obscured yet discoverable, rather than transparent and explicit. We argue that visitors' conceptual understandings of scientific phenomena are seeded via rapid iterative cycles of explorative co-attuning between processes of instrumenting and instrumentalization. The Instrumented Activity Situation (IAS) model (Verillon & Rabardel, 1985) highlights the intermediary status of instruments. It orchestrates multiple relationships which bind together the three elements constitutive of instrumented activity situations: subject (visitor), object (goal), and instrument (exhibit).

The potential significance of the work: the science center context

Exhibits are designed to provoke a series of anticipated physical manipulations that guide the visitor through potential physical actions with the object. Ideally, as a result, the visitor discovers the *exhibit effect* and further explores the scientific phenomena. Research provides evidence of visitors' signification of their physical experiences. Some researchers interpret visitors' continued repetitions of purposeful attempts to achieve the *exhibit effect* along with their exploratory behaviors as pre-symbolic perceptions and actions (van Schijndel, et al., 2010). Under this paradigm, the process of conceptualization can be envisioned as a negotiation between naïve (embodied) and cultural (verbalized) ways of perceiving phenomena. This negotiation can be seen as a dialogue that celebrates both perspectives while seeking reconciliation between them (Abrahamson, 2017).

The theoretical and methodological approach: towards an understanding of visitors' epistemic practices

The Instrumented Activity Situation model highlights the intermediary status of instruments (here: exhibits). It orchestrates the multiple relationships which bind together the three elements constitutive of instrumented activity situations: 1) subject (visitor), 2) object (goal), and 3) instrument (exhibit). The use of an instrument is indicative of the triad and of the multiple interactions which result from it, forming the common core characteristic of instrumented activity situations as a class. Accordingly, an exhibit becomes an instrument only when a visitor (subject) "has been able to appropriate it for himself – has been able to subordinate it means to his ends – and, in this respect, has integrated it with his activity" (Verillon & Rabardel, 1985, p. 85). Precisely at this moment, when an exhibit is treated as a tool (instrument), the visitor becomes a designer of the action in his or her own right. In the ISA model, the instrument mediates the subject–object interaction. In the case of the visitor–exhibit interaction, the exhibit is the instrument for the effect-object. Thus, the adapted ISA model focuses on the subjects' intentionality – their goals and actions – with rapid iterative cycles of explorative co-attuning design interpretations. The exhibit design plays a mediating role between the instrument and the object.

Design is hence understood as the concept of an artifact (exhibit) posited by a designer, that is interpreted by a user. Thus, the exhibit as an instrument of action is conceptualized equally by its designer and the user (visitor). Visitors' *action* is thus the (re)interpretation of the artifact, (re)discovering an exhibit's design. Possibilities for action are discovered by a visitor in real-time. Often, we can observe tension between the *exhibit*

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effect and the visitors' goal (i.e., what the user wants to do with the exhibit at the moment). Usually, visitors' *goals* are multiple, provisional, and change during the interaction – they emerge or get updated as the visitor goes along, constantly (re)developing sensory-motor schemas. Through exhibits, the science center aims to model a particular kind of scientific practice. This practice enables visitors to experience the type of agency that occurs during a design process. Therefore, in this paper, we investigate 2 cases of the visitor–exhibit interaction as a design situation.

Case Swirling Sands: a case of high confluence between the designers' and visitors' designs

The Swirling Sand exhibit consists of three slowly spinning disks covered in fine-grained sand (Figure 1). As the disks turn, visitors can draw in the sand using their hands or props, such as paintbrushes, scraper tools, and small scoops, available at the exhibit. Visitors can also change the speed of the disk's rotation using a small knob. The motion of the rotating disks and visitors' fingers produces a variety of intricate circular patterns and shapes. The three workstations also add a social dimension to the interaction through which visitors can observe and re-mix each other's work. The data excerpts presented below are from a young female adult visiting the Swirling Sand exhibit for the first time. Using a flexible protocol, the authors engaged participants in using the exhibit. The interactions were videotaped for subsequent analysis. Once the researcher asked the participant to use the exhibit, no additional instruction or cues were provided. The participant decided by herself what to do and how long the interaction should take. After she ended her interaction with the exhibit, the participant ("Pola") was shown a video recording of her interaction and was asked to describe her actions and goals. If the participant omitted certain actions, the researcher asked additional questions, such as "What were you doing at this point?" and "Why?" The goal of the semi-structured stimulated recall protocol was to examine the participant's conceptualization of her goals and actions. Pola used the exhibit for approx. 5.5 min. She was the only person interacting with the exhibit during that time. An analysis of the interaction is presented in the table below. Pola spent almost 80% of interaction time exploring the exhibit and its various features. She began using the exhibit with some sand on the plate and a relatively high rotation speed. After 5 min., Pola decided to start making patterns using the exhibit as a tool to achieve the effects predicted and intended by the designers.

Conclusions

In our analysis of these two examples, we have demonstrated how the adapted ISA model helps to analyze visitors' interactions with exhibits. One direction for further discussion is the evaluative value of the model. Is the degree of intuitiveness of an object equivalent to the extent of the confluence between designers' and visitors' effects? Conversely, does dissimilarity of designers' and visitors' effects entail a design failure, or rather successful discovery? How does the visitors' signification of their physical experience change according to the formal or informal context? Such discussion holds promise for implications for exhibit design and facilitation.

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Design Considerations for A Middle School Computer Science Pedagogical Content Knowledge Instrument

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Abstract: K-12 Computer Science (CS) education is developing rapidly but still lacks a comprehensive measure for CS teachers' pedagogical content knowledge (PCK). We respond to this need by describing the design of a CS-PCK instrument for 'Algorithms and Programming' that measures three broad constructs: (a) teachers' understanding of standards and standards-alignment, (b) teachers' formative assessment practices, and (c) teachers' self-efficacy for teaching and assessing CS.

Introduction and significance of the work

Various theoretical and empirical studies have emphasized the significance of teachers' pedagogical content knowledge (PCK) in determining the quality of instruction and student learning. PCK is defined as teachers' ability to integrate their knowledge of content and pedagogy to guide, "ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1987 p. 9). In K-12 Computer Science (CS) education, the dramatic increase in recent years in the number of CS course offerings and thus the need for qualified CS teachers highlights the need for research on promoting teachers' CS PCK. Early research in CS education focused primarily on developing curricula and software that lower the barriers to computing and inspire student interest, and less on the pedagogy for K-12 CS education. In order to promote and improve CS PCK, it is critical to have an accurate and comprehensive way to measure it that can inform the design of teacher professional development (PD) aimed at improving CS PCK.

The CS PCK literature is currently limited and has mostly been informed by work conducted in other disciplines such as science and math education because key elements of PCK are similar across disciplines. Research in these fields has suggested that teachers have distinct PCK for different topics, resulting in PCK being measured with topic-specific instruments rather than subject-specific ones (Hill et al., 2008). Also, some studies have measured teacher PCK using labor-intensive qualitative methods such as analyzing teachers' lesson plans, and interviewing and observing teachers (e.g., Park & Chen, 2012). Topic-specific instruments and labor-intensive methods have made it challenging to scale measurement of PCK. In CS, one well-known PCK instrument is that by Yadav and Berges (2019) in which teachers are presented with vignettes describing student programming challenges and are asked to select strategies they would use to identify and/or address the challenges. While less labor-intensive and more amenable to scaling, this instrument does not include various common PCK components such as teacher knowledge of CS standards, ability to analyze CS curricula, and formative assessment practices which are aspects of PCK highlighted in the CS teacher standards (what teachers should know and be able to do) outlined by the Computer Science Teachers Association (CSTA, 2020). Further, this PCK instrument does not include measures of teacher efficacy and attitudes as suggested by the literature (Park & Chen, 2012).

To address the abovementioned issues, we developed a CS PCK instrument aligned with the topic of middle school 'Algorithms and Programming' that assesses teachers' knowledge of CS standards and standards-alignment, formative assessment literacy and practices, and self-efficacy for teaching and assessing CS. While not completely comprehensive, our instrument will allow for the measurement of many different aspects of CS PCK within one CS content area and may serve as a model for others developing additional CS PCK instruments.

CS-PCK Instrument design and development

We aligned our instrument with the 'Algorithms and programming' content area and a set of skills and abilities outlined by the CS teacher standards. We expect the instrument to take teachers 30-40 minutes to complete.

Component 1: Knowledge of standards and standards-alignment of CS activities

An important aspect of PCK is a deep understanding of disciplinary standards and ways in which students can engage with standards. It includes an understanding that each standard is a broad statement that can be further decomposed into a set of fine-grained learning targets. This component of our instrument targets teachers' understanding of CS standards (CSTA, 2017) and ability to identify what standard(s) and what aspects of standards a given CS activity is targeting. We developed 3 multiple-choice PCK tasks that provide an example of a CS curricular activity or a CS assessment task and ask teachers to select aligned standards and/or learning targets.

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Component 2: Formative assessment literacy and practices

This component of our PCK instrument targets teachers' formative assessment practices, in particular teachers' ability to (i) select appropriate formative assessment tasks to elicit evidence for (or against) particular student challenges, (ii) design rubrics to evaluate and interpret student responses to CS activities, (iii) predict outputs of student-generated correct and incorrect code, (iv) interpret student work and identify potential student challenges and causes for student errors, and (v) determine appropriate follow-up strategies based on student performance.

We developed a set of 8 PCK tasks involving a combination of selected and constructed responses. As an example, for one PCK task, we present a CS programming task and ask teachers to evaluate three student responses for both correctness and level of sophistication. In another task, we assess teachers' ability to select appropriate formative assessments by presenting a few tasks and having teachers select which student challenges they would be able to identify using the tasks. A third type of PCK task asks teachers to outline aspects of student responses to include in a rubric for a given CS activity. This will provide information on how well teachers are able to identify critical aspects of student work and recognize the importance of rubrics that go beyond correct/incorrect scoring of student responses. Another category of PCK tasks assess teachers' ability to interpret student work and diagnose student challenges on programming concepts. While it is important for teachers to be able to interpret student work, it is also critical that they know what to do with the information, especially if they have diagnosed student challenges. To address this aspect of teacher PCK, we developed three tasks that assess teachers' knowledge of instructional strategies. Each task starts with a vignette describing an instructional activity and targets a specific programming challenge. Teachers need to diagnose the student challenge and then select from a list of pedagogical approaches to indicate which approach(es) they would use to address the challenge.

Component 3: Self-efficacy for Teaching Algorithms and Programming

To create a measure of CS teacher self-efficacy for teaching algorithms and programming concepts and using formative assessments, we selected and adapted existing items from validated surveys that measure teachers' self-efficacy for teaching CS and using formative assessments. An example item for teaching self-efficacy is "I understand the algorithms and programming concepts well enough to be effective in teaching them to my students." For using formative assessment, an example item is "I understand how to diagnose students' understanding of algorithms and programming concepts in all stages of instruction." A total of eight 5-point Likert-type items with four for each sub-component constitute this component of our PCK instrument.

Next steps and future directions

This PCK instrument is part of a larger project to promote middle school CS teachers' PCK by supporting their understanding of CS standards and ability to use formative assessments related to these standards. Next steps on this project include piloting the PCK instrument for validation purposes, analyzing teacher responses to the tasks, and using the instrument as a pre-post-measure of how the project intervention is affecting CS teachers' PCK.

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Emergent Social and Emotional Learning Outcomes through Collaborative Reasoning Discussions

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Abstract: Social emotional learning (SEL) has been identified as critical to meet students' needs. This study examined the potential of a small group discussion approach, Collaborative Reasoning (CR), on supporting students' SEL. Transcripts of debriefings after CR discussions and students' post-study interviews were analyzed for indicators of interpersonal competencies. Findings suggested students benefited in social awareness and relationship building skills after taking part in a series of CR discussions.

Introduction

The global experience of the Covid-19 pandemic has drawn increased attention to the social and emotional learning (SEL) needs of students. Yoder et al. (2020) found that more than two-thirds of states in the United States have identified SEL as a top priority and that more than four-fifths of states said that SEL has increased in importance during the pandemic. At the same time, schools are addressing concerns about academic learning gaps that have arisen even in well thought out pandemic responses (Engzell et al., 2021). It is clear that schools need to consider and implement practices that simultaneously address both academic and SEL needs.

The Collaborative for Academic Social and Emotional Learning (CASEL) has worked to identify programs that best promote the SEL competencies. They recognize that programs may take on different forms: explicit instruction in social and emotional skills and attitudes, interactive teaching practices such as class discussions, and integration of SEL with academic learning (CASEL, 2020). Among the fifty elementary school programs identified by CASEL only five utilized academic integration a means of supporting SEL. Further, only two of those five tracked and found significantly improved academic outcomes alongside SEL outcomes (CASEL, n.d.). These findings suggest that there is a lack of evidence-based programs that use academic integration and interactive pedagogy.

Small group collaborative discussions are one promising option for addressing the cognitive and affective learning needs of students through interactive pedagogy. Social constructivist theory (Vygotsky, 1934) suggests that communities of students that learn from and with each other create positive social structures to support academic learning while also promoting prosocial behaviors. Collaborative Reasoning (CR) is one model of structuring small group class discussions aligned with both academic and SEL goals.

CR is "an instructional method designed to engage elementary school children in group discussions about controversial issues raised in their readings" (Reznitzskaya, et al., 2009). In CR, children read a story and engage in peer-led and teacher-supported interactive argumentation on a Big Question arising from the text. The majority of prior research on CR has demonstrated the positive cognitive outcomes for students experiencing CR, such as enhanced argumentation skills. It is less known, however, whether CR can lead to SEL benefits. Li et al. (2007) identified children's emergent leadership during CR, which is potentially linked to some SEL skills such as social awareness. Lin et al. (2021) found that CR students exhibited greater peer acceptance and less aggression towards others. This study aimed to expand on this developing body of research around the benefits of CR discussions on children's SEL competencies. More specifically, we asked: Can CR support students' development of interpersonal SEL competencies that include social awareness and relationship skills?

Methods

76 fourth-grade children and their three teachers from an elementary school from northwestern U.S. participated in this six-month study. Two groups of five to eight students were randomly selected from each class to be videotaped during the eight CR discussions. The stories used in the CR discussions were deliberately selected to present multiple perspectives for students to consider. This included both fictional scenarios (*Should a mouse dentist help a fox in pain?*) and scenarios about children they might relate to (*Should Tyler be allowed to climb Mt. Everest?*). Transcripts of debriefings after each CR discussion as well as a post-study decision making interview (n = 68), were coded using the indicators of interpersonal SEL competencies identified in the CASEL literature (CASEL, 2021). Due to space limitations of this short paper, a subset of the relevant indicators (one from 'Social Awareness' and one from 'Relationship Skills') are presented in Table 1 below to highlight emergent SEL competencies that appeared during or after the CR discussions.

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Table 1
Coding Scheme: CASEL Indicators of Interpersonal Competency: Social Awareness Relationship Skills

CASEL Indicator	Example
Recognizing strengths in others (Social Awareness)	"I like how Lisa spoke up and also, like, how Ryan used kind of her schema //. And kinda, she took what Danielle thought--it was kind of like she challenged, it kind of felt like she was challenging her own thinking." (reflection)
Resolving conflicts constructively (Relationship Skills)	"They should at least talk it out on a group, respectfully, and nicely, instead of fighting like that or fighting over which one-idea is better. It's better to work to-together…" (interview)

Results

The discussion debriefings and student interviews revealed that CR discussions helped students recognize different perspectives, one essential component of social awareness. For example, a more talkative student shared in the first debriefing: *"…and not interrupting other people even if you're excited about your idea. Wait for the other person to end their idea."* This quote illustrates the student's developing social awareness and the recognition of the need to exercise self-management. As shown in the example in Table 1, students gained greater awareness of their peers' ideas and strengths by actively listening to each other.

Meanwhile, students suggested and implemented practices to foster better group interactions, a critical element of relationship skills. In the second example in Table 1, a student transferred their learning about working as a group to a hypothetical group that was "stuck." Other interviews and debriefings included ideas around effective communication, offering help and support when needed, standing up for the rights of others, practicing teamwork and collaborative problem-solving, and resisting negative peer pressure. One student shared: *"I think they should like put it together and see what the ideas are together. Maybe they can work together to make it all work."* Students that experienced CR were able to move from a largely "I" perspective to greater peer recognition.

Discussion

The findings of this study support and expand on prior work examining the benefits of CR on students' SEL competencies. Although still at the preliminary stage, our analyses revealed a promising confirmative answer to our research question, that is, students are likely to further develop social awareness and relationship skills during CR discussions. This finding is aligned with previous research on emergent leadership during CR (Li et al., 2007) where students successfully managed the group discussion, as well as research on the benefits of CR on students' social relationship with peers (Lin et al., 2021). This finding might particularly interest school administrators and state stakeholders who have been searching for an interactive approach to integrate SEL within academics.

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Designing a Method for Turmoilization of Understandings through Multi-voiced and Multi-contextual Reflection

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Abstract: This study first points out the importance of "Turmoilization of understanding," that is, reconstructing a coherent understanding once established through multi-voiced and multi-contextual reexaminations into a form that incorporates indeterminacy. Then, we propose a method to support the turmoilization of understanding. The pilot study suggests some aspects of the effectiveness of this method. In future work, we will establish a method through a detailed effect examination.

Introduction

Understanding is the act of associating facts and associating pieces of knowledge into a coherent whole (Nickerson 1985). To apply or restructure the understanding in various places, the learner needs to incorporate indeterminacy and conflicts into their understanding, rather than simply tracing the partially consistent theory given by the teacher. In other words, it is necessary to develop relatively subjective and incomplete "personal knowledge" (Entwistle & Smith 2002, Fyrenius et al. 2007). Murray (2006) argues that the uncertainty of knowledge (ambiguity and paradox) is the impetus for creation and that eliminating the uncertainty limits knowledge and makes it unusable. In recent years, it has been pointed out from studies of "Negative Capability" (e.g., Senge et al. 2004) that the incorporation of indeterminacy into understanding is effective for its subsequent utilization and expansion.

Although there are previous studies on the significance of incorporating indeterminacy into understanding, no systematic training method for reorganizing understanding in such a form has been proposed. Therefore, in this research, the authors propose a training method for understanding turmoilization.

Turmoilization of understanding

What does it mean to "turmoilize" an understanding once it has been established? For example, if you have understood what ZPD means through textbooks or lectures. The understanding is coherent, and there are no uncertainties. Here, we are convinced that we have understood it. However, this state is nothing more than an illusion of certainty (Bencze & Hodson 1998). To break this illusion, learners should reexamine the understanding from a perspective other than themselves—assimilated into a textbook, and try to reconstruct the understanding in a context different from the context of the lecture. Due to the reconstruction, the understanding once established becomes a conditional understanding, and other possibilities of interpretation or expansion are embedded into the understanding. It is important to try to eliminate such indeterminacy, but it is more important to keep an understanding as a form that includes such instability. Such an understanding can be an embryo for the expansion of learning. This discussion corresponds to the dual function of the text pointed out by Lotman (1988). That is, Lotman argues that the text comprises two distinct functions: a univocal function that perfectly matches the interpretation of the speaker and the listener, and a thinking device-like function that finds a new interpretation from the disagreement between the speaker and the listener. Turmoilization of understanding can be seen as adding the function of a thinking device to the established univocal understanding.

Designing a method to enhance “Turmoilization of understanding”

Here, we propose a training method for the turnover of understanding based on the above considerations. This method comprised four stages. That is, A. expressing initial understanding, B. mutual commenting activity based on given viewpoints, C. reflection, and D. reconstruction of the expression of understanding. In A, the learner represents their understanding as a written article. In B, the learners are supposed to comment on each other's articles from the given person’s perspective. This can be regarded as an application of the mutual teaching method (Palinscar & Brown 1984) in that the processing performed within the individual is externalized as a role between individuals. The viewpoints are tentatively set as follows to provide a scaffolding for reexamining understanding from the viewpoints of others and other contexts: a) a person who seeks an interpretation of their experience; and b) a person who seeks a means of problem-solving based on the related knowledge. By engaging in this activity, learners are expected to be able to internalize multiple perspectives for understanding and utilize them in internal

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dialogue. In C, the learner examines the comments received from other learners and verbalizes how their understanding has been shaken. Metacognition is important during this stage. Therefore, as a scaffolding, we introduce "reflection from the viewpoint of a commentator." Through this support, students can calmly look back and grasp how their understanding is turmoilized from an objective perspective. In D, the student rewrites his understanding based on C.

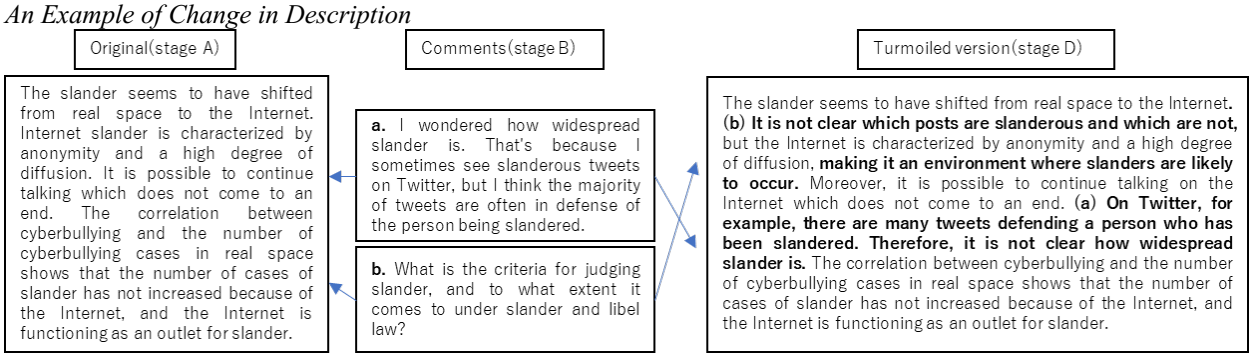
Pilot study

A pilot experiment using this method was conducted with 18 undergraduate students. In this pilot study, the students first read a report on slander on social media, and after a brief discussion, they expressed their understanding of the rules of writing. Afterward, they exchanged documents with other students and conducted mutual comment activities from two viewpoints. The viewpoint set in the experiment was as described above. The subjects then examined comments on their documents. Then, they rewrote their expression of understanding into the form of having a fluctuation of understanding in the expression of their understanding. To simplify this procedure, reflection based on the commentator perspective was omitted to focus on the evaluation of stage B.

This preliminary study suggests that the proposed method may facilitate the turmoilization of learners' understanding. Figure 1 shows how one subject's original description was revised into a turmoilized version based on the comments from two perspectives. The final description of the understanding contained uncertain elements. These are considered effective in expanding understanding and applying knowledge. However, notably, the turmoilized version only incorporates comments as is, and there is limited inter-text interaction between the original description and the comments. To support this, a review from the commentator's point of view in Stage C would be effective.

Figure 1

An Example of Change in Description



Conclusion

In this study, we discuss the importance of incorporating uncertain elements in understanding and propose a method for this. The pilot study demonstrated the partial effectiveness of this approach. In future work, we will establish a method through a detailed examination of the effect of this method.

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Does where you start matter? The interaction between prior knowledge and effectiveness of game-based interventions

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Abstract: The current study investigated how prior knowledge moderated the effects of three educational technologies (*From Here to There*, *DragonBox 12+,* and problem sets in *ASSISTments*) on seventh-grade students' later algebraic knowledge. Pretest scores only moderated effects of *From Here to There*, with larger effects among students with higher pretest performance. Our findings have implications for understanding how prior knowledge interacts with design features within game-based applications to impact algebraic understanding.

Introduction

Algebra is a critical foundation for advanced mathematics, but many middle school students struggle to understand basic algebraic concepts (Kieran, 2006). Much of the difficulty stems from understanding how to create, transform, and interpret statements expressed in standard algebraic notation. Educational technologies use varying design philosophies to address this difficulty and teach algebraic concepts. Some tools, such as *From Here to There* (FH2T; https://graspablemath.com/projects/fh2t) and *DragonBox 12+* (DB; https://dragonbox.com/products/algebra-12), engage students in game-based learning, allowing students to interact with algebraic notations and solve puzzle-like problems in a playful environment. Other tools, such as online problem sets in *ASSISTments* (Heffernan & Heffernan, 2014), provide timely support and feedback on traditional homework problems. However, how the impacts of these different approaches vary with prior knowledge have yet to be thoroughly examined. Understanding whether students with higher or lower prior knowledge gain more from these technologies is important for providing effective and efficient instruction that supports all students. On one hand, students with high prior knowledge may be more equipped to benefit from these interventions compared to students with low prior knowledge (e.g., Swanson et al., 2008; Wood et al., 2020). On the other hand, students with low prior knowledge may have more room for improvement (e.g., Murphy et al., 2020; Ramani & Siegler, 2011). The current study builds on our prior work comparing the impacts of three distinct educational technologies—two game-based applications, FH2T and DB, and two modes of online problem sets in *ASSISTments*—on algebraic understanding among 1,847 seventh-grade students (Decker-Woodrow et al., in prep.). We present preliminary analyses of whether students' prior knowledge moderated the effects of these technologies on students' algebraic understanding.

Method

Seventh-grade students (N = 1,847) were recruited from 10 middle schools within a large suburban district in the Southeastern United States. Students completed nine 30-minute intervention sessions in one of four educational technology conditions (randomly assigned at the student level within each class): FH2T, DB, problem sets with immediate post-response feedback, or problem sets with post-assignment feedback (control condition). Teachers chose the days that their students would work on the assignment in class, and students had two weeks to complete each assignment. The study occurred between September 2020 and April 2021, during the peak of the COVID-19 pandemic in the United States. Prior to the fall semester, students and their families chose whether to attend school 100% in-person or 100% virtually, with the option to change their selection during the year. Regardless of instructional modality, all study assignments were administered online, and students worked individually at their own pace using individual devices. Before and after the intervention, students received a 40-45 minute 10-item pre- and post-test algebraic knowledge assessment (Star et al., 2015; α = .89).

Results

We conducted two, 3-level hierarchical linear models, with students nested within classrooms (n = 127), nested within teachers (n = 34). The outcome variable was students' post-test scores; classroom format (in-person vs. virtual) was a Level 2 predictor, and all other variables were Level 1 predictors. Covariates included race/ethnicity,

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gender, and participation in advanced mathematics classes, an Early Intervention Program, or an Individual Education Plan. Pre-test scores were grand mean-centered, and all other covariates were dummy-coded. The first model revealed a significant intervention main effect ($\chi2(3) = 23.3$, $p < 0.001$), in which FH2T and DB significantly outperformed the control condition on the post-test. Next, a significant interaction was observed between intervention condition and pre-test scores ($\chi2(3) = 11.0$, $p = 0.01$) but only for FH2T ($\gamma = 0.14$), reflecting larger FH2T effects among students with higher vs. lower pre-test performance.

Discussion

After a 4.5-hour intervention, students in both FH2T and DB significantly outperformed students in the control condition on algebraic knowledge, suggesting that game-based contexts may increase students' interest and engagement with mathematics, and in turn, support their performance. However, only FH2T had larger effects among seventh-grade students with higher pre-test performance. One key difference between the two technologies is that FH2T grounds in-game actions in algebraic notations from the start, whereas DB gradually transitions students from pictures of monsters to abstract notation as the game proceeds. Thus, for this age range, FH2T's immediate introduction of algebraic notation may be more effective for those with higher starting algebraic understanding. Future work will explore potential mechanisms (e.g., if prior knowledge promotes greater engagement when algebraic notation is introduced from the start, or if prior knowledge supports connections between gesture-actions and concepts). The findings provide evidence that game-based learning platforms are effective for improving algebraic understanding, but that students' starting points need to be considered.

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Game-Based Punctuation Training to Promote Clause Analysis: A Proposal

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Abstract: High-school-level standardized exams devote 10-15% of its content to grammar and punctuation skills, yet the rules of and best practices for training punctuation are often elusive. We describe an ongoing pilot study where students preparing for the ACT/SAT participate in game-based training sessions for advanced English punctuation. Game levels require active organization of sentences, and students are supported through (1) text from a virtual agent, (2) hints, and (3) a visual cognitive organizer.

Introduction

In this proposed study, we explore the impact of a browser-based ACT/SAT-level grammar training game on students' grammar performance, simultaneously comparing two implementations of a learning support tool. First, for the quantitative component, we use pre-/posttest scores and in-game performance data to assess whether mandatory or optional learning support is more effective and determine what factors contribute most to improving learning and engagement. Second, for the qualitative component, we use gameplay observations and learner interviews to identify patterns in learner confidence and motivation during gameplay, as well as tutors' preferences and questions surrounding the use of games in teaching punctuation strategies to their students. We supplement our investigation with interviews with online tutors working 1-on-1 with the same population of students to better understand tutors' perspectives on student needs and obstacles facing educators concerning the use of such online tools in remote learning settings.

Background

In this study, we investigate the potential of a web browser-based game for training grammar skills at the college entrance exam level (e.g., ACT/SAT). Students often struggle remembering and applying punctuation rules, particularly in complex, multi-part sentences. Practicing using correct punctuation in a computer game with access to sentence organization tools may help students (1) identify patterns in how sentence parts are joined, and (2) accurately complete punctuation-related problems in standardized testing situations.

The general question of providing assessments and learning support in game-based learning has been the subject of reviews concerning best design practices (Ke, F., & Shute, V., 2015). Second, the practical importance of punctuation skills for students preparing for the ACT/SAT is evident in that one fourth of each exam is devoted to English grammar and editing strategies. Game-based learning can reduce anxiety for students (Yang et al., 2018). Wouters et al. (2015) also note that instruction can be helpful in game-based learning, especially when it involves identifying relevant new information for learners. This provides motivation for the qualitative component of this study, wherein we investigate the role instructors (in this case, tutors) can play in game-based learning for their students—if overt instruction by a human is helpful for students during gameplay, then it is important to better understand the perspectives and attitudes of tutors toward engaging with their students in digital game-based learning. Because the ACT and SAT exams are specifically for high school students preparing for collegiate study in the US, this criterion helps limit the subject pool to high school students for whom advanced English punctuation skills are relevant. Recruitment focuses on students either preparing for the ACT/SAT or independently studying English as a second language because these are the two groups for whom the intervention and research questions are most pertinent.

Methods

The learning intervention is a browser-based punctuation training game, wherein subjects create a virtual character and help "decode encrypted messages" by assigning correct punctuation to multi-clause sentences. Each level comprises a single sentence divided into four parts (Figure 1), in-game support such as pop-up text hints (Figure 2), and an organizer tool displayed as a screen overlay where subjects can label sentences and see common punctuation patterns as a reference while solving each level (Figure 3). As a web application, students can access this through most browsers on most computers, tablets, and smartphones, but subjects are recommended to use computers or Chromebooks or tablets while completing the 21 game levels for this study, to ensure consistent performance by the software. Learners are individuals preparing for the ACT or SAT exam,

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or are studying English as a 2nd language. Learners are excluded if they cannot complete the intervention either in a session with their tutor or independently outside of tutoring sessions (they must not complete only half of the intervention outside of session, for example). Learners are also excluded if they are below grade 9.

There are two types of data collection. First, learners take a pre-test (10 questions) in ACT/SAT English format, and after learners complete 21 game levels, they are given a post-test. Pre-test and post-test scores are saved automatically, as well as game performance data for each round they complete, including how much time they spend on certain game-tasks, how many times they answered correctly or incorrectly, and how long they viewed feedback text or the organizer tool. The second type of data collection is an open-ended survey for learners and informal interviews with professional online tutors who have a chance to use the intervention with their student(s). These are brief interviews with open-ended questions where tutors can share their general thoughts and experience with the intervention and related learning games. Pre-/post-test data and in-game performance data are all collected automatically through the RPG Maker MV game engine.

Recruitment of learners began in July, 2021 and continues on while learners participate in the intervention. This depends on learner availability. Learner surveys will be administered after learners finish the main portion of gameplay (21 levels + post-test). Informal interviews with tutors will take place sometime convenient for them after their students have completed the intervention (1-3 weeks after).

Analysis

Quantitative data is coded anonymously, downloaded, and analyzed using IBM's SPSS software. Survey and interview data is coded using a qualitative framework. For the qualitative component of this mixed methods study, main themes that arise through analysis of interviews will be summarized and presented to subjects who participated in the interviews by email within 1-6 months of the completion of research procedures. Subjects will have the chance to voice agreement or disagreement (text responses by email) with how their stories will be represented and the researchers will update qualitative summaries accordingly. Like all other data in the study, this will be stored using the coded name of the participant and under the same password protection.

Finally, we will continue to explore results to identify game performance and affective patterns as students engage with the game. By comparing data from the two groups, we address whether the delivery of learning support made an impact on how students engage with the game. We will also address to what extent student interaction with in-game support features interacted with learning outcomes or affective states during gameplay, such as engagement and confidence level.

Table 1

Post-test score improvement and number of correct submissions and toggles of the organizer.

Participant	5	2	7	8	1	4	6	9	10	3
Posttest - pretest score	-3	-2	-2	-1	0	2	2	2	2	3
Correctly completed organizer	3	17	12	15	13	21	15	21	20	20
Organizer accuracy	63%	51%	54%	83%	26%	74%	40%	50%	78%	78%
Times organizer toggled:	48	150	130	121	89	101	81	118	103	155

Note. Post-test and pretest scores are the number of correct questions out of 10.

As seen in table 1 above, preliminary results from our first 10 participants point to a general trend where students showing score improvement on the post-test (4, 6, 9, 10 and 3) completed the organizer for more game levels and tend to have higher organizer accuracy overall. However, these students are not always the ones who toggle the organizer most often (row 4). How accurately students complete a sentence-part organizer support tool with higher accuracy is a better predictor of SAT/ACT-level grammar accuracy improvement than how often learners access the support. When designing similar learning interventions, designers may consider incentivizing accuracy and full completion of syntax-focused learning support to enhance learners' score gains.

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Intergenerational Conversations Through Redesigning Tabletop Games: Playing, Designing, and Learning with Canadian Families

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Abstract: In this poster, we present our study of the activities for families in Canada to redesign tabletop games, reflective of their interest and culture on their own time during the global pandemic. We collected data through online communications (e.g., video recordings, games). We describe how they expressed what matters to them individually and collectively.

Research has shown that game play and design position learners as individuals who engage creatively and critically with disciplinary ideas. Many tabletop games are played across generations (e.g., *Mancala* in Africa), and are reflective of cultures and ways of knowing, learning, and being. Using movements and gestures with physical objects also makes tabletop games suitable for supporting communication among players of different ages and linguistic backgrounds (Kim et al., 2021). Our research explores how tabletop game redesign activities can help participants invent ways to draw on and connect with intergenerational differences and cultural practices, by seeing individual differences as resources for social learning (Ladson-Billings, 1995).

Cultural Practices and Tabletop Game Redesign

Our work is supported by the cultural-historical significance of tabletop games. Crist et al. (2016) described how board games were used to facilitate interactions "across kinship, ethnic and socio-economic boundaries" (p.181) and were adopted into varying societies by being decorated and reimagined appropriately to their cultures. While designing games engages learners in inventing alternative ways of knowing (Civil, 2002), *re*designing activities could enrich linguistic and cultural diversity. In a study of students' redesigning a game for mathematics learning (Kim et al., 2021), students demonstrated their reimagined play by adopting rules from the games from their cultures and showed that culturally-relevant games have the potential to bring historical and cultural contexts to disciplinary thinking (e.g., mathematics; Bayeck, 2018). Historical and school game redesign work resembles how culturally sustaining pedagogy seeks cultural and linguistic pluralism in schools (Paris, 2012, p. 95), and may help educators capitalize on learners' diverse resources. Learning should be seen as critically enriching strengths, moving away from replacing deficits and aligning with linguistic and cultural hegemony (Lee & Walsh, 2017). Here, we see cultures as meanings and practices of the families and other social groups they may belong to, inherited or (being) formed individually and collectively.

Research Design

A pilot study was conducted through distant video communications with Canadian families during the global pandemic. The research team created a general guideline for their game redesign process. We explored the families' approach to the project, the game they selected, their ideas for designing their own game, and their experience of game redesign as a family. They provided written descriptions and visual data from their in-progress designs and final artifacts. In our analysis, we reviewed our notes and recordings of the online meetings and identified how they interacted as families and how redesign ideas formed. We examined their artifacts (i.e., games, play-recordings, photos, blog) to understand the connections made with their different interests and practices.

Tabletop Game Redesign by Families

Many adult participants intuitively identified the shortcomings of existing games, compared cultural gaming practices from their youth, and reflected on intergenerational relationships and games they play in different occasions. On the other hand, the game design process and the redesigned games did not exhibit overt cultural markers. Instead, we observed that games and game design practice could allow cultures to exist and influence action and decision-making in the process. Through this process, the families may engage in understanding their own cultures and what matters to their family members more deeply.

Understanding and expanding a child's cultural practices

Some families focused on understanding and expanding a child's practices through the process. For example, one family (Caucasian) redesigned the card game *Love Letter,* led by Ellie (the 5th grade daughter), "to correspond to

[her] current favourite book series, *Warriors* by Erin Hunter" (blog post). In our conversation, they discussed how there are parallels between the life represented in the renaissance courting theme of *Love Letter* and the hierarchal nature of the *Warriors* series' characters: "((In)) *Warriors* there's different ranks. There's a leader, a deputy and medicine cat or you're, um, kind of an apprentice" (Ellie). They crafted cards to play-test the game as family to see how the game works and to adjust rules. Supporting the redesign of the card game and playing the redesigned game provided an opportunity to learn about the literature that Ellie was invested for this family. Ellie was also motivated for the possibility of contributing to the *Warriors* online community. After the redesign was complete, the family created a blog page to share with the *Warriors* community to download the cards and the rules.

Exploring the different interest of all family members and engaging in intergenerational conversations

Exploring the different interest of family members was another pattern. A family with Chinese background redesigned *The Game of Life* to make it more relevant to their current and future experiences. This game was of interest to the two daughters in grade 5 and 7, Alia and Eira. While brainstorming, they pointed out how the choices and life paths in this game do not resonate with their perspectives. For example, they considered the careers in *The Game of Life* "outdated" and discussed a collection of careers to add to the game. The process of choosing the careers sparked conversations through which the parents got to know the careers the kids knew about and introduced other careers that they did not know. They also decided to create a board that reflect each family member's interest and put all four boards together to create the game. "Originally, all of us had different ideas and now we could pare it down into more of a team effort.... I think it was interesting because each of us had a role to guide one another... how we want to start this ((the game)) and how to end this" (Hailey, mother). Across the boards, they explored how action and chance cards could be similar but also different. Through redesigning the game, they had the opportunity to learn and appreciate each other's interest and find ways to make them as a coherent whole. They underscored how each tried to attend to others' viewpoints and what they valued.

Discussion and Conclusions

We explored how families invent ways to draw on and connect with intergenerational differences and cultural practices while redesigning tabletop games. We observed that the families focused mainly on expressing their interest through the design while noticing invisible boundaries between them. Without explicitly exploring their cultural practices, families expressed what mattered to their members individually and collectively. They had opportunities to value and support the members' interest, while the cultures outside of their family boundaries (e.g., fan-based practices, other cultures) contributing to their practices. They did not see their current game design as the end but as having the potential to evolve and expand. They demonstrated the value of redesigning an existing game by questioning what is depicted as dominant, taken-for-granted practices in the original game, which shows the glimpse of family's developing critical consciousness. In our pursuit of redesign activities, we see the significance in: (1) identifying traditional and evolving ways of acting in diverse social and cultural systems; (2) creating activities to develop critical consciousness; and (3) positioning diversity as resources for interdependence (Joyce, 2017; Ladson-Billings, 1995; Paris, 2012). This pilot study showed the tabletop game redesign as an initial step to deepening intergenerational conversations and develop critical consciousness as families.

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International Society of the Learning Sciences

Categorization and Framing Teaching Discussions in an Online Physics Classroom

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Abstract: We analyze written discussions of in-service high school physics teachers as part of the coursework of an online Master in Physics with Teaching Emphasis program. We categorize the form and scope of teaching talks made in response to course structure using the theories of community of practice and framing: *Strategies for Teaching Math in Physics; Integration of MPTE Course Content into High School Courses; Pedagogical Strategies for Teaching Physics.* We discuss the instructional implications.

Introduction

Physics Education research (PER) has led to the development of research-based curricula such as tutorials that can be directly implemented in physics classrooms by instructors. However, many of these efforts historically do not include pedagogical insights of instructors in the development process. (Elby & Yerdelen-Damar, 2020). When teachers dialogue around teaching practices, their classroom experience could provide a valuable perspective in considering how curriculum is developed and implemented. This provides a venue for teachers to form a community and discuss the shared goal of teaching practices in high school physics curriculum aligned with the definition of the community of practice (Wenger, 1999).

An online Master in Physics with Teaching Emphasis (MPTE) program has been developed to strengthen high school physics teachers' content and pedagogical knowledge. The course work includes 6 core courses. A central part of each course design is participation in weekly online discussion boards which gives rise to teaching discussions. We categorize teaching talks and contribute examples of teachers' discussions by exploring how teachers share about their approach to teaching physics concepts in their own high school classrooms, the mathematical concepts that is used in teaching physics, pedagogy, and how to connect advanced math and physics topics that they learn as part of the MPTE program into high school classrooms.

Structural factors can promote classroom community formation and participation in practices (Irving & Sayre, 2014). In our community, we observed that the course structure (content of lectures and prompts from the course instructor embedded in the video lectures) tends to inspire different forms of teacher talk. For instance, physics lectures focused on the 'advanced math content' tend to fuel more discussion related to *Teaching Math in Physics*, while prompts presented in the video that asked 'How do you teach this physics topic in your class?' prompted more discussions related to *Pedagogical Strategies for Teaching Physics*. The theme related to *Integration* was represented in most of the weekly discussions, as the MPTE course content design is intended to be relevant to the teachers' teaching topics (See Table 1).

Methods and Context

In this study, we focus only on teaching discussions that form as part of the online problem solving discussion forums of a 12-week Electricity & Magnetism for Educators course in the MPTE program. Each student is required to make at least two posts weekly. Students in this program are mostly in-service high school teachers. Of the 38 teachers from Spring 2018, 22 participated in the study. Two independent researchers first read the posts followed by discussions. Analysis of the first 5 weeks with existing teaching talks revealed commonalities among posts, which led to development of an initial coding scheme. Another round of analysis of further weeks revealed that some of the posts that overlap in the discussion theme are different in scope.

Framing provides a window to better see the scope of the practices in a situation based on the expectation of 'What is going on here?' (Tannen, 1993). Prior study has applied framing to problem solving situations, where a student in a narrow frame tends to focus on a task at hand, whereas a student in an expansive frame is more open to take a general approach (Irving et al., 2013). Taking the guide from the study by Irving et al. (2013), we characterized expansive vs. narrow discussions in the teaching context. Narrow teaching discussions describe activities that are more focused and implemented to the 'in the moment' of the classroom, such as when teaching a math skill in a specific way to make it understandable for the students. On the other hand, expansive teaching discussions describe teaching practices that can be applied across multiple classroom contexts (e.g. other physics classes), such as teaching students to use mathematical equations in physics.

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Table 1
Teaching discussion themes and frames discussed by teachers

Theme	Narrow Scope	Expansive Scope
Strategies for Teaching Math in Physics	Discussing teaching a specific math concept/skill needed in physics	Discussing teaching a math concept/skill applicable to various physics concepts
Integration of MPTE Course Content into High School Courses	Discussing boundaries for curricular expectations for a specific course/level	Discussing whether a broad physics topic is represented in the curriculum teachers teach
Pedagogical Strategies for Teaching Physics	Discussing a specific technique to address student confusion of a particular physics concept	Discussing techniques for supporting student learning of physics that can be applied throughout the broad curriculum

Findings and examples

For the theme of *Strategies for Teaching Math in Physics*, in narrow discussions, teachers tend to identify specific mathematical skills and concepts that students must utilize while studying physics. Teacher 1 addresses student difficulty with a particular mathematical concept (dot product) used in physics. The teacher suggests that teaching students to use the relevant trigonometric function rather than defining the 'dot product' has avoided their student confusion. We classified this comment as a narrow scope as it is focused on teaching a specific math skill. The teacher is not discussing a broad teaching strategy of how to address a mathematical approach but instead focusing on a small topic of how to teach 'dot product' to students. The teacher has chosen to 'neglect' addressing the comparison of 'dot product' to 'cross product', which reinforces the limited scope of the teaching practice, as making this connection for students would have been an expansive approach.

> *Teacher 1: I have so far neglected mentioning 'dot product' versus 'cross product'… and I've never really had a whole lot of confusion from the students based on that idea.*

In an expansive discussion, teachers request for or discuss with each other general strategies for teaching math in physics. Teacher 2 discusses a general approach for teaching math skills in physics problem solving with variables (e.g. alphabet soup) vs. numbers. The teacher suggests a flexible teaching method of providing some numerical examples initially and then transitioning to more symbolic examples. We classified this comment as an expansive scope as it can be applied to different physics problem-solving situations.

> *Teacher 2: I too prefer the alphabet soup, but my students are not always with me. I generally start with problems with numbers and angles, so that my students can get comfortable with the process and then do some with just the alphabet.*

Conclusions and implications

The categorization scheme presented in this study can be useful in analyzing discussions among teachers in a learning community. Additionally, the examples suggest that teachers make intentional decisions about utilizing a particular scope of their instruction in the classroom to support their students' learning process. The reasons behind these choices can inform and aid in the development of physics curriculum for high school students that which portions of it might benefit from a narrow or an expansive perspective.

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Developing Dynamic Dashboards for Classroom Orchestration

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Abstract: Classroom orchestration is a multifaceted pedagogical challenge, requiring teachers to simultaneously manage activities across multiple social levels and under various constraints. Teacher dashboards are commonly developed tools to aid orchestration; however, many fall short in real-time classrooms. To address this impediment, we used participatory design sessions with teachers to better understand their needs, based on which, we plan to build a dynamic dashboard with real-time actionable metrics.

Introduction

Classroom orchestration is the process of managing the flow of activities, student configurations across multiple social levels (individual, group, and class), materials, and class progression within a learning environment during its enactment. The need to monitor these various facets of the classroom in real-time and providing both conceptual and logistical support is challenging and places a heavy load on teachers (Dillenbourg et al., 2009). Dashboards have seen growing interest as a tool that can potentially reduce orchestration load as it provides a lens into classroom activity and progress, which is helpful because teachers cannot simultaneously attend to all groups in their classrooms (Matuk et al., 2015).

Teacher dashboards typically present data at three levels: progress of individual students, progress and participation patterns from groups, or trends across the whole class (Tissenbaum & Slotta, 2019). Different performance metrics can be useful for each level, e.g., participation metrics can provide insights on which group members are contributing to discussions (Martinez-Maldonado, 2019), whole-class metrics can alert the teacher which students need help, and individual progress metrics can provide insights if a particular student is off task or has a question (Dickler et al., 2021). Providing a lot of information while the class is in progress can overwhelm teachers and not all the information is always relevant (Tissenbaum & Slotta, 2019). We propose a dynamic dashboard that is customizable and addresses the changing needs in a classroom.

We conducted participatory design sessions with teachers to better understand their orchestration needs and inform our resulting dashboard designs. Participatory design necessitates teachers' involvement in the development of the technologies they will be implementing in their classrooms to ensure its usefulness and usability (Holstein et al., 2019; Matuk et al., 2015). In the first study, we asked teachers about what types of information might be most useful to them. We created mockups of a dashboard interface based on their input, and in the second study, showed the teachers the mockups and asked for their feedback on specific features.

Participatory design studies with teachers

Study 1

Our objective in the first study was to understand what dashboard features and progress metrics teachers would be most interested in, given different classroom situations. Eight middle school science teachers from the Midwestern U.S., with teaching experience between 9 and 34 years, participated in the initial study. It was conducted via Zoom over three sessions, each lasting two hours, with no more than three participants.

Teachers were presented with three scenarios focusing on: *individual students* (e.g., progress, focus, etc.), *groups* (e.g., participation patterns or off-task discussions), or the *whole class* (e.g., covering challenging material) and what information would allow them to best refine their classroom strategies. After the scenarios were verbally explained to the teachers, they placed the functionality they found most useful for each scenario on a blank tablet template. Researchers were available for further explanations on functionalities or scenarios.

Results

The teachers chose a maximum of nine functionalities across the 20 dashboards they created across different scenarios, including both *features* (e.g., messaging students) and *metrics* (e.g., question analysis). Different teachers chose different metrics depending on the presented scenario. For example, 100% of the teachers

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thought a *close-ended question analysis* metric would be useful in the whole class, compared to 33% in the group, and 57% in the individual scenarios respectively. All the teachers chose the *student participation in groups* metric for the group scenario but none chose it for the individual and class scenarios. A 0% or 100% consensus was found in only nine out of the 45 possible functionality-scenario combinations (20%), together with a constant shift between selected functionalities, highlights the need for a dynamic dashboard.

We identified six key metrics based on the teachers' responses, i.e., at least one teacher requested a particular metric across all three scenarios, or more than 50% of the teachers requested that metric in at least one scenario. They are: (a) *Class Status* (a high-level insight on what is happening in the class as a whole), (b) *Group Progress* (which group is at which point in the activity), (c) *Group Participation* (amount of individual participation in group discussions), (d) *Close-ended Questions* (an overview of students' responses to close-ended questions (e.g., multiple choice)), (e) *Open-ended Questions* (insights on how students are utilizing science ideas and concepts in their essay writing, using different NLP techniques), (f) *On-task/Off-task Behavior* (granular insights on which students are off-task). As we need more time to determine how to capture off-task behavior (f), we used the first five metrics (a-e) to create low-fidelity dashboard designs.

Study 2

The aim of our second study was to get teachers' feedback on the initial dashboard designs based on the results of Study 1. Study 2 was conducted in-person with six teachers, four of whom had participated in Study 1. All were middle school science teachers in the Midwestern U.S. who had taught science for 7 to 34 years. We presented teachers with five dashboard designs visualizing information on class status, group progress, and individual progress. We found that teachers had differing ideas about the relative importance of specific information, in terms of when the information will be most useful and how they will use it in the classroom. Based on the teachers' feedback, we have been working on a generalizable framework that includes *what* information should be displayed, *when* the information should be displayed, *how* to visualize the information (charts, sounds), and *who* should have access to the information (teacher, assistant, etc.). This will enable us to design dashboards that are dynamic and customizable by teachers.

Conclusion and Future Directions

Our studies emphasize the importance of participatory design to co-create technologies that teachers would actually use in their classrooms and the need for a dynamic dashboard that teachers can customize to their specific needs. Future studies will focus on building a dynamic dashboard with the identified five key metrics (Class Status, Group Progress, Group Participation, Close-ended Questions, and Open-ended Questions).

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Exploring Epistemic Network Analysis Diagrams as a Tool for Developing Teacher Noticing of Classroom Dialogic Features

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Abstract: Our designs for teacher learning focus on generating representations that help teachers attend to how they structure opportunities to learn for students of color. This paper explores the affordances of Epistemic Network Analysis (ENA) for generating representations of epistemic networks in science class discussions for teacher reflection on their facilitation. We examine representations of data of two secondary science teachers and discuss the possibilities of ENA for mapping the intellective nature of science discussions.

Our work takes the view that equity can take shape in micro-level interactions in classroom dialogue, and teachers play a critical role in providing robust opportunities to learn science, particularly in classrooms that serve students of color. There is a growing body of research that highlights the impact of dialogic pedagogy on student learning (e.g., Clarke et al, 2015). However, large-scale surveys of classroom dialogue highlight the scarcity of these forms of pedagogy in low-performing schools that serve minoritized children (Kelly, 2008). In this paper we ask, *how do we build teachers' noticing of how their classroom discussion facilitation shapes opportunities to learn for their students?* This paper proposes an amalgamation of the techniques of Epistemic Network Analysis (ENA) by Shaffer et al. (2016) and Hennessey et al.'s (2015) analytical frame for decomposing classroom dialogue, to generate representations of classroom discussions that afford possibilities for teachers to notice (e.g., van Es & Sherin, 2006) how dialogue is deployed in their classrooms.

Theoretical Frameworks

ENA helps identify and quantify connections among elements in coded data and represents them visually and statistically through network models (Shaffer et al., 2016). This is useful for data where patterns of associations between different elements of the data may be meaningful in illuminating the extent to which the dialogue is academically productive. The ENA representations, therefore, offer a powerful way to help teachers develop their professional vision (Goodwin, 1994) for productive dialogue. To codify the classroom discussion data for ENA, Hennessey et al. (2015) offer a Scheme for Educational Dialogue Analysis (SEDA) which speaks directly to our interest in academically productive dialogue. Their scheme helps classify parts of discussion data or "communicative acts" according to their dialogic function.

Methods

ClassInSight is a study of teacher professional learning around classroom dialogue. It is a research-practice partnership with two school districts in north and south county San Diego, which serve a diverse (ethnic and linguistic) population of students. Science classroom discussions of two high school science teachers were audio-recorded, transcribed, and verified. These lesson transcripts were then segmented into turns and coded by a team of three researchers using a coding scheme adapted from SEDA (Hennessey et al. 2015). Each pair of coders achieved a Cohen's Kappa of .7. Data were segmented into sequences using Wells and Arauz's (2009) notion of a sequence as an intermediate unit of analysis between an episode and an exchange. The coded files were then appropriately formatted according to the recommendations of Shaffer et al., (2016) and uploaded to the webkit. 'Whole conversation' was used instead of a 'moving stanza' because all associations within a given sequence were meaningful.

Findings

ENA in conjunction with an adaptation of SEDA was found to be useful in developing coarse representations of associations between dialogic moves in classroom discussion and to also contrast representations within and between teachers. This is illustrated through a comparison of two teachers' lessons below.

Illustration: Teacher H and T's lessons

Teacher H's lesson represented in Figure 2(a) was a guided activity to make different structural isomers of a molecule using manipulatives. Teacher T's lesson represented in Figure 2(b) was also a guided activity to identify

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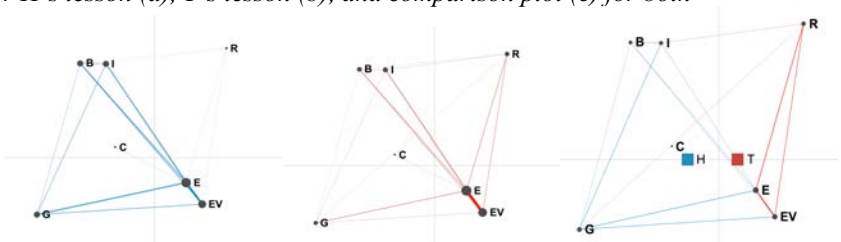
types of rocks. So the students were prompted a lot to share their ideas (classifications of rocks) which were evaluated by T. Figure 2(c) is the comparison plot which is Figure 2(b) subtracted from 2(a)

The representations show that both classes had complex interactions with frequent co-occurrences of E(expressing or inviting ideas)-I(invitation for elaboration or reasoning), E-B(building on ideas), and E-G(guiding the discussion) pairs along with E-EV. However, we can also see from the comparison plot that H engaged in more G moves as they helped students construct various structural isomers. While T engaged in more frequent R (reasoning) moves as they helped students explain their reasoning for their classification of different rocks and evaluated the reasoning. Therefore, these diagrams are effective in characterizing how dialogic moves were deployed by them to help students engage in specific kinds of learning experiences.

Figure 2

ENA diagrams for H's lesson (a), T's lesson (b), and comparison plot (c) for both



(a) (b) (c)

Discussion

Such ENA diagrams can highlight for teachers how codes co-occur in their discussions and, therefore, help them reflect on the extent to which they align with their objectives and/or on how they *think* discussions operate in their classroom. Hypothetically if teacher H intended to use this classroom discussion as a way to gauge students' comfort with the concept of isomers, then the extent to which they were guiding the students instead of observing them would be a cause for reconsideration of their approach to this discussion. Thus, there is ample possibility for the ENA diagrams developed by facilitators of teacher professional development to help teachers notice dialogic features of their classroom which structure the learning in it and instigate dissonance (Clarke et al., 2020) for the teachers, which could be triggers for reflection, learning, and refinements in dialogic practices.

Conclusion

This paper sought to offer a possibility of using the techniques of ENA and a coding scheme for classroom dialogue to help scaffold teachers' noticing of how dialogue operates in their classroom discussions to structure learning experiences. Further inquiry in this regard is necessary but the approach appears to provide promising opportunities for teachers to reflect on how they use classroom dialogue to structure students' opportunities to learn.

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Trajectories of Practice: Characterizing Students' Decision Making Agency in Science Investigations

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Abstract: An aim of science education is for students to be able to participate in science by making adaptive local decisions that interconnect and integrate scientific practices. We build towards this goal by articulating a *trajectory of practice* -- a series of moves students make to pursue the scientific aims of their investigations, and showing how this description can be used to investigate the role of curriculum in supporting students exercising decision making agency.

Motivation for Trajectories of Practice

Describing science as a "practice" is an alternative to depictions of science as an ordered list or cycle of activities—e.g., "the scientific method" (Ford, 2015). While scientific practice is composed of component practices, expertise entails more than just an ability to successfully perform these components in isolation. Practice foregrounds the decision making processes required to "adopt" and "adapt" component practices to the needs of specific contexts (Manz, 2015), a kind of knowledge that Ford described as a "grasp of practice" (Ford, 2008).

In this view of scientific practice, agency is central. In part this is because of the inherent uncertainty in the activity of science, which is often captured in spatial metaphors that describe practice as unfolding in a "field" or "space" of possibilities (Pickering, 1995; Gooding, 1990). Navigating through this space requires scientists to engage in reasoning about where they are, where it makes sense to go next, and how such choices will be viewed by the scientific community. In this way, the path through this space can be considered a unique trajectory that emerges as scientists encounter and respond to the particular difficulties and opportunities that they encounter as they attempt to satisfy their goals.

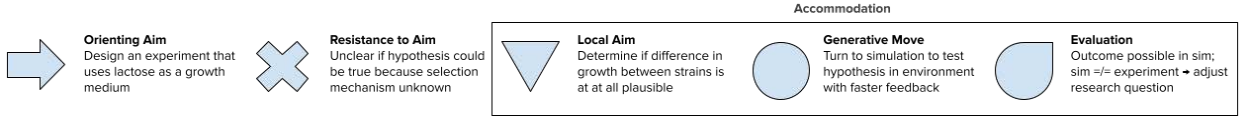
Pickering (year) described these choices as "free moves", expressions of human agency made by scientists to pursue the aims of their investigation. These moves, or accommodations, are shaped in response to resistances to achieving scientific aims. We propose the idea of a trajectory as a way to characterize students' scientific decision making as enacted in context, over time.

A trajectory of practice is guided by an orienting aim that describes students' intentions for how to carry out their scientific investigations. Descriptively, orienting aims are useful for cohering accounts of students' decision making in science investigations. They also situate resistances as *resistances to aims*, which is aligned with Pickering's (1995) description of the Mangle, and is implicit in the account Manz (2015) gives of student activity with the wild backyard. For example, when Manz described "the changing nature of plants" as a resistance it is as a resistance to "students attempt(ing) to draw conclusions about them." (Manz, 2015, p. 104)

The trajectory further describes a series of accommodations to resistances, comprising local aims, generative moves, and evaluations (see Figure 1). Each of these components foregrounds student decision making. Local aims describe students' bids to overcome a resistance, generative moves represent the construction of ideas or practices adapted to meet the local aim, and evaluation represents students' assessment of how well the move served to accomplish the local aim and accommodate to the resistance.

This work provides a way to identify and characterize student agency in scientific investigations, a necessary precursor to understanding the instructional and curricular features that support it.

Figure 1
Trajectory of practice constructs



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Study Context

This research takes place within an introductory-level undergraduate biology laboratory course. The central design emphasis is on students conducting their own investigations, in groups of three to four, by designing experiments with organisms, and conducting simulation trials within an agent-based computer model (Gouvea et al., in press).

Using Trajectories of Practice to Unpack Student Activity: Two Case Studies

In this poster we illustrate two episodes of student groups' scientific activity using trajectories of practice. In the first episode, Group A works to design an experiment. We describe how their moves, such as turning to the simulation to validate their ideas when stuck, sustains their design work in the face of theoretical and practical challenges to their initial experimental proposal. In the second episode, Group B works to make sense of unexpected experimental data by replicating their experiment on a computer simulation. We describe how their moves, such as carefully calibrating the simulation *inputs* to match their wet-lab design, leads to them expanding their conceptualization of the study system, through reasoning across and within these two data production modalities (experimental design and computational model).

We then show how this description of decision making activity can be used to identify features of the curricular implementation which contributed to sustaining Group A's engagement in conducting the design of their experiment, and to expanding Group B's conceptualization of the system.

Discussion

This work is an initial attempt to expand the research on students' decision making agency in science investigations. Our focus is on identifying evidence of students making local, adaptive decisions that contribute to a sustained engagement in making progress towards their own research aims.

We see this characterization of student-driven trajectories as an important refinement of resistance and accommodation as a dynamic articulation of emergent, locally adapted scientific practice for two reasons. By making orienting aims an explicit construct we can consider how resistances *to aims* intersect with student framing of lab spaces. For instance, if a student frames the lab as about demonstrating a fact about how plants grow, and sets their orienting aim around doing so, then resistances caused by unexpected patterns in plant growth might prompt an accommodation of searching for experimental error, rather than developing more productive sensemaking practices (Hayes, 2021). Furthermore, expanding accommodations to include student decision making around local aims, generative moves, and evaluation provides researchers with a concrete way to identify evidence that students are engaging in a dialectic of construction and critique that comprises adaptive scientific practice (Ford, 2008; Manz, 2015). With these markers identified, researchers can investigate the role of curricular enactment in supporting such student activity.

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International Society of the Learning Sciences

Using Participatory Software Design to Reconfigure Traditional Power Asymmetries Between Dominant School Systems and Nondominant Families

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Abstract: We describe an iterative participatory development of a software application based on Ishimaru's (2019) model of equitable collaboration between nondominant families and dominant school systems. We share (1) findings from our qualitative analysis and collaborative software design with two family focus groups, (2) the design process that led us to the development of a family notebook to balance traditional power asymmetries, and (3) the current version of the software design.

Introduction

In this paper we present the current results of an iterative participatory-design research project (Bang & Vossoughi, 2016) and social design experiment (Gutiérrez & Jurow, 2016). Our collaborative design centered nondominant families as experts (Barajas-López & Ishimaru, 2020) in the design of a software application aimed at facilitating communication between families and early childhood settings during their children's behavior support process. Given the historical inequities between nondominant families and dominant school systems, our design was grounded in Ishimaru's (2019ab) work on equitable collaborations in an attempt to address the power asymmetries between nondominant families and dominant school systems.

Participants

We collaborated on the software design with 10 families. The family participants spoke English and Spanish. They identified as white, Black, Latino, and Hispanic. Nearly all of their children had an individualized behavior support plan and several had already been suspended or expelled from preschool or other early learning settings. The final design of the software application was grounded in the expertise of Black and Latino families.

Methods

As part of our participatory design research process, we conducted and recorded data from two different focus groups (FG1 and FG2 hereafter); those involved qualitative, survey, and informal methodologies as part of our initial data collection. We recorded, transcribed, and coded conversations between family members as well as collected design artifacts. As part of our design process, we asked families to respond in a semi-structured interview and discussion format to questions about their partnerships in early childhood programs. The families made it clear to us early on that given their inequitable experiences with school systems, the software had to facilitate communication and position families as equal participators in their children's support process. Talking about their past and present experiences families expressed feelings of shame, fear, and guilt when hearing negative and judgmental communication about their child. Thus, they emphasized the importance of positive, reciprocal, and human centered communication, i.e., communication that is compassionate, respectful, and strengths-based. Families also expressed a clear desire to learn about their child's behavior and the behavior support process from professionals in their child's early learning program, while also being able to provide their own expert feedback to program staff. Lastly, families wanted to contribute to and be acknowledged as part of their child's support process. When asked questions about technology, families requested a practical communication system allowing for transparency and quick access to their child's process.

After analyzing the initial data from FG1, we set out to translate our findings into several graphic versions. We arrived at a family-school notebook as a design which addressed reciprocity, family contribution as well as access and transparency. To confirm whether we correctly interpreted the family voices, we brought the first family notebook design a few months later back to the families from FG1 for member check as well as to some new families. We asked our FG2 to further help clarify and improve on the design. For our design activity with families in FG2, we printed out the first family notebook design and then asked families to write, mark, and place stickers indicating questions, approval, or disapproval.

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Results

Nondominant families in the focus groups were much more likely to share negative experiences about their relationships with their children's early learning programs. Their experiences had a profound impact on our design thinking. Two questions that arose in response were, (1) how can software design help ameliorate the trauma and stress of nondominant families in dominant school systems? And (2) how and what aspects of the traditional power asymmetries could we shift (or balance) through collaborative software design and architecture?

In response to our first question, the main aspect of the family notebook that attempted to ameliorate stress was an intentional slowing down of the communication process. Unlike common formats of communication made available through messaging apps (i.e., immediate, instant, and dialogic), the design of the notebook asks families and teachers to leave notes for each other asynchronously (family members can also communicate with each other). Once logged in, for a family member to see teacher notes and vice versa, family members must leave their side of the notebook by toggling a switch to the teacher's side of the notebook.

To address the notion of power in our design, we analyzed our qualitative data through the lens of Ishimaru's (2019a) framework of equitable collaboration. A major feature that addresses the main *dimensions of equitable collaboration strategies* allows family members to invite other family or community members e.g., advocates, translators, or community elders to be part of the family notebook with access to all documentation as well as the ability to communicate with the teachers and each other. The ability of families to add as many members of their family, friends, advocates, or community members to the notebook as needed is directly linked to existent power asymmetries. This design move inherently shifts (1) the intervention level from individual/parent/student to a collective expertise, family, and community level. (2) Moreover, the shared space created by the notebook shifts the unilateral power held traditionally by school systems towards shared and relational power by making transparent the documentation of the child's support process to the families and those members of the notebook that families choose to add. In the same context, (3) the notebook design shifts the directionality of possible partnerships between schools and families from a historically unidirectional to a reciprocal mode of interaction.

Conclusions

The family notebook design is currently in its next phase of user testing. There were two main design components that we translated from the input by our family experts into a core feature of the notebook which addresses equitable collaborations. The one feature we wanted to focus on in this short paper was the ability of families to add as many collaborators to their notebook as they wanted. It is a subtle feature, not explicit, yet one that directly engages with the equally subtle violent ideologies present in learning settings. Equally subtle, the concept of place as understood by cultural and human geographers (e.g., Cresswell, 2014; Tuan, 1977), i.e., "produced by practice that adheres to (ideological) beliefs about what is the appropriate thing to do" (Cresswell, 1996). The notion of place was an everpresent heuristic in the transformation of power asymmetries in an intermediate space between families and learning settings, i.e., the notebook, connected to a dominant system of education, yet with its own specific set of rules. In the case of our social design experiment, those rules were (re)defined by a software architecture designed by those who occupy nondominant positions on the power spectrum.

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International Society of the Learning Sciences

How do middle school students think about climate change?

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We use natural language processing (NLP) to train an automated scoring model to assess students' reasoning on how to slow climate change. We use the insights from scoring over 1000 explanations to design a knowledge integration intervention and test it in three classrooms. The intervention supported students to distinguish relevant evidence, improving connections between ideas in a revised explanation. We discuss next steps for using the NLP model to support teachers and students in classrooms.

Objective

This research connects two studies to characterize students' understanding of factors impacting climate change and improve student ability to evaluate actions that slow climate change.

Embedded assessment "Group Effort"

We designed the Group Effort item to engage students in reasoning about ways to slow climate change. Students use an online data tool with rates of electricity usage for several devices from a local gas and electric company to evaluate plans for reducing electricity usage proposed by three fictitious students. Key to the analysis is that each device uses electricity at a different rate. Students record the pounds of CO_2 saved for each plan to compare, evaluate, and explain what the three friends could do to increase their impact.

Knowledge integration guidance

The knowledge integration (KI) framework outlines four key processes to help students develop coherent understanding of science phenomena: *elicit* student ideas so they can be compared and refined, *discover* new ideas by exploring models, *distinguish* between initial and new ideas, and *reflect to connect* their ideas (Linn & Eylon, 2011). Curriculum designs using the KI principles engage students in multiple cycles through all four KI processes, providing students with opportunities to continuously integrate their new ideas with their prior understanding (Gerard et al., 2020). Student performance on embedded assessments might reveal that they still need support to fully integrate their ideas. We argue that, at this point, students benefit from guidance to distinguish between alternative perspectives or conflicting evidence.

Study 1: Students' ideas and NLP model

Participants, data source, and scoring approach

Seventeen middle and high school teachers from 8 diverse schools administered an online science assessment at the end of the school year, including the Group Effort question. We analyzed 1146 student responses.

We developed a scoring rubric (1-3) to assess students' understanding of the mechanism (connecting energy use to CO_2 emissions and human impact on climate change) and data practice (using evidence to evaluate plans). A knowledge integration score (1-5) indicates whether students connected ideas within and/or across dimensions. Two researchers independently coded 70 responses, iteratively refining the rubrics until reaching Cohen's Kappa of > .85 on each coded dimension. Then each researcher coded 50% of the entire data set.

NLP model building & results

We used a state-of-the-art neural network scoring model architecture that leverages a pre-trained transformer language model "fine-tuned" for the KI scoring task. These models have been pre-trained to identify words that have been masked from the input and to predict whether one sentence follows another. The word representations the model learns to do these tasks and the self-attention based transformer architecture, yields word representations that are useful across many NLP tasks. We used a model based on the Bidirectional Encoder Representations from Transformers (BERT) model (Devlin et al., 2019). This model architecture, adapted for the KI scoring task, has achieved state-of-the-art performance on the ASAP Short Answer Grading dataset (Steimel & Riordan, 2020). The models were trained to predict an ordinal score from each response's text. Since KI is concerned with the content of the response, the models did not consider grammatical or usage errors in scoring.

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Human-machine agreement was good with weighted Kappa of .79 for the mechanism, .88 for data practice and .89 for KI. By analyzing students' responses, we learned that students often used time on a device as evidence to judge the effectiveness of the solutions rather than kWh of energy use, indicating students need support to distinguish between time a device is used and how much energy per hour each device uses.

Study 2: KI guidance intervention

To help students distinguish between relevant evidence, we developed a KI guidance intervention. Students use a data tool to analyze a TV, video console, and desktop computer. They reduce the use of each device from 2 to 1 hour, enter the evidence in a table and compare how much CO_2 is saved. Students then rank each device according to how many kWh and pounds of CO_2 are saved. Students then revise their Group Effort explanation.

Participants, data source, analytical approach, and statistical analysis

Three middle school science teachers from two schools and their 397 6th grade students participated in the study. The Group Effort item is embedded in an online unit on global climate change featuring interactive models and activities (https://wise.berkeley.edu/). A total of 345 students completed the activity during remote instruction.

We used the NLP model to score the initial and revised responses to the Group Effort item which are logged in the learning environment. We used repeated measures ANOVA to test whether students' understanding improved from before to after the KI intervention. We used the open-source statistical software jamovi, set an alpha level of 5% and applied Bonferroni correction ($\alpha/n = .05/3 = .02$) to control for multiple testing.

Effectiveness of the KI intervention

We used the initial KI score as measurement point 1 and the revised KI score as measurement point 2 and included the teacher as a between subjects factor to test if there was a teacher effect. Students' KI scores increased from initial ($M = 2.79$, $SE = 0.05$) to revised explanation ($M = 3.23$, $SE = 0.06$), $F(1, 342) = 90.42$, $p < .001$, $\eta^2 = 0.04$. A non-significant interaction effect between time and teacher indicates that students' KI scores did not increase at different rates across teachers ($F(2, 342) = 1.36$, $p = .257$, $\eta^2 = 0.001$).

To unpack whether the change in KI is due to students connecting more ideas to explain the mechanism or use data as evidence, we used repeated measures ANOVA. Students connected more ideas about the mechanism in the revised DCI ($M = 1.42$, $SE = 0.04$) than in the initial ($M = 1.24$, $SE = 0.03$) explanation $F(1, 342) = 43.11$, $p < .001$, $\eta^2 = 0.02$. They also connected more data as evidence: initial $M = 1.50$, $SE = 0.04$ and revised $M = 1.77$, $SE = 0.04$ explanation, $F(1, 342) = 62.44$, $p < .001$, $\eta^2 = 0.03$.

Discussion and conclusion

The NLP scoring model can be used in future classrooms to provide teachers with information about their students' reasoning or to adaptively guide students (Gerard et al., 2020). The KI intervention targeted towards sorting ideas not only helped students to engage in the sophisticated practice of distinguishing between time versus kWh as evidence, but also helped students integrate this data practice with a mechanistic understanding as they connected their ideas about electricity usage, CO2 emissions, and human impact on climate.

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International Society of the Learning Sciences

Nayah-Irú: the design of a participatory game to foster critical data literacy through storytelling and

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Abstract: Countering oppressive practices in digital spaces is essential to prevent control and exploitation. Youth need to be empowered to reflect on their use of such spaces. In this poster, I present a design for an alternate reality game that engages learners in participatory research and storytelling in a virtual world to develop data tactics to repurpose data practices.

Introduction

In understanding how technology can become oppressive for youth, I focus on the inequalities present in digital spaces. With the growing use of personal digital devices and mass platforms, there is an unprecedented rate of data generation, often collected without the individual's knowledge. Without the knowledge to counter oppressive practices in digital spaces, youth are often traced, tracked, and policed through the use of their personal data leading to a state of automated inequality (Eubanks, 2018). Using Pangrazio and Selwyn's (2019) framework of personal data literacies, I seek to explore how storytelling and games in virtual worlds can support the development of data tactics to counter or repurpose current data practices within a youth participatory action research (YPAR) framework where the boundaries between fiction and research are purposefully blurred.

The use of stories to engage youth in making sense of digital spaces can be drawn from indigenous practices regarding place-making. Abenaki author Lisa Brooks used *awikhigawôgan,* an ongoing and collective writing activity, to reconstruct the community (2008). According to Basso (1996), building "place-worlds" is a deeply human activity that does not require any storytelling skills but a sense of curiosity. Through the use of letters, scrolls, maps, portraits, and photographs, Brooks (2008) was able to engage in making sense of the different spatial experiences of the community. In this design, I imagine *awikhigawôgan* as virtual worlds created by learners to make sense of their experiences with data in digital spaces.

Based on Freire's (1992) notion of the "consciousness of the possible," I seek to understand how learners can engage in a collective experience of designing possible futures through virtual worlds that could reverberate to inspire change in their communities. To engage in storytelling, I designed an alternate reality game (ARG); a game that takes place in the real world by intertwining fictional elements. This game was inspired by Ask Anansi, an ARG developed by Antero Garcia (2017) where youth connected with a fictional character who engaged them in a research process through questions and conversations. While Ask Anansi was mostly an in-person experience for students, the research context for my design required the development of a virtual world. This poster describes the design principles that support the game.

Design principles

In order to engage learners in recontextualizing their relationships with digital spaces, the game introduces, Nayah-Irú, a 16-year-old girl from the future who claims to be from what was once known as Uruguay. After a series of puzzles and cryptic messages, Nayah-Irú reveals that she lives in a future where all forms of digital space have been banned. Nayah-Irú, who is fascinated by the digital spaces in the 21st century, ignores the ban and finds a way to communicate with students through multiple platforms to find out why they were prohibited.

Context and purpose: an ARG environment to support a spatial analysis of data practices

In July 2021, Nayah-Irú contacted a group of 18 students aged 15-20 from rural Uruguay who attend a secondary education center for learners who have fallen out of formal education. The program provides instruction in core knowledge areas, physical education, vocational workshops, and information technology. The game was played with learners during two weekly periods over twelve weeks during the information technology class.

The main character interacted with learners in three ways. Through automated bots that asked questions to students during the week or sent text messages when student solved a puzzle; through e-mails and social media posts which often introduced the weekly challenge; and finally, as a character in the Gather platform, an avatar-based videoconference system which served as the virtual world for the game. I played two roles in this design: I facilitated the meetings with students using my personal identity, and I also engaged in conversations with learners as a fictional character.

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The main purpose of this design is to provide learners with a platform to reflect upon data use in digital platforms in order to imagine possible ways to resist or repurpose oppressive data practices (Pangrazio and Selwyn, 2019). The game design was structured in three stages which provide learners with opportunities to understand the digital spaces they inhabit, engage in performative work through storytelling, and eventually transform their communities by extending their performance towards shared knowledge (Garcia, 2020).

Making sense of data in space

During the first stage of the game, players are required to explore different worlds created by Nayah-Irú in Gather. The activities are designed as scavenger hunts which lead to videos, story fragments, or illustrations that promote reflections and discussions. As they solve each challenge, they uncover more fragments of the story. One feature of the game in this stage is that players are not allowed to share any personal information since Nayah-Irú believes their communications may be intercepted. Thus, students engaged in discussions using their avatars and usernames without revealing their identities. After six weeks, Nahay-Irú shifts from the game puppeteer and leads players into asking their own questions. In turn, students turn from participants in the story to storytellers.

Nayah-Irú requests information about the nature of datafication in their lives which she will use to stand against her regime. To answer these questions, students had to develop their own research questions to understand why digital spaces are banned in the future. Some of the questions in this first iteration of the game focused on how data can be tracked, the addictive characteristics of social media, and the impact of digital spaces on mental health.

Mapping new spaces for the community

Students were trained to use a wide variety of research methods discussing their ethical implications, the quality of the data they were collecting and how the data would serve the purpose of telling their story. Once students collected data to answer their questions through interviews, observations, and surveys, they were encouraged to design a virtual space to communicate their message. At this stage, participants designed their own scavenger hunt where they hid their message to Nayah-Irú. Students had to discuss whether they wanted to give Nayah-Irú a grim perspective of digital spaces which could justify the digital ban or incorporate a rich myriad of perspectives to support her decision to resist. The storytelling is discussed by students to determine whether this is a story of hope.

Since students are not capable of sending the virtual space to Nayah-Irú into the future, she suggests they place a physical poster around their city with a link to the virtual space. This activity allowed learners to create their own cryptic puzzle to impact their community. By interacting with the poster, community members could visit the virtual space, solve the mystery, and listen to the videos and messages designed by students.

Current progress and future work

At the time of this poster, a working prototype of Nayah-Irú has been piloted with a group of students and received feedback from both the students and other educators. The second iteration of the game will involve a new cohort of students and incorporate new characters designed by the current participants.

Some of the areas to be explored within this design are the affordances of virtual worlds for youth to engage in participatory research through storytelling and how educators can facilitate game-based participatory research experiences with youth.

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International Society of the Learning Sciences

Writing to rewrite dominant discourse(s): Some design dilemmas from global south

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Abstract: This poster considers some design elements that can potentially work through the double bind of English education for culturally marginalized students in post-colonial contexts. English writing in such contexts often plays out as an overwriting on native consciousness. Using the framework of counter stories, I look at the Facebook compositions of Sangita, a young indigenous girl from India. Her composition illustrates the potential to rewrite dominant notions around indigenous food systems and offer some possibilities for design.

Introduction: Double bind of english language learning

In postcolonial settings, learning of the English Language presents one of the most complicated double binds. The historical origins of English language education in India emerged primarily as a tool for governance. Almost two centuries later, language scholars argue that the colonial tendency of the English language is far from over, as it continues to play a strong imperialistic role in the global south (Phillipson, 2009). On the other hand, in a caste ridden society like India, English is pitched as the only language of emancipation for the marginalized (Ilame, 2020). In a society where educational opportunities were reserved for some; English became a tool to bypass the upper caste hegemony. In such a situation, English is both empowering and disempowering for learners from culturally and linguistically marginal backgrounds. This calls for a culturally responsive English language learning framework that works through this double bind.

Writing counter stories

What do great writers who come from marginalized communities do and should do? For pragmatic reasons they emulate the structures of successful writing and earn economic and social recognition. But often they engage in counter storytelling, which means presenting the world from a position of marginality. They write into the discourse, that which resists being written. They write in ways that it challenges the contours of what writing is supposed to look like. At a level of abstraction all great artists produce that which is not a part of the dominant conversation or that which may subvert common sense. Thus, I argue, that counter stories are a good format on which writing may be modeled. The concept of counter stories has been evoked under similar names like 'critical storytelling' and 'counter- narratives', and it emerged in various disciplines like law, social work and critical pedagogy (Miller et al., 2020). The concept was eventually more formally grounded in the domain of education (Solórzano & Yosso, 2002). Over the years, some studies have tried to integrate counter storytelling as powerful way to engage with literacy and language development (Kelly, 2017).

Research context and analyses

In this poster I provide an illustration of writing by an 18-year-old Santhal girl Sangita. Santhal community is an indigenous community in India. She is one amongst the many Santhal youth who are part of on online language learning project. When Sangita started posting on Facebook, she made all kind of posts. For my analyses I focus on the posts that centers indigenous/local food systems. We do so, because local food systems are a central node to understand various layers of identity, culture, and knowledge. In addition to this, there is an urgency to the health and nutrition crisis in the region. At a social level, Santhal food items are threatened because of the dominant discourse around 'civil food'. Dominant stories around what is 'good food' dissuades young indigenous people away from a whole range of local food practices, which are categorized as 'backward' (Bose, 2016).

In one of her posts (Image a) she explains the context of rat hunting in terms of the agriculture cycle. Hunting of field rats is play, pleasure, group activity, learning and a form of nutrition that kids (boys) generate for themselves. She centers her world and normalizes it by asking her non-Santhal Facebook friends if they have ever done rat hunting. The children are placed strategically, holding the bunch of rats in the middle through a stick along their shoulders. In the background one can get a good glimpse of a path and some younger children, who over time would also learn this traditional practice. The children are not hunting in the picture, but rather a thumbnail of the practice is stylistically choreographed. Thus, these posts do not just re-produce, but rather re-style and reinvent the cultural connections for their audience and for the Santhal youth themselves. I want to highlight two key counter story elements to this post. First, it unsettles the hierarchy of food in the region, where rat eating is usually something that Santhal community considers a guilty pleasure. Second, this

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image runs in contrast to images that national newspapers carry about the community and nutrition crisis. Generally, rural children are portrayed as recipient of free meals, looking up in desperation of relief. In another post (Image b) she asserts the significance of local food systems in the times of Covid. There has been a huge movement to get rural ingenious communities integrated with markets, and then the lockdown enforced the closure of all markets for many weeks. Within such a context, she makes a case for the sustainability of locally available 'wild' food. Apart from the content, her Facebook composition is noticeable for translangauging and multimodality.

Figure 1

Some students used Santhali, Hindi and English in their own ways to compose their posts. Here it reads- "Two children have hunted down field rats. After the rice harvest, Santhali people engage in this hunting activity. At this time you get a lot of rats in the field. Do you also for rat hunting?"

a.

Slowly they started making use of more English in their composition. More importantly student in the post highlight the importance of relying on locally available food at a time when lockdown was prevalent.

b.

Implications for design

What can we learn from such online compositions of indigenous youth? What implications it has for designing writing spaces for culturally marginalized students in postcolonial contexts? One element that needs to be incorporated and engaged with is the practice of translanguaging. This comes fraught with the tensions and hierarchy that exist within multiple languages and the explicit desire to move to a 'pure' English space. Another major component that needs to be part of the design is a critical engagement with community knowledge. One way to do that is using mentor texts that illustrate counter narratives. Another way to do that is to build on the aspect of multimodality. By encouraging students to use images and visual expression, we may allow for community knowledge and practices to enter classroom discourse. I think another important aspect of writing on community practices, involves integrating community experts in the process of writing. This may be done as part of student's research into an issue, that has the power of remediating relationships in the community. A major challenge would be to design novel criterion for assessing such writing artifacts. Standard ways of assessment and standard writing methods (5 paragraph essay) may undermine some of the innovative aspects of composing counter narratives in this way. Finally, to really engage with the double of english language, it would be crucial that writing designs are informed by and generative of theories from the global south, rather than confirming to frames set by the global North.

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International Society of the Learning Sciences

Static and Changing Roles in Transdisciplinary Co-Design

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Abstract: Transdisciplinary computing arts experiences provide potential to merge practices and cultures from across disciplines to create an inclusive learning environment. However, this can be hard to do, especially when instructors within these spaces feel their expertise lies mainly within either computing or the arts. In our work, we analyzed facilitator reflections on the co-design and implementation of a 14-week online computing-arts experience designed to integrate computing, poetry, and visual arts. We found that focusing on the static and changing roles assumed by the co-designers provided a lens to understand how to build knowledge across one another's disciplines in the pursuit of creating new practices within transdisciplinary education.

Introduction

Co-design has been defined as a "team-based process in which teachers, researchers, and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need," (Roschelle et al., 2006). The practice emphasizes collaborative meaning-making, connecting design to a real context for learning, and integrating reflective practices for developing an understanding of the design. In transdisciplinary education, once siloed disciplines have the opportunity to become something new as the practices, norms, and cultures merge (Nicolescu, 1999). Much of the work in artistic computing education emphasizes how learners can explore CS concepts in a discipline that they care about as they leverage their prior knowledge to develop computing-artwork that becomes meaningful through the expressivity of learners' identities and cultures and ability to be shared beyond the environment. Few works examine how arts educational practices can change processes within the learning environment outside of the artifacts. Our work explores how a co-design team composed of three professional teaching artists and three CS education researchers from New York University and Georgia Tech reflected on roles within the design and implementation of an online physical computing, visual, and literary arts experience. We analyze teaching activities, individual interviews, an instructor focus group, and learners' final presentations examining the research question: *How do roles emerge and change within a co-designed computing-arts experience among its facilitators?*

Methods

This research took place within Community-Word Project, a non-profit arts organization that provides K-12 arts education within New York City public schools. During the 2020-21 school year, the facilitation team co-designed a remote curriculum in which students incorporated elements of their identities and cultures in conjunction with art activities and physical computing "tech" kits to create artifacts belonging to socio-futurist communities. The tech kits contained introductory programmable digital components, such as a BBC micro:bit, servos and sensors.

We collected semi-structured interviews and a one hour focus group with all facilitators to capture the facilitators' thoughts, feelings, and personal gains from the co-design experience. We also obtained a recording of the curriculum's 2-hour finale in which students presented their final projects to each other, parents, and community members. The data was analyzed using thematic analysis (Braun & Clarke, 2012). We identified how facilitators reflected on various elements of the program and their role in supporting learners and mediating between disciplines. Through multiple rounds of coding transcriptions of the collected data, we generated a codebook composed of themes of exercising roles within the planning and execution of the program.

Findings and discussion

Assumed, avoided, and adopted roles

Each facilitator approached the collaboration with a strong sense of identity and confidence in their own skills and contributions, therefore assuming a specific role within the co-design process. Among the co-designers, the

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roles of *tech-person*, *art-person*, and *researcher* were used to describe themselves and each other. While the facilitators were interested in crossing the disciplinary content, they still connected primarily to these roles.

Facilitators also distanced themselves from specific activities and disciplines. For example, two teaching artists felt disconnected from the research efforts of the program and deferred research-oriented roles to the CS ed researchers. Avoided roles became apparent when discussing facilitators' varying levels of comfort with computing technologies, as one of the teaching artists candidly said referred to herself as "not a tech person" despite a history in making digital art. In contrast, one CS ed researcher distanced herself from literary arts, saying she does not consider herself someone who practices poetry. We observed that facilitators openly expressed uncertainty and concerns around how the different roles would contribute to the curricular goals and shared vision for the program. Some facilitators found it challenging to envision how the tangible art making and physical computing practices would be integrated throughout the curriculum, both in students' artifacts and in the literary activities preceding them. One teaching artist was most concerned with being unable to support the students in the computing tech components, while a CS ed researcher was concerned with overshadowing the artistic learning goals with computing in the curriculum.

Facilitators discussed acquiring knowledge and skills that had the potential to contribute to their own identities, empowering them to adopt new roles during the program and after. One teaching artist who at first struggled with the writing and poetry activities and self-identified as a "visual person" was really motivated to start her own journal (an activity students practiced in the program) and write more. The teaching artists each had their own tech kit so that we could test out the instructional resources and enable them to play with, build, and program a circuit. One of the teaching artists shared how she found the electronics challenging at first, but that it led to valuable learning that she was happy to receive.

The CS ed researchers did not experiment with the arts activities since there was less uncertainty of failure of those activities. However, they did reflect on learning from teaching artists' disciplinary practices. For example, one researcher reflected on a writing exercise led by a teaching artist after the verdict of the George Floyd police violence case was announced. They were impressed with the "ways [the teaching artists] handle different situations," and how it led to insightful discussion with the students. Another CS ed researcher echoed this sentiment and saw new purpose in writing and talking about one's personal community.

Pushing beyond static roles

We found that the facilitators' instructional and disciplinary practices aligned with the roles they assumed in the co-design process. Further, as they distanced themselves from certain roles, they also distanced themselves from certain disciplinary practices—i.e., not practicing poetry. Despite building new knowledge through an understanding of each other's roles, a majority of the co-design led to recognition rather than implementation, such as the CS ed facilitators recognizing the power of the poetry activities but never leading any. Our work suggests that embodying roles within an interdisciplinary environment provides opportunities for identity work that can help instructors bridge disciplinary boundaries in order to push beyond them. While the teaching artists identified the ways they learned about computing as a discipline, the CS ed researchers did not identify learning art practices. We hypothesize that this may have been because the CS ed researchers did not engage in enacting roles of the teaching artists in the arts activities while the teaching artists did so with the computing activities.

Disciplinary and instructional roles also carried implications for facilitating greater engagement of the co-design team with the role of *researcher.* The role of researcher was dominated by the CS ed researchers, which created an imbalance in the focus and practices enacted within the research. Prior to assisting with data analysis, the teaching artists felt *disconnected* from that aspect of the co-design. This is important because researchers in these spaces are more often coming from computing disciplines than the arts. Drawing on participatory action research approaches could present useful tools to engage teaching artists in research framing and investigation design in order to center the role of researcher in the co-design process and address power imbalances.

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International Society of the Learning Sciences

Examining Gender Differences in Identity Development Within an Online, Global, Collaborative, Informal STEM-learning Community

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Abstract: This study examines how a learning environment that incorporates aspects of intergroup contact might impact identity development and expression. Adolescent students collaborate on creating STEM-related media projects in this global, virtual environment during weekly video conference calls, which were coded for social and self-identity constructs and analyzed using epistemic network analysis (ENA) to compare differences by gender. Literature anticipated that female students would reflect social identity constructs and male students reflect self-identity constructs, but the opposite was found indicating intergroup contact might defy expected outcomes and complement student identity development among adolescents.

Introduction

Adolescents shape perceptions of self and others based on lived experiences and socio-cultural norms. The development of self-concepts is essential in how an adolescent views themselves in their educational contexts. By engaging students with intergroup contact, bias between groups can be reduced and potentially form positive group and self-identity concepts that can overcome their societal identity. Allport (1954) recognized that intergroup contact can reduce prejudice and discrimination with four factors to reduce prejudice: (1) equal status amongst group members, (2) common goals, (3) intergroup cooperation, and (4) the support of authorities. Social identity theory posits that an individual's self-concept is informed by their role in a social group or groups and the emotional attachment one gives to that role (Taijfel, 1981). Previous research indicates that social identity correlates more so with females, whereas self-identity is attributed more so to males (Hwang, 2010). Social identity consists of three constructs (group self-esteem, self-categorization, and commitment to the group) and two for individual self-identity (personal self-esteem and personal identification).

This study involves an afterschool community of adolescent students across four continents who collaborate together on developing media artifacts such as videos and presentations related to science, technology, engineering, and math (STEM) topics of their choice. Students from two or more countries participate in video conference calls to share ideas and projects (online global meet-ups) supported by a facilitator. Four components of intergroup contact theory are present: a virtual setting produces a space for students to join as equals, interact in a collaborative manner that creates intergroup cooperation, work towards a common goal of promoting peer-led STEM learning, all while receiving support from the facilitators throughout the process. This study explores the effect of intergroup contact on identity development through an initial comparison by gender.

Methods

The data used in this analysis consisted of discourse from transcripts of five online global meet-ups: February 2020 (3 females, 7 males), April 2020 (3 females, 3 males), August 2020 (6 females, 7 males) and two in March 2021(one with 5 females, 1 male, the other 1 female, 3 males) with participants from Brazil, Cameroon, Kenya, Mexico, Namibia and the U.S. The transcriptions were coded (see Table 1 for codebook) for three social identity and one self-identity construct adapted from Ellemers et al. (1999) and three identity-oriented constructs unique to the data. Coding was done independently by two raters, followed by social moderation.

Table 1

Codebook of Identity Constructs Included in the Analysis

Category	Code	Description	Example
Social Identity	Group Self-esteem	Expressing positive feelings about the group or referencing another individual	*"I really liked the presentation and I think that every topic…it's been much needed…."*
Social Identity	Self-categorization	Identify with other members of the group	*"I think the same as [student]…"*
Social Identity	Commitment to the group	A want to continue working with the group; Dedication to group goals	*"…we will do this though it requires a bit of much research. But I know we will collaborate"*
Self-identity	Personal self-esteem	Belief in one's own abilities; State confidence that they can accomplish tasks as well as others	*"…I like to explain to people, about math and physics. So, I think that I could do it."*
Identity-oriented	Knowledge Acquisition	Reflective of learning or acquiring new knowledge	*"I never knew they could use… materials to filter water…I learned something."*

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Identity-oriented	Curiosity	Seeking clarification, elaboration for better understanding of content-related issues	*"...question for you....are you addicted to smartphones?"*
Identity-oriented	Self-Awareness	Indicative of the state of recognition, realization, or emotion about oneself,	*"I'm really bothered before exams..."*

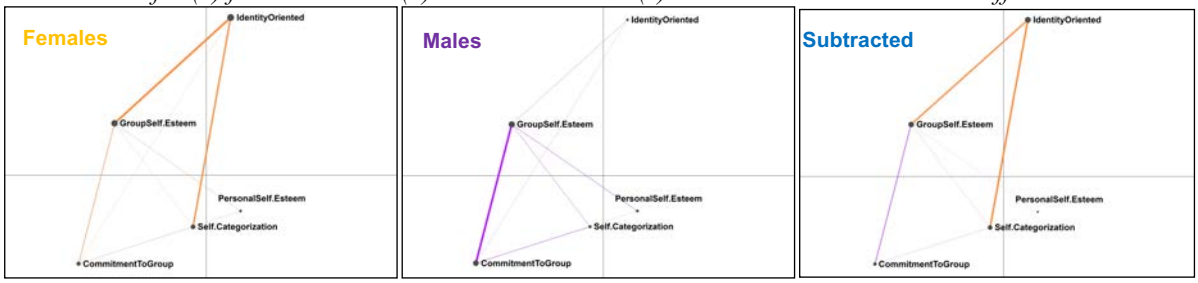
After the coding process was completed, data was examined using epistemic network analysis (ENA), an approach in quantitative ethnography to visualize data through statistical methods, to identify patterns among the relevant constructs. ENA generates network models of the connections among relevant constructs by quantifying the frequency of their co-occurrences within conversations in the data (Shaffer, 2017). For this study, each utterance (separated by turn of talk) was used as the unit of analysis, and each meet-up by date constituted a conversation to which the connections were limited. Only patterns of student discourse were examined.

Results

The ENA models of identity constructs for female and male students can be seen in Figure 1. The nodes represent each coded identity construct and the lines between the nodes (edges) which represent the strength of the connection between each construct within the stanza window size. A thick line indicates a stronger connection between the constructs while a thin line represents a less strong connection. Edges were scaled to 3.5.

Figure 1

ENA models for (a) female students (b) male students and (c) subtracted network to show differences.



(a) (b) (c)

In examining both the female student and male student network models, they share complementary patterns. Females draw more connections to Identity and Group Self-Esteem and Self-Categorization, while males exhibit stronger connection between Group Self-Esteem and Commitment to the Group. While there is no statistically significant difference between the compared groups, the network models help visualize the similarities among the construct patterns. The subtracted network model provides further insights on the female students' stronger connections to self-identity oriented constructs and male students' stronger connections to social identity.

Discussion

Based on previous social identity research, it was anticipated that males would demonstrate a stronger association to self-identity constructs, whereas females would show stronger affiliations to social identity (Hwang, 2010). However, the results found that males showed stronger connections to social identity constructs: group self-categorization and group self-esteem while female participants exhibited stronger connections to identity-oriented constructs. The unique context of this learning environment may have impacted the hypothesized relations between gender, and social- and self-identity. Using ENA, these insights help show how a learning environment that incorporates aspects of intergroup contact can shift what is expected in identity development.

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Chin Youths' Epistemic Agency in an Afterschool STEM Learning Environment

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Abstract: We implemented an afterschool STEM program for Chin youth to engage them in critical science literacy while using their full linguistic repertoires. For the present study, we conducted a grounded theory analysis of 24 interviews from this project to reveal how translanguaging supported epistemic agency in this space. Our findings from four youths' narratives suggest that the youth integrated translanguaging as an extension of their everyday discursive practices to foster shared epistemic agency among their peers. In addition, we identified structures from their school science classrooms that inhibited translanguaging and stunted their epistemic agency.

Introduction

Our research has explored the way in which multilingual refugee youth engage in critical science literacy through *translanguaging* in informal learning programs (Ryu & Daniel, 2020). Translanguaging is the fluid and flexible use of full linguistic repertoires that integrate multiple named languages to achieve specific communicative purposes (Blackledge & Creese, 2014). In the present work, we contrast Chin youths' experiences in our community-based after school setting and school science classes to explore whether and how translanguaging fosters shared epistemic agency in STEM learning.

We draw upon Miller et al. (2018) to operationalize epistemic agency as "students being positioned with, perceiving, and acting on, opportunities to shape the knowledge building work in their classroom community" (p. 1058). Furthermore, we draw on the idea that shared epistemic agency arises "during collaborative activities aimed at the creation of shared knowledge objects" (Damşa et al., 2010, p. 146). Specifically, learners exercise shared epistemic agency through collaboratively identifying gaps in knowledge, naming problems, and generating ideas. With these constructs in mind, we asked, *How does translanguaging support Chin refugee youths' epistemic agency in STEM learning environments?*

Context and methods

We conducted our afterschool program for high school-aged youth in collaboration with a non-profit Burmese Organization in a historically White neighborhood on the outskirts of a major city where Chin people established an ethnic enclave (see Ryu & Daniel, 2020). We conducted and analyzed 24 total interviews with 14 youth who regularly attended the STEM program to understand their relationship with science learning in our program, in school, and in their daily lives. For this paper, we draw on four youths' narratives: Nyunt, Kevin, Joshua, and Da Zin. Although we identified epistemic agency throughout the data set, the excerpts here were particularly powerful and salient.

We used constructivist grounded theory methods (Charmaz, 2014) to center the youths' voices in the analytical claims. After transcribing the interviews verbatim, the first author engaged in an iterative qualitative analytic journey. After multiple rounds of initial and focused coding, initial codes such as "translanguaging to help others," and "naming who has authority over English" coalesced to relate to themes of agency, positioning, and power. To better articulate these themes, we visited the literature in science education, sociocultural theories, and refugee studies. The second author drew on field notes and earlier analysis of the data set to provide ethnographic insights into the construction of our findings.

Findings

Our analysis revealed that translanguaging is an essential practice of the Chin youths' sensemaking and daily life. Thus, the youth in our program exercised shared epistemic agency through translanguaging. However, school science classrooms marginalized their linguistic assets which restricted opportunities to exercise epistemic agency.

The youth in our STEM program translanguaged every day. Across the 14 regular attendees, they spoke a total of 13 named languages and dialects. In the interviews, they shared that it was "fun", "special", "comfortable", and "normal" to mix languages with their classmates, friends, and family. For instance, Nyunt learned the Mizo language growing up, Burmese in school, English throughout resettling, and Matu after she arrived in the U.S. because her parents wanted to preserve their ethnic heritage language. Nyunt shared that she

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and her friend Rosie frequently translanguaged in the STEM program: "When she talk in Matu, I just reply to her in Burmese. We do that all the time." The youth readily translanguaged because it was historically, socially, and politically embedded in their lives.

In our STEM program, the youth exercised their shared epistemic agency by organically generating ideas to make sense of terminology through translanguaging. The Chin youth faced a unique linguistic conundrum in science: There were no direct translations for many Western scientific jargon among the languages they spoke. In Joshua's group, the group mates took turns sharing their conceptions of terms after they did some researching. He said, "We did by group, we split like 2 or 3… The vocabulary, the word, we tried to find what does that mean and after that we explained to other people, like presentation." Kevin, one of Joshua's group mates, was persistent in getting their small group to translanguage, even though none of them were entirely confident speaking each others' primary language. Kevin elaborated, "Since he [another peer] don't speak English, I just talking to him, 'Tell me in Falam,' and then [if] the things that he say is kind of easy, then I make him to say it [in English]. Then if I think it is kind of hard to say it, I kind of translate it [from Falam to English]." Through translanguaging, the youth positioned one another as collaborators in scientific sensemaking, expanding the shared epistemic agency among them.

Contrary to the possibilities realized in our STEM program, the dominant assumptions and practices in school science classrooms constrained the youths' opportunities to translanguage. Subsequently, they were positioned with less epistemic agency relative to themselves in our STEM program and to their American peers in school. Kevin, who worked hard to build linguistic bridges between his peers in the STEM program, brought to light exclusionary behaviors by his school peers: "There's people who just don't interest in making friend with whoever is not American… If the teacher told them to work with non-English people, they will never talk to them, even if they sit together. They will not even stare each other." Another youth, Da Zin, who also felt excluded by American students, said she felt "embarrassed" and "angry" because they would not let her help. The American students' behavior and expectations dominated the classroom norms such that everyone else was positioned as "not English" to the detriment of their participation in school science.

Discussion

These Chin youths' epistemic agency is contingent on positioning and opportunities with respect to translanguaging. Whenever the Chin youth congregated together, translanguaging was the norm, and it fostered their epistemic agency in science learning. In their school classes, the monolingual English-speaking Americans determined the norms which rendered their translanguaging resources ineffective. Although it could not be represented here, the shared epistemic agency reflected in these youths' narratives will be further corroborated by video data in future analyses. We urge researchers and practitioners to embrace heterogeneity to equitably expand epistemic agency in science learning.

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Fostering Community for Current and Future Latinx Science Teachers Through *Testimonios* and Co-Design

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Abstract: This study explores how a network of current and future Latinx secondary science teachers engaged in co-design activities to explore and attend to the issue of Latinx underrepresentation among US science teachers. Using *testimonios* as data to inform the design of an infographic report, the co-design process yielded insights into the Latinx science teacher shortage and provided a valued community space for participants to find support.

Introduction

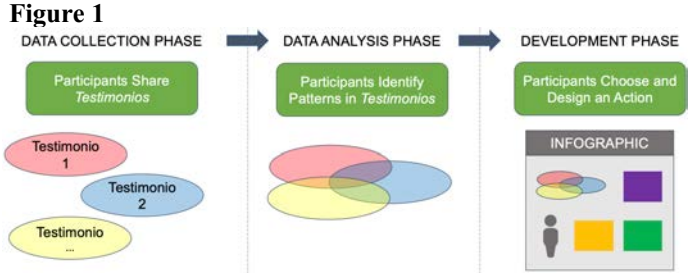
Despite evidence of the benefits of having a more diverse teacher workforce (e.g., Dee, 2005), minoritized demographic groups in the US remain underrepresented in the teacher workforce. In science education at the secondary level, only 8% percent of science teachers in the US identify as "Hispanic" (Taie & Goldring, 2020), although nearly 1 of 4 US students identify similarly (Fry & Lopez, 2012). While several studies have broadly examined the "pipeline" issue for Latinx teachers (Ocasio, 2014), the challenges faced by Latinx students as they seek to become science teachers remains underemphasized (Basile & Murrey, 2015). For this study, we recruited a network of current and future Latinx science teachers to engage in collaborative design (co-design; Voogt et al., 2011) focused on exploring and developing an action to address the Latinx science teacher shortage. Our research questions were: (Q1) How well can co-design activities surface insights into the Latinx science teacher shortage?; and (Q2) How might current and future Latinx science teachers' benefit from engaging in co-design activities?

Methodology

Design Methodology

Situated learning, particularly the notion of "communities of practice," informed our organization of the co-design process. We purposefully recruited participants with differing levels of participation in becoming science educators. Participants included two female undergraduates with no science teaching experience, three graduate masters students (two female, one male) working to receive their science teaching credential, and one early career male science teacher. Participants in this study all identified as Latinx. Undergraduate and graduate students attended the same western US university. The science teacher received his masters and teaching credential from there as well. Co-design occurred in three phases (see Figure 1) over eight 3 hour sessions spread over 6 months.

Figure 1



All activity took place online via Zoom during the 2020-21 school year. Researchers played an important role in facilitating each session. Of note, participants' personal *testimonios* served as the main source of data within the co-design process. Testimonio is a knowledge sharing genre common to Latin America where presenters seek to contextualize their experiences by seeking "to bring to light a wrong, a point of view, or an urgent call for action" (Reyes & Curry Rodríguez, 2012, p.525). Participants shared their story (so far) of becoming a science teacher and gave special emphasis to the academic, familial, and societal challenges they personally faced. Participants then analyzed each other's testimonios to identify and discuss patterns of challenges – as well as promising supports – they deemed significant. With researcher assistance, participants chose to develop an infographic highlighting the patterns they identified. This infographic has begun to be shared via social media with members of the university and local community and has already been viewed several thousand times.

Research Methodology

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While participants' own analyses of their testimonios provided a compelling emic perspective for Q1, researchers performed a separate complimentary analysis in order to discern insights into Q2. All Zoom meetings underwent verbatim transcription and a joint coding process consisting of rounds of inductive and deductive coding (Emerson et al., 2011). This process reduced the data to excerpts which served as patterns of evidence for making claims.

Findings

Claim 1: Co-design surfaced compelling challenges for Latinx science teachers

Participants identified three main challenges across their testimonios (see Table 1).

Table 1

Challenge	Description from Participants	Example of Evidence from Testimonios
Family Expectations	All of our families scaled obstacles (e.g., immigration) to provide us with opportunity. While studying science was accepted, science teaching was less accepted.	*"When I was telling [grandma] that I was going to pursue teaching instead of health care...She called me a glorified babysitter.*" -Undergraduate Student 1
Systemic Roadblocks	Nearly all of us struggled early on in college with many of us feeling unprepared, particularly in our first required STEM classes (i.e., "weed out" courses)	*"In high school your teachers generally don't want you to fail. But in college, it's like, no, you can fail."* -Graduate Student 1
Maintaining Community	Many of us noted the importance of community as a support and motivator. We need more opportunities to belong and contribute to community.	"*Where is this place where we gather and support each other? And talk to each other?*" -Graduate Student 2

Claim 2: Co-design provided a valuable community space for participants

All but one participant explicitly noted how engaging with other Latinx science teachers (current or future) in the co-design space provided them with a supportive community. For example, the current science teacher noted how his participation provided community he had previously lacked, "Like I've said before, I didn't realize how much I needed to talk to other Latinx teachers before this… I would really like this to continue and see where I can help." Similarly, Graduate Student 2 shared how she felt she found community within the co-design work: "[w]hen you're looking for community, like you're definitely gonna stay if you end up finding it. I know, like, I look forward to these meetings."

Discussion and Conclusion

This study provides a promising example of how researchers can utilize co-design to work closely in partnership with minoritized teacher populations to surface not only new insights into longstanding issues of equity in education, such as the underrepresentation of Latinx science teachers in the US, but how to foster much needed support and community for participants. Notably, the use of testimonio in this study provided an innovative and wholly effective anchor for co-design activity, providing highly contextualized data as seen in previous testimonio work (Reyes & Curry Rodríguez, 2012), which sparked rich discussions among participants that mediated the development of community as well as ownership of products like the infographic. Additionally, this study demonstrates the promise of organizing co-design spaces to include participants at differing levels of participation in becoming teachers, and points to possible future directions for participatory design research methodologies.

Acknowledgements

Special thanks to the current and future science teachers who took part in this co-design work.

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International Society of the Learning Sciences

Examining Learning-by-Teaching Effect in a Secondary Math Course

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Abstract: The present study aims to identify which phases during learning by teaching play the critical roles and to investigate how student ability and pairing types mutually influence students' performance in each phase and the overall achievement. To this end, learning-by-teaching was applied with the form of reciprocal peer tutoring in a seventh-grade math course. Students' achievement scores, preparing-to-teach worksheets and verbal records during tutoring were collected for future conversational and quantitative analysis.

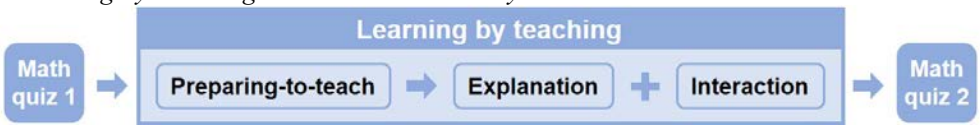
1 Introduction

It is well-studied and well-supported that *teaching* can be an effective strategy to facilitate learning (Fiorella & Mayer, 2016). *Teaching* encompasses more complex mental processes than only learning for oneself (Duran, 2017). According to Chi's Interactive-Constructive-Active-Passive (ICAP) framework (Chi & Wylie, 2014), learning increases when students behave higher-level cognitive engagement. Particularly, the act of explaining can strengthen deeper and longer learning effect than solely preparing to teach (Fiorella & Mayer, 2013). Furthermore, interacting, such as questioning and answering, helps tutors avoid the proclivity for *knowledge-telling* and stimulates them to generate *reflective knowledge-building* (Roscoe, 2014).

Learning-by-teaching has also been implemented in classroom practices with various forms, such as cooperative learning, peer tutoring, reciprocal peer tutoring (RPT) and so forth. Ample studies had revealed the benefits of those tutoring activities on students' academic achievement (Alegre, Moliner, Maroto, & Lorenzo-Valentin, 2019). However, in addition to overall advantages, there is still a lack of classroom study that further investigate the respective effect of each phase within tutoring process (Fiorella & Mayer, 2016). Hence, the present study not only implemented RPT in a seventh-grade math course but also applied Kobayashi's (2021) three-phase teaching framework to explore students' learning patterns and outcomes in each phase (Figure 1). That is, throughout RPT sessions, all students were required to prepare for their own teaching and thereafter to tutor each other through explaining and interacting. Two questions are examined in the study:

- Q1: To what extent did preparation, explanation and interaction influence overall learning achievement?
- Q2: How did student ability and pairing types influence tutoring performance and overall achievement?

Figure 1
Learning-by-Teaching Framework in the Study



* The framework was adapted from Kobayashi's (2021) face-to-face teaching framework.

2 Methodology design

The study was conducted in a seventh-grade math classroom at a public middle school in Taiwan, involving 23 students (11 females and 12 males). Written informed consents were obtained from all the students and their parents. A total of six RPT sessions were implemented: three training sessions and three formal sessions with a three-week break in between. Each RPT session was carried out after the math teacher's one- to two-week instruction for the topic. The math topics covered in the six sessions were (1) *Intro to Exponents and Scientific Notation*, (2) *Factor and Multiple*, (3) *Greatest Common Factor and Least Common Multiple*, (4) *Laws of Exponents*, (5) *Simplifying Algebraic Expressions*, and (6) *Algebraic Equation*.

Prior to the beginning of the study, the students had been assigned to fixed pairs or triads by the teacher. Because each *tutoring phase* also encompassed two sub-phases — *heterogeneous RPT* and then *homogeneous RPT*, every student had two different pairs or triads (i.e., one for *heterogeneous RPT* and the other for *homogeneous RPT*). Accordingly, ten pairs and one triad were included in *heterogeneous RPT*, and six low-achieving pairs, four high-achieving pairs and one high-achieving triad were contained in *homogeneous RPT*.

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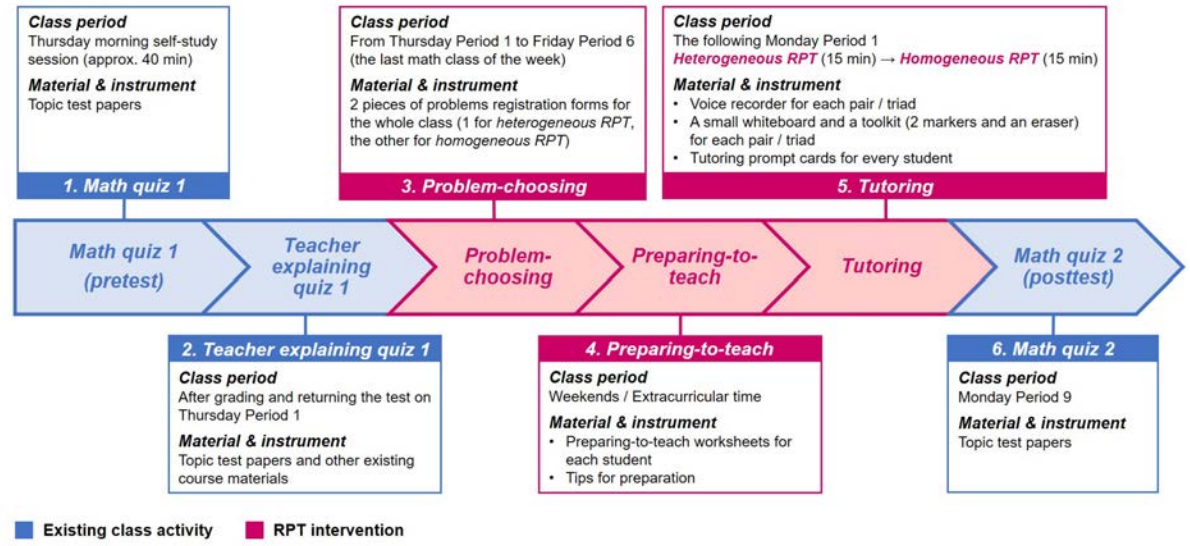
Procedure for each of the six RPT sessions was identical. Figure 2 outlines the involving phases, class periods for implementation, and required materials and instruments. For each session, all students took the *pretest* after the teacher completed instructing in the topic. The pretests contained a combination of multiple choice, calculation and word problems. During *problem-choosing phase*, students picked out their problems from the pretest paper and filled in the *registration forms* so their partners could see and prepare to teach those problems. Then, during *preparing-to-teach phase*, students were required to write their teaching preparations (i.e., problem-solving processes and math concepts or formulas used in the problems, etc.) on the *preparing-to-teach worksheets*. In each RPT session, students were expected to prepare four problems totally (two for each of *heterogeneous RPT* and *homogeneous RPT*). Afterwards, in *tutoring phase*, students worked in pairs/triads and took turns being *tutors* or *tutees*. The first 15 min were *heterogeneous RPT*, then students re-grouped and turned to *homogeneous RPT* for the next 15 min. At last, all students completed the *posttest*. Question types and difficulty level of the posttests were the same as those of the pretests. All tests were graded from 0 to 100.

Figure 2

Procedure of Every RPT Session



Pretest scores, posttest scores, and students' *preparing-to-teach worksheets* from six RPT sessions were collected. Verbal interaction from all pairs and triads during *heterogeneous* and *homogeneous RPTs* in three formal sessions were recorded and transcribed. Data analysis is in progress: marking rubrics for *preparation quality* and *qualities of verbal explanation and interaction* are in design; quantitative descriptive analysis, correlation, multiple regression, and ANOVA are expecting to carry out for answering the two research questions. Although taking with small sample and might filled with unmanageable confounding variables, the present study made attempts to evaluate *learning-by-teaching effect* of every RPT phase in a real classroom setting.

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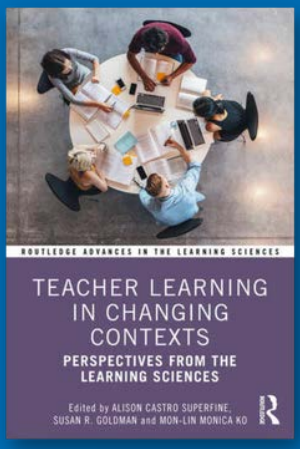

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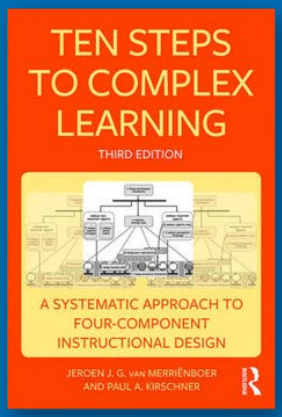

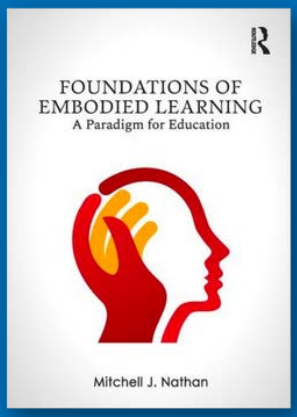

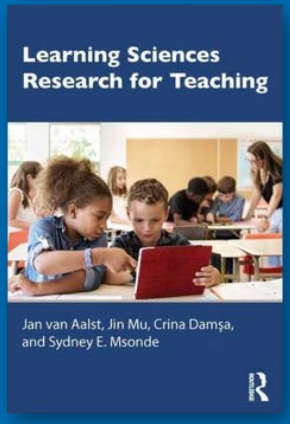

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